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The Benefits of BIM Use to Improve Information Flow; Making the Design Process More Leaner

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Abstract

The construction industry faces many problems, such as poor productivity and efficiency, that mainly occur during the design process. Many construction problems associated with the design process are due to a lack of effective information flow management through innovative and technological strategies. As the technology matures, the amount of information and data generated and shared during the construction design process has rapidly increased. Despite the increased amount of available information in the design process, most of the shared information not only adds any value to the project but also generates waste. So, it is critically important to improve the design information by managing the information exchange effectively.

Ineffective information sharing is a significant contributing factor to waste and the root cause of many construction problems. Major design problems related to information management are due to a lack of appropriate information exchange and effective information flow. Therefore, effective information flow management is crucial to project success. This can be achieved through the application of new innovative and technological approaches such as Lean and Building Information Modelling (BIM).

Due to the lack of systematic exploration between the information flow management challenges, and the application of BIM and Lean, this research intends to make a number of significant and original contributions in this area of research. In identifying this gap in knowledge, this research makes a substantial contribution to the theory in understanding how information flow management could be improved by studying the implications of using the BIM/Lean approach from a cross-case studies perspective.

Although the application of BIM and its benefits in the design process is commonly seen, its application with Lean construction in different BIM maturity levels and in relation to effective information flow management is seemingly very poor. The existing research suggests multiple reasons for this situation; however, the gap in theoretical grounding leaves it vulnerable to interpretation. Therefore, this study aims to explore how the information flow in the design process could be improved by applying BIM and Lean approaches in relation to the BIM maturity levels.

A qualitative methodology is being followed to provide an explanation for the social phenomenon based on realist ontological and epistemological principles and assumptions. This study is structured under four phases; the first phase focuses on research design, providing a deeper understanding of the problem, and the second phase is the preparation and collection of

information based on the research problem. The findings are analysed and developed in the third phase. The final phase is dedicated to discussing the findings and developing the solution to meet the research aim and objectives.

Three case studies are selected to obtain in-depth information on effective information flow management, the challenges associated with the management of information flow, and the role of BIM/Lean in improving information flow management in relation to different BIM maturity levels. Semi-structured interviews are conducted within the three case studies as the data collection method, while data is analysed using thematic analysis to form the research findings.

The research brings together scholarly work on effective information flow management and the role of BIM/Lean in information sharing and exchange while interrogating different value theories to develop a unique understanding of how the usage of BIM/Lean could improve information flow management in the design process and in relation to the BIM maturity levels. Value's role as the primary dependent variable in social science has contributed to a deep understanding of the phenomenon. This research reveals how value is represented through challenges and benefits, and possibilities of value enhancement through adapting BIM/Lean to improve information flow management. This leads to a new perspective by identifying challenges of information flow management as unfulfilled expectations of users, therefore, act as recommendations for improvement required in managing information flow by the adaption of BIM/Lean approaches and in relation to different BIM maturity levels to help promote the best practice.

Finally, the research contributes to the knowledge by providing a great insight into the problems and challenges of information flow management in the design process and how these challenges can be better tackled and addressed through the implementation of BIM/Lean.

This study intends to make both academic and practical contributions. This research contributes to raising awareness regarding the challenges associated with information flow management in relation to projects' BIM maturity level and how these challenges could be tackled through a set of recommendations. Therefore, the findings of this research would help academic professionals to rethink the importance of research in information flow management by the BIM/Lean and IPD application with its relation to the BIM maturity level.

Also, this study would benefit the construction industry practitioners to better understand the critical information flow management challenges and how these challenges could be reduced through a set of recommendations. The beneficial role of BIM/Lean and IPD to enhance information flow would be better realised by industry professionals. This would assist them in taking logical and necessary actions to enable the practical application of BIM/Lean and IPD, thus achieving better-enhanced information flow management. A set of recommendations are designed which would help both industry practitioners and academia to realise the importance of effective information flow management and how BIM/Lean could enhance effective information flow management and to take recommended actions to better manage the information flow in practice.

Abbreviations

AEC	Architectural Engineering Construction
BIM	Building Information Modelling
CDE	Common Data Environment
ICT	Information Communication Technologies
IM	Information Management
IPD	Integrated Project Delivery
ISO	International Standards Organisation
IT	Information Technology
LOD	Level of Development
MEP	Mechanical, Electrical and Plumbing
PM	Project Manager
RFI	Request for Information
TPS	Toyota Production System

Chapter 1. Introduction

1.1 Background

The construction industry is a key sector which plays a vital role in the development and economic growth. Currently, the UK construction industry contributes £117 billion to the UK economy, 6% of the total economic output (Rhodes, 2019). Also, UK construction comprises more than 280,000 businesses covering 3 million jobs, equivalent to about 10% of total UK employment (Department for Business, Innovation and Skills, 2013). This reveals the importance of the construction sector as one of the largest sectors in the economy of the UK, which reaches every corner of the UK and touches each individual’s life (Construction Sector Deal, 2019).

Despite the importance of construction, the construction industry faces many problems both in the UK and internationally. It is widely believed that the process of construction is highly inefficient. According to Mollasalehi et al. (2016), the construction process is not an efficient process due to the high level of non-value-adding activities that reduce the overall productivity and performance of the construction. These non-value-adding activities are also argued to be the main contributor to the delays of plans and cost overruns in the construction process (Han, Lee, & Pena-Mora, 2012).

Moreover, poor construction project management is also considered to lead to inefficiency (Yap, J. B. H., & Shavarebi, K., 2022; Liberda, Ruwanpura, & Jergeas, 2003). A lack of effective construction management would have negative impacts on overall construction performance and productivity. Poor productivity has been considered one of the most critical problems the UK construction industry has faced during the past decades (Martin, 2021; McKinsey Global Institute, 2017; Naoum, 2016, Yi & Chan, 2014).

Many studies have emphasised the importance of construction productivity improvement. However, the construction industry's performance has not yet improved significantly. Nevertheless, numerous challenges are facing the construction industry, specifically in the UK, concerning inefficiency and poor productivity (Martin, 2021; McKinsey Global Institute, 2017; Naoum, 2016, Yi & Chan, 2014). It is essential to understand an industry’s productivity level and growth to assess its competitiveness, development potential and economic impact. This is particularly true for the construction industry, which has been regarded as having lower productivity and slower productivity growth than other industries and the rest of the economy for a very long time (Martin, 2021).

It can be found that recognising the opportunities and challenges in the construction industry concerning productivity could lead to improved overall efficiency and productivity of construction. This is because many activities and processes within the construction have significant impacts on overall productivity. These activities and processes also affect the information quality throughout the project lifecycle. The inefficiencies and lack of appropriate methods to improve the overall project efficiency in the construction industry have been highlighted in several reports over the years.

Even though poor productivity and inefficiency can be considered barriers to a successful construction process, it was argued by Department for Business, Innovation and Skills (2009) that the productivity and efficiency of the construction could be improved significantly. As the issues still exist, recent reports have also addressed the need and the possible improvements in the construction in terms of productivity (Martin, 2021; McKinsey & Company, 2020; McKinsey Global Institute, 2017; Naoum, 2016).

There have been many suggestions on different ways to improve construction productivity, mainly addressing the need to move towards intangible and technological assets, which would lead to better managing the construction processes through enhanced collaboration and digitalisation. The usage and investment of Information and Communication Technology (ICT) in the construction industry would be significantly beneficial to improve productivity and efficiency in the construction industry (McKinsey & Company, 2020; Ruddock, 2006).

The need for change and improvements in the construction was taken into consideration dating back to the Simon report published in 1944 and is seen by many as the first in a long line of major, public reports criticising the modern construction industry in the UK. Following Simon's report, many other reports were also published to provide general views on construction performance improvement (Murray & Langford, 2003). These include reports such as Emmerson (1962), Banwell (1964), What’s Wrong on Site (1970), Wood (1975), Faster Building for Commerce (1988), and Simon (1994).

In the period of 1944-80, the published reports were initially more focused on providing general overviews about the possible performance improvements and potential achievement approaches (Murray & Langford, 2003). The later reports provided more specific targets specifically for time and cost saving (Murray & Langford, 2003). Nevertheless, the more recent reports, Latham and Egan, have not only specified time and cost-saving targets but also emphasised the critical challenges faced by the construction industry. The fragmentation nature of the construction industry was considered by Latham (1994) to be a significant factor that contributes to the poor collaboration and communication between project teams.

It was also argued by Koskela (1992) that fragmentation is one of the main contributing factors to different construction issues, such as waste and cost/time overruns. The extensive use of subcontracting in the UK construction industry also makes it a highly fragmented and complicated industry (Harvey, 2000, cited in Dave, 2013) which prevents the industry from improving in terms of performance and efficiency (Egan, 1998).

Latham’s report was mainly focused on collaboration, whereas in Rethinking Construction (Egan, 1998), the focus was not only on collaboration but also on processes. Egan (1998) identified five key drivers for change which are as follows;

- Committed leadership
- Focus on the customer
- Product team integration
- Quality driven agenda
- Commitment to people

Understanding the root causes of construction problems is very important in overcoming some of the construction problems, such as waste and time/cost overruns. Dave (2013) argued that understanding the key drivers for change and critical success factors is also very important and vital. Zhang (2005) identified some of the essential factors of success for the construction projects’ outcomes. The top five factors are listed below;

- Planning and Control
- Communication/coordination
- Labour availability and quality
- Equipment and tools (availability)
- Working methods

All these five factors determine the success of a construction project. Though, Dave (2013) argued that the first two factors are more significant in terms of impacting the construction project as they also affect the following three factors to a certain degree.

Even though the construction industry faces many challenges and issues, there has always been a drive to change. The construction industry is more likely to overcome its challenges if implementing effective approaches and technologies is taken into consideration more significantly. Lean construction and Building Information Modelling (BIM) are widely known as the effective approaches that the construction industry needs to adapt to overcome some of its major issues that have been mentioned above.

1.2 Justification

It has been recognised that there is a need for change in terms of improving productivity and performance for more than 50 years (e.g., Simon 1944; Emmerson 1962; Banwell 1964; Latham 1994; Egan 1998; Naoum, 2016; McKinsey Global Institute, 2017; McKinsey & Company, 2020; Martin, 2021). Generally, there have been drivers for improvement in construction over the last 50 years. Many reports, including government reports, have been driving the industry to improve construction projects by implementing innovative technologies and processes (Latham, 1994; Egan, 1998; Egan, 2000; Department for Business, Innovation and Skills, 2009; Cabinet Office, 2020; McKinsey & Company, 2020). Therefore, the number of construction projects adopting different innovative and technological processes such as BIM and Lean thinking has rapidly increased over the last decade (McGraw-Hill., 2009; Arayici et al., 2011; Dave, Boddy, & Koskela, 2013; Tillmann et al., 2015).

It can be found that many construction projects have realised the importance and the benefits of adopting new innovative and technological approaches in their projects. Many companies could improve their efficiency and productivity by embracing digitalisation and digital technologies. This is evidenced by the several reports published by the National Building Specification (NBS) showing the results from the different surveys over the years, including but not limited to the NBS The Technology Survey (2011), NBS Construction Technology Report (2019), Digital Construction Report (2021).

These reports demonstrate that technology usage has been recognised and increased in recent years. Thus, it is vital to study technology usage in construction projects considering its various aspects throughout different phases of construction projects.

Information technologies play an essential role in construction design, specifically regarding design information exchange (Egan, 1998; Al Hattab & Hamzeh, 2013; Leite et al., 2016; Andersen & Findsen, 2019). They assist in developing innovative solutions and improving the design process in terms of adding value to the process while reducing and eliminating non-value-adding activities or waste, such as rework (Egan, 1998). However, due to poor information flow management, there are still many challenges and issues in the design process that will create activities and information that add no value to the process and produce waste (Hicks, 2007; Phelps, 2012; Al Hattab & Hamzeh, 2013). These non-value-adding activities and information mostly occur during the design process because the design phase involves many critical decision-making processes and a massive flow of information (Formoso et al., 1998; Koskela, Huovila, & Leinonen, 2002).

Even though there have been many research papers in the field of information management, it appears to be a limited focus on the flow of information that led to non-value-adding activities or waste (Loria-Arcila, & Vanegas, 2005; Hicks, 2007; Phelps, 2012) and how it could be improved by the usage of BIM and Lean approach.

Moreover, the concept of waste and its consequences have been covered over the years (Koskela, 1992; Egan, 1998; Howell & Ballard, 1998; Koskela, 2000, 2004; Koskela, Bølviken, & Rooke, 2013; Bølviken & Koskela, 2016) but less attention has been paid to the concept of waste and value within the information flow management specifically with the application of BIM and Lean (Hicks, 2007).

Furthermore, as the technology matures, the possibility of applying these techniques and processes to support the suggested improvement, improving the information flow using BIM and Lean in terms of adding value and reducing non-value-adding activities and information in construction design, is an area of research. Despite the necessity for such research, little work has been described in the literature.

Therefore, it can be found that there is a need for research in this field to fill the knowledge gap. This study intends to provide a comprehensive insight into the key challenges of information flow and provide a better understanding of the concept of value and waste within the information flow through BIM and Lean adoption.

1.3 Problem Statement

Many construction problems related to information integration and communication, and collaboration are due to a lack of implementing effective innovative and technological processes (Egan, 1998; Isikdag, Underwood, & Kuruoglu, 2012; Andersen & Findsen, 2019). Therefore, this significantly impacts the construction industry's efficiency and performance (Latham, 1994; Egan, 1998, 2002). The improved and effective exchange of information during the project's lifecycle could result in better project performance and, thus, the overall project's productivity. So, as the construction project's productivity improves, the overall productivity of the construction industry would consequently improve as well.

Even though new technology adoption in the construction industry has lagged far behind other sectors (Flanagan, Ingram, & Marsh, 1998; Ruddock, 2006; Hewage et al., 2008; NBS Construction Technology Report, 2019), there has been significant growth in demand for adoption of new innovative and technological processes, such as BIM and Lean construction, over the last 10 years. However, there are still many issues facing the construction industry (Smits et al., 2016). Major construction issues seem to be related to the design process and the design information exchange (BEDC, 1987, cited in Austin, Baldwin, & Newton, 1994).

According to Mokhtar et al. (1998), "the interdisciplinary coordination of design information is a major problem for the construction industry". Also, it was reported by NEDC that more than 50% of the construction site problems were related to poor design information (1987, Cited in Baldwin et al., 1999). Likewise, Egan (1998) pointed out that one of the significant problems in the whole construction process is poor design information which will result in a large amount of redesign work.

Therefore, it is critically important to improve design information management as major design problems are related to a lack of information management, including information exchange and information flow (Baldwin et al., 2010). In order to improve process efficiency, it is crucial to manage not only the information but, most importantly, the flow of information (Krovi, Chandra, & Rajagopalan, 2003).

It is argued by Groak (1993) that the key to successful design process planning is information flow management. This is because the flow of information has significant impacts on all other resource flows (Dave, Boddy, & Koskela, 2010).

The need for more effective information flow between project teams has been recognised by the construction industry since 2010 and is still valid (Baldwin et al., 2010; Bilge & Yaman, 2021) as ineffective information flow management is the major cause of information waste (Hicks, 2007; Phelps, 2012; Al Hattab & Hamzeh, 2013).

Therefore, adopting new innovative technologies and processes, such as BIM and Lean construction, are critically important to tackle problems, such as waste, associated with information flow management.

1.4 Research aim and objectives

1.4.1 Aim

The aim of this research is to explore how the information flow in the design process could be improved by the usage of BIM/Lean and in relation to the BIM maturity levels.

1.4.2 Objectives

The objectives of this research are;

- To establish the key challenges in information flow considering three aspects of technology, process, and people in the design process of construction
- To critically analyse the role of BIM and Lean construction to enhance information flow in the design process in relation to the BIM maturity levels
- To evaluate the potential benefits of BIM and Lean approaches in terms of information flow management

To achieve the aim and objectives of this research, several phases are developed, which are mapped in Figure 1. The first phase of this research, "Phase 1. Literature Review", consists of reviewing the existing literature to form the foundation of the research aim and objectives. Also, the first phase would directly influence the next phase of this research in terms of identifying the information and data that need to be collected to meet the objectives of this research.

The second phase of this research, "Phase 2. Data Collection – Interviews", which aims to collect data through interviews, would be directly linked to all the research's objectives. This phase attempts to address all objectives of this research which are linked to different aspects of this phase, as demonstrated in Figure 1.

All the data collected in phase two will be analysed in “Phase 3. Data Analysis and Findings” to meet all the research aim and objectives through three case studies. Each objective is addressed in this phase, where the data will be analysed to establish key research findings.

To gain a comprehensive insight into the research aim and meet the research objectives, all findings from phase three would be analysed and discussed collectively in “Phase 4. Cross Case Data Analysis and Discussions”.

The findings from the previous phase represented each case study, whereas, in this phase, all three case studies would be collectively compared and discussed through cross-case data analysis. This is followed by the discussions mainly focused on addressing the aim and objectives of this research.

Finally, based on the findings from previous phases, the research is concluded in this phase. The conclusion is formulated in a systematic approach to demonstrate how the research addressed the aim and objectives of this project. This is followed by some recommendations for future research for industry and academic professionals.

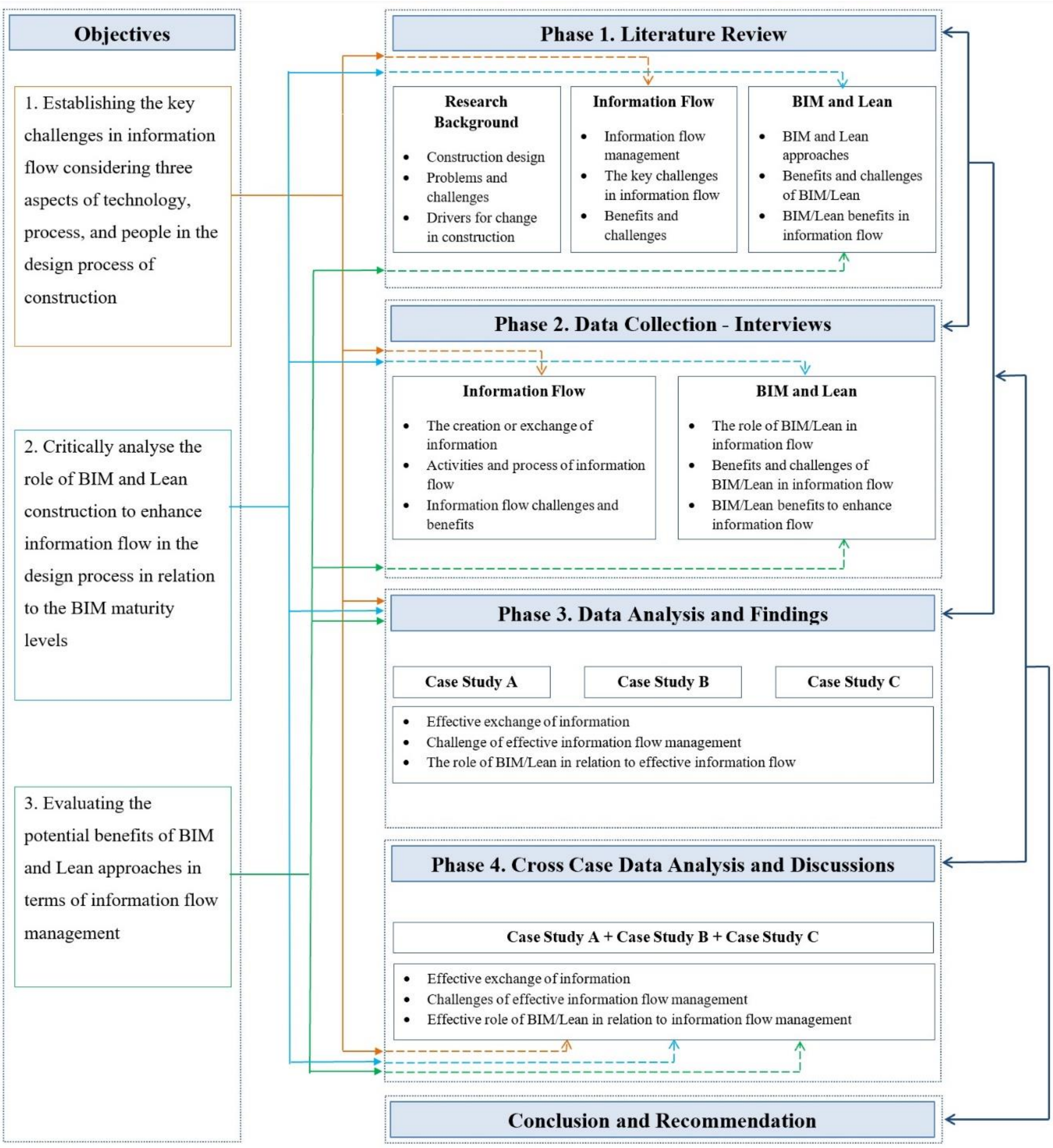


Figure 1 - Research Process Map

1.5 Research target and scope

Based on the discussed research problems and justification, this research does not consider all stages of the construction project's lifecycle. Therefore, the scope of this research is focused only on the design process of construction because of the following aspects:

- Many construction problems can be traced back to the design process, as the design stage involves many critical decision-making processes and a massive flow of information
- The flow of information within the design process needs to be improved to benefit the overall project performance in terms of reducing non-value-adding activities and information or waste while increasing value-adding activities and information

Within the scope of this research, this study does not specifically strive to focus on the process of BIM and Lean implementations but on a more detailed exploration of the beneficial role of these two approaches in terms of improving information flow.

This research is targeted at project participants in the design process. The focus of this research is on understanding the information flows through the design process in relation to levels of BIM and Lean approaches with the intent of enhancing information flow management.

1.6 Summary of Research Methodology

In order to conduct research and meet the aim and objectives, a systematic approach is required to be conducted by the researcher (Fellows & Liu, 2003). In this study, a qualitative research methodology was chosen as it enables the researcher to study complex phenomenon and is also suitable for cross-case comparisons (Madondo, 2021), which fits well in the context of this research.

As it was pointed out by Creswell (2007), qualitative research is conducted when a problem or issue needs to be explored. In this research, the information flow challenges as a phenomenon need to be explored to address the research aim and objectives.

This research needs a detailed understanding of the information flow challenges which can only be established by speaking directly to project participants, through interviews, in the design process and by understating the contexts in which they address the information flow challenges using BIM and Lean approaches in relation to different BIM maturity levels

(Creswell, 2007; Madondo, 2021). Therefore, interviews and case study approaches have been adopted as research strategies for this study's qualitative method research design.

For the data collection, multiple sources of evidence were used as both secondary and primary data. This research uses a combination of secondary data types in which data is gathered through literature reviews on published work such as books, journals, government surveys, government publications and reports. The data collected through these sources would enable the researcher to form the interview questions and themes concerning information flow management and the challenges associated with considering the use of BIM/Lean to improve those issues in comparison to different BIM maturity levels. So, based on the findings from the literature review and to meet the aim and objectives of the research, the case studies are selected, and the data collection protocols are designed to conduct interviews.

As illustrated in Figure 2, this study's research process comprises 4 phases in terms of its methodological process. Phase 1 is the phase where the literature review is carried out on information flow management, Lean construction, the BIM concept and the interaction of BIM and Lean approaches. This review provides an in-depth study of the information flow management challenges, a detailed evaluation of the benefits of BIM and Lean concepts, and the interaction between these two concepts to improve project processes and information flow management. Based on the findings of this phase, the selection of the case studies in relation to BIM maturity levels and the data collection protocols are designed.

Phase 2 includes the engagement of project participants in three case studies through semi-structured interviews, which enables the researcher to ask questions based on the developed themes from the previous phase to explore the key challenges of information flow and the role of BIM and Lean to improve information flow in the design process and in relation to the different BIM maturity levels in three case studies.

The data collected from phase 2 is then analysed through thematic analysis across all three case studies in phase 3 to develop the research findings. The cross-case analysis is then carried out in phase 4 based on the previous phase's findings, followed by a comprehensive discussion.

All findings and discussions from previous phases would then form the conclusion of this research. Conclusion and recommendations are presented in this study's final phase to show how this research's aim and objectives are met.

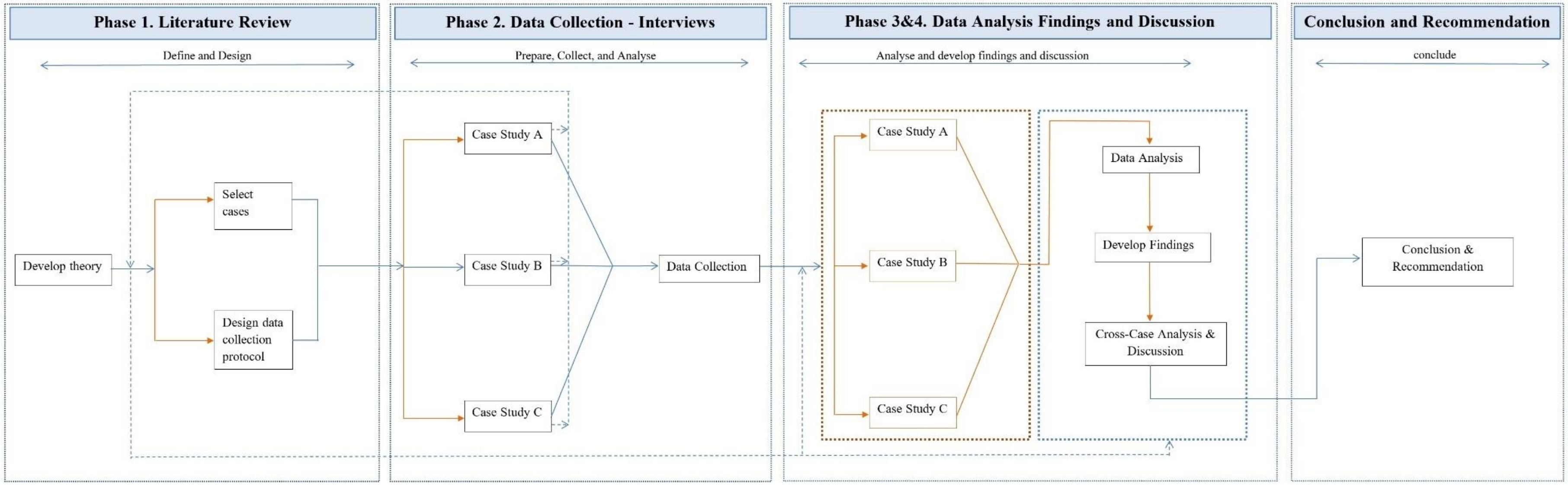


Figure 2 - Research Process Flow Chart

1.7 The Thesis Structure

The thesis contains 8 chapters. A summary of the content of each chapter is presented in this section to demonstrate the progression of the thesis work. This is followed by an illustration of the thesis breakdown structure in Figure 3.

Chapter 1 – Introduction

This chapter introduces the research background and problem statement with the justification needed to conduct this research. The aim and objectives of this research are also presented in this chapter, followed by an overview of the research target and scope. The design and structure of the thesis are also presented to direct the reader.

Chapter 2 – Literature Review

This chapter presents a critical analysis and review of the literature. It investigates the construction design to provide a solid background to the importance of focusing on the design process. Information flow management is also discussed in this chapter, followed by reviewing the definitions, applications, benefits and challenges of both BIM and Lean construction concepts. Also, this chapter synthesises the different approaches and strategies aimed at improving information flow management by the usage of BIM and Lean construction and the interaction of these two concepts.

Chapter 3 – Research Methodology

The research philosophy, approach, methodology, and strategies that were adapted to deliver the research aim and objectives are presented in this chapter. Justification for each chosen method is given, as well as a comprehensive explanation of how the data will be collected and analysed.

Chapters 4 & 5 & 6 – Data Analysis and Findings - Case Study A, B, & C

The deficiencies in managing the information flow in the design process through BIM and Lean implementation using the literature review as well as the proposed methods to solve the revealed issues, were highlighted in previous chapters. Three case studies are chosen as part of the research method to be analysed and explored in relation to the research aim and objectives in Chapters 4, 5, and 6. Each case study represents each BIM maturity level to provide a great insight into the research aim.

A Series of interviews are conducted to explore the aim and address the objectives of this research. These interviews are conducted collectively for each case study and analysed to form the findings of this research in each chapter. So chapter 4 provides the findings related to Case Study A, followed by chapter 5, which presents the results of Case Study B, and finally, Case Study C's findings will be discussed in chapter 6.

Chapter 7 – Cross Case Data Analysis and Discussions

The previous chapter presented the findings for each case study individually. In this chapter, the findings of all three case studies will be analysed and discussed collectively to meet the research aim and objectives. The discussions in this chapter are structured and categorised consistently regarding the main case studies themes that emerged from the basis of the literature and the aim and objectives of this research.

Having discussed the findings from all cases, the chapter will be concluded through a set of recommendations for improving information flow management based on the discussed findings.

Chapter 8 – Conclusion

The overall success of the research in achieving the aim and objectives of this research is reviewed in this chapter. This chapter revisits the main research objectives, followed by a critical reflection on the observations and findings from the previous chapters. This chapter articulates the main contribution of this research to the importance of improving the information flow management in the design process by the usage of BIM/Lean and in relation to the BIM maturity levels.

The knowledge created by the research based on the chosen research methods and processes is highlighted in this chapter. After that, the constraints and limitations of the study and recommendations for further work are presented.

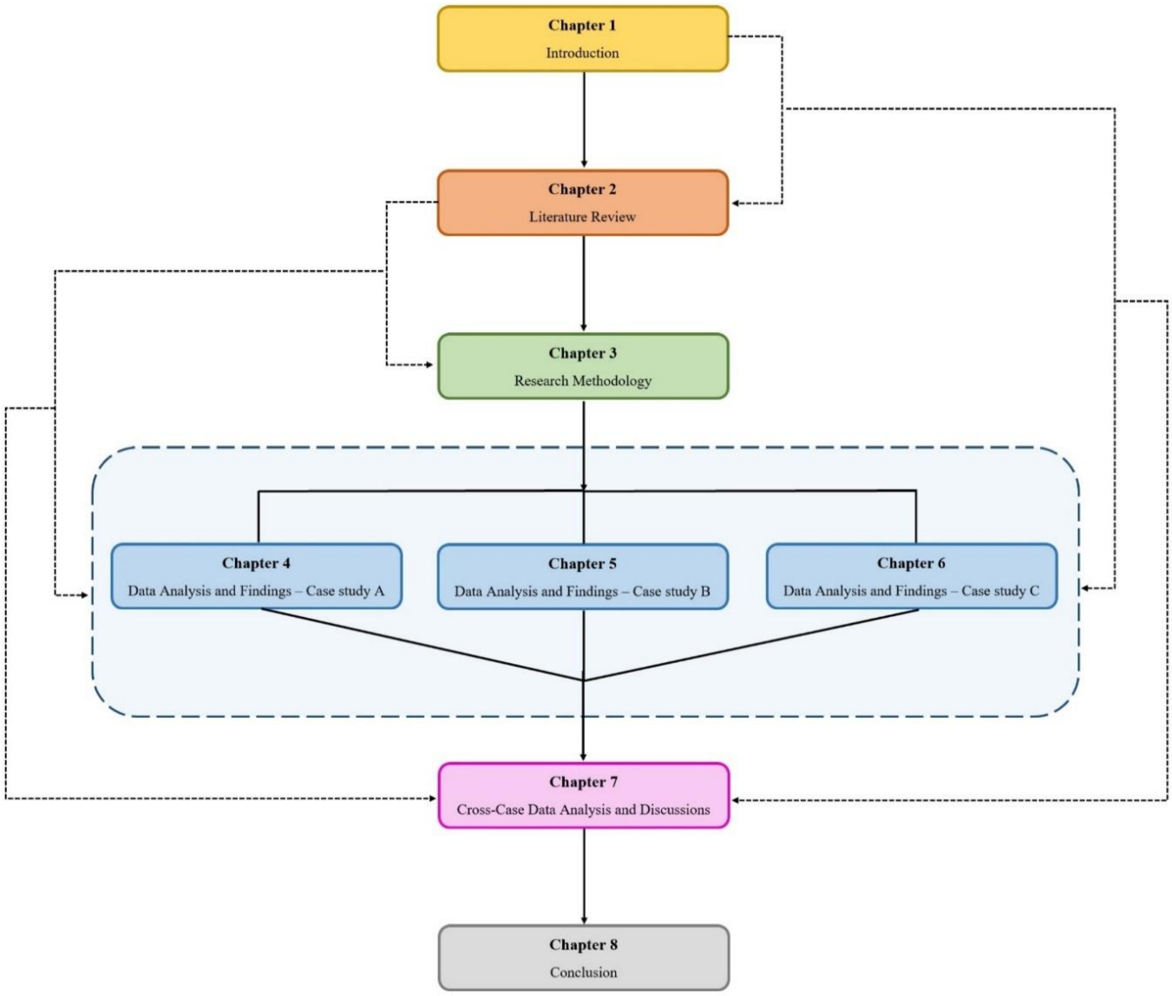


Figure 3 - Breakdown of the Thesis Structure

Chapter 2. Literature Review

2.1 Design Process in Construction

A construction project's design stage is fundamental since it impacts project performance and improvement, as well as the time and cost of the project (Formoso et al., 1998; Tzortzopoulos & Formoso, 1999; Freire & Alarcón, 2002; Herrera et al., 2019; Bashir et al., 2022). Due to the many critical decisions that must be made, the design process is challenging to manage because it involves tight budgets and limited resources (Ballard & Koskela, 1998; Formoso et al., 1998; Tzortzopoulos & Formoso, 1999). A project also consists of a variety of people with different backgrounds and skills, making the management of the design process more difficult (Formoso et al., 1998; Ballard & Koskela, 1998). In addition, the design process will identify the customer's needs and the project's requirements (Ballard & Koskela, 1998) and has a direct impact on the project in terms of its efficiency and standardisation (Cabinet Office, 2020).

While the design process is underway, numerous project activities are undertaken, such as documenting objectives and outcomes, conducting feasibility studies, developing conceptual designs, preparing cost information, formulating project strategies, and preparing detailed and technical designs (Information on architecture, structural, and building services are included) (RIBA, 2013; RIBA, 2020). So, many critical decision-making processes and essential activities occur during the design process.

Moreover, there are other aspects of the design process which would impact the design process. Many factors influence the design process, such as new forms of procurement, modern construction methods or new drivers, which make the design process more complex (RIBA, 2020). In order to meet a client's requirements and minimise any issues related to the design process, it is crucial that the design process is managed effectively (Baldwin et al., 1999). Therefore, managing the design process is an essential factor for a project's success, and to do that there needs to be a definitive design and process management tool.

To provide an excessive insight and clarity on to the different stages of a project process including the design process, a framework was developed by the RIBA Council (RIBA, 2013). The RIBA Plan of Work is a document that outlines all stages of the project, including the planning, design, and building process, from conception to completion on site.

As shown in Figure 4, a detailed description of each stage of the design process can be seen in a table with the stages identified and sorted by requirements and activities (RIBA, 2020).

According to the RIBA's (2020) plan of work, the project is planned at every stage of its lifecycle. Nevertheless, this study is concerned with only the major design stages (stages 0 to 4).

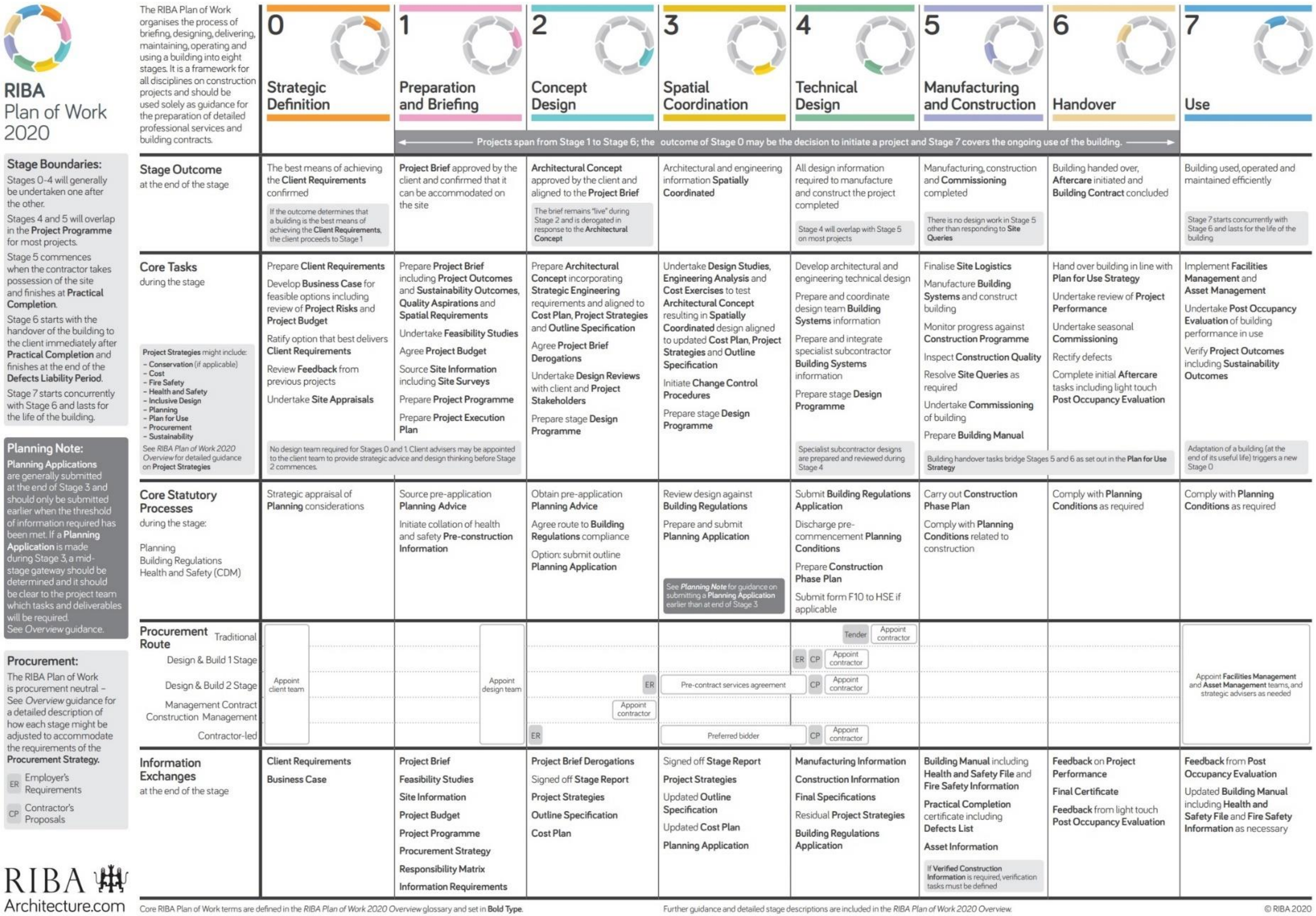
Construction performance can be significantly affected by minor design issues, as demonstrated by Glavan & Tucker (1991, cited in Austin, Baldwin, & Newton, 1994), because the decisions made during the design phase can have a significant effect on the subsequent stage (Herrera et al., 2019). According to the BEDC Report, many major construction problems are caused by poor design management (1987, cited in Austin, Baldwin, & Newton, 1994). This is because a lack of effective decision-making processes and design errors not tackled during the design phase would result in challenges at later stages of the project.

To reduce any uncertainty and complexity in the design process, the control and plan of the process must be considered more effectively (Formoso et al., 1998; Herrera, Mourgues, & Alarcón, 2018). As reported by Herrera, Mourgues, and Alarcón (2018), many quality errors in the project are due to the modification and correction times that exist in the project planning. Thus, project planning is vital during the design process. A lack of proper planning during the design phase will result in an inefficient exchange of information among the project team members and a lack of information needed to complete the design task (Formoso et al., 1998; Herrera et al., 2019).

Moreover, there are also several issues related to design process management, including poor communication and briefing, inadequate documentation, unbalanced resources distribution, lack of coordination, inadequate or missing input information, as well as unreliable decision-making, and design changes (Austin, Baldwin, & Newton, 1994; Ballard & Koskela, 1998; Herrera et al., 2019).

As a result of all of the mentioned problems, waste will be generated during the design process and construction (Faniran & Caban, 1998; Koskela, 2000; Ningappa, 2011). Nonetheless, poor information flow management spawns a host of challenges and problems in the design process, which leads to activities and data that add little value and create waste (Hicks, 2007; Phelps, 2012; Al Hattab & Hamzeh, 2013). As a result, managing information flow effectively would significantly impact the design process.

Design in construction is traditionally viewed as a single phase (Formoso et al., 1998). However, single control of the design and construction processes would have a positive impact, according to Jergeas (1989). Currently, the design process is regarded as a process linked to all stages of construction projects by applying Lean Construction principles during the design phase (Tzortzopoulos & Formoso, 1999; Herrera, Mourgues, & Alarcón, 2018). A Lean Construction approach coupled with Building Information Modeling (BIM) would have significant benefits in the design process, which would help to overcome some of the problems mentioned earlier, as well as reduce some of the construction waste (Sacks et al., 2010; Dave et al., 2013; Moud, 2013; Machado et al., 2020; Nguyen & Akhavian, 2019).



RIBA Plan of Work 2020

The RIBA Plan of Work organises the process of briefing, designing, delivering, maintaining, operating and using a building into eight stages. It is a framework for all disciplines on construction projects and should be used solely as guidance for the preparation of detailed professional services and building contracts.

Stage Boundaries:
Stages 0-4 will generally be undertaken one after the other.
Stages 4 and 5 will overlap in the **Project Programme** for most projects.
Stage 5 commences when the contractor takes possession of the site and finishes at **Practical Completion**.
Stage 6 starts with the handover of the building to the client immediately after **Practical Completion** and finishes at the end of the **Defects Liability Period**.
Stage 7 starts concurrently with Stage 6 and lasts for the life of the building.

Planning Note:
Planning Applications are generally submitted at the end of Stage 3 and should only be submitted earlier when the threshold of information required has been met. If a **Planning Application** is made during Stage 3, a mid-stage gateway should be determined and it should be clear to the project team which tasks and deliverables will be required.
See *Overview* guidance.

Procurement:
The RIBA Plan of Work is procurement neutral – See *Overview* guidance for a detailed description of how each stage might be adjusted to accommodate the requirements of the **Procurement Strategy**.
ER Employer's Requirements
CP Contractor's Proposals

	0 Strategic Definition	1 Preparation and Briefing	2 Concept Design	3 Spatial Coordination	4 Technical Design	5 Manufacturing and Construction	6 Handover	7 Use
		Projects span from Stage 1 to Stage 6; the outcome of Stage 0 may be the decision to initiate a project and Stage 7 covers the ongoing use of the building.						
Stage Outcome at the end of the stage	The best means of achieving the **Client Requirements** confirmed If the outcome determines that a building is the best means of achieving the **Client Requirements**, the client proceeds to Stage 1	**Project Brief** approved by the client and confirmed that it can be accommodated on the site	**Architectural Concept** approved by the client and aligned to the **Project Brief** The brief remains "live" during Stage 2 and is derogated in response to the **Architectural Concept**	Architectural and engineering information **Spatially Coordinated**	All design information required to manufacture and construct the project completed Stage 4 will overlap with Stage 5 on most projects	Manufacturing, construction and **Commissioning** completed There is no design work in Stage 5 other than responding to **Site Queries**	Building handed over, **Aftercare** initiated and **Building Contract** concluded	Building used, operated and maintained efficiently Stage 7 starts concurrently with Stage 6 and lasts for the life of the building
Core Tasks during the stage **Project Strategies** might include: – **Conservation** (if applicable) – **Cost** – **Fire Safety** – **Health and Safety** – **Inclusive Design** – **Planning** – **Plan for Use** – **Procurement** – **Sustainability** See *RIBA Plan of Work 2020 Overview* for detailed guidance on **Project Strategies**	Prepare **Client Requirements** Develop **Business Case** for feasible options including review of **Project Risks** and **Project Budget** Ratify option that best delivers **Client Requirements** Review **Feedback** from previous projects Undertake **Site Appraisals** No design team required for Stages 0 and 1. Client advisers may be appointed to the client team to provide strategic advice and design thinking before Stage 2 commences.	Prepare **Project Brief** including **Project Outcomes** and **Sustainability Outcomes**, **Quality Aspirations** and **Spatial Requirements** Undertake **Feasibility Studies** Agree **Project Budget** Source **Site Information** including **Site Surveys** Prepare **Project Programme** Prepare **Project Execution Plan**	Prepare **Architectural Concept** incorporating **Strategic Engineering** requirements and aligned to **Cost Plan**, **Project Strategies** and **Outline Specification** Agree **Project Brief Derogations** Undertake **Design Reviews** with client and **Project Stakeholders** Prepare stage **Design Programme**	Undertake **Design Studies**, **Engineering Analysis** and **Cost Exercises** to test **Architectural Concept** resulting in **Spatially Coordinated** design aligned to updated **Cost Plan**, **Project Strategies** and **Outline Specification** Initiate **Change Control Procedures** Prepare stage **Design Programme**	Develop architectural and engineering technical design Prepare and coordinate design team **Building Systems** information Prepare and integrate specialist subcontractor **Building Systems** information Prepare stage **Design Programme** Specialist subcontractor designs are prepared and reviewed during Stage 4	Finalise **Site Logistics** Manufacture **Building Systems** and construct building Monitor progress against **Construction Programme** Inspect **Construction Quality** Resolve **Site Queries** as required Undertake **Commissioning** of building Prepare **Building Manual** Building handover tasks bridge Stages 5 and 6 as set out in the **Plan for Use Strategy**	Hand over building in line with **Plan for Use Strategy** Undertake review of **Project Performance** Undertake seasonal **Commissioning** Rectify defects Complete initial **Aftercare** tasks including light touch **Post Occupancy Evaluation**	Implement **Facilities Management** and **Asset Management** Undertake **Post Occupancy Evaluation** of building performance in use Verify **Project Outcomes** including **Sustainability Outcomes** Adaptation of a building (at the end of its useful life) triggers a new Stage 0
Core Statutory Processes during the stage: Planning Building Regulations Health and Safety (CDM)	Strategic appraisal of **Planning** considerations	Source pre-application **Planning Advice** Initiate collation of health and safety **Pre-construction Information**	Obtain pre-application **Planning Advice** Agree route to **Building Regulations** compliance Option: submit outline **Planning Application**	Review design against **Building Regulations** Prepare and submit **Planning Application** See ***Planning Note*** for guidance on submitting a **Planning Application** earlier than at end of Stage 3	Submit **Building Regulations Application** Discharge pre-commencement **Planning Conditions** Prepare **Construction Phase Plan** Submit form F10 to HSE if applicable	Carry out **Construction Phase Plan** Comply with **Planning Conditions** related to construction	Comply with **Planning Conditions** as required	Comply with **Planning Conditions** as required
Procurement Route: Traditional	Appoint client team	Appoint design team			Tender; Appoint contractor			Appoint **Facilities Management** and **Asset Management** teams, and strategic advisers as needed
Design & Build 1 Stage					ER; CP; Appoint contractor			
Design & Build 2 Stage			ER	Pre-contract services agreement	CP; Appoint contractor			
Management Contract / Construction Management			Appoint contractor					
Contractor-led			ER	Preferred bidder	CP; Appoint contractor			
Information Exchanges at the end of the stage	**Client Requirements** **Business Case**	**Project Brief** **Feasibility Studies** **Site Information** **Project Budget** **Project Programme** **Procurement Strategy** **Responsibility Matrix** **Information Requirements**	**Project Brief Derogations** Signed off **Stage Report** **Project Strategies** **Outline Specification** **Cost Plan**	Signed off **Stage Report** **Project Strategies** Updated **Outline Specification** Updated **Cost Plan** **Planning Application**	**Manufacturing Information** **Construction Information** **Final Specifications** Residual **Project Strategies** **Building Regulations Application**	**Building Manual** including **Health and Safety File** and **Fire Safety Information** **Practical Completion** certificate including **Defects List** **Asset Information** If **Verified Construction Information** is required, verification tasks must be defined	**Feedback** on **Project Performance** **Final Certificate** **Feedback** from light touch **Post Occupancy Evaluation**	**Feedback** from **Post Occupancy Evaluation** Updated **Building Manual** including **Health and Safety File** and **Fire Safety Information** as necessary

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Core RIBA Plan of Work terms are defined in the *RIBA Plan of Work 2020 Overview* glossary and set in **Bold Type**.

Further guidance and detailed stage descriptions are included in the *RIBA Plan of Work 2020 Overview*.

Figure 4 - RIBA Plan of Work (RIBA, 2020)

2.2 Current State of Construction Design

It is widely believed that the root causes of many construction problems and challenges could be found in the design process as the design process involves many critical decision-making processes and a massive flow of information. The BEDC report found that "the majority of construction problems are related to poor design management" within the design process (1987, cited in Austin, Baldwin, & Newton, 1994). Similarly, it was demonstrated by Glavan and Tucker (1991) that even minor problems that are related to design could affect construction performance significantly.

One of the leading construction concerns is considered to be waste which is believed to be unavoidable (Guerra & Leite, 2021). The root causes of many construction waste could be traced back to the design process. However, it was believed by Talla and McIlwaine (2022) that there is an opportunity to reduce waste through better design. In addition to its impact on the project's overall efficiency and performance, the design process also affects the cost and time of the project (Formoso et al., 1998; Tzortzopoulos & Formoso, 1999; Freire & Alarcón, 2002; Herrera et al., 2019).

The MacLeamy curve which was introduced in the Construction Users Roundtable in 2004, suggests that if the design effort is moved earlier in the project (as shown in Figure 5), this will make the project and the processes more efficient than the traditional design process (MacLeamy, 2004). This diagram highlights how the design effort positively impacts cost reduction when concentrated in the initial stages of the design process. As can be illustrated in Figure 5, the design process has a significant ability to impact the cost and performance of the overall construction project lifecycle.

Therefore, improvement of early decision-making, performance and information flow management through BIM and Lean can impact the overall cost, time, functionality, and the outcome of the project positively (Eastman et al., 2011; Guo, Wang, & Xiong, 2022).

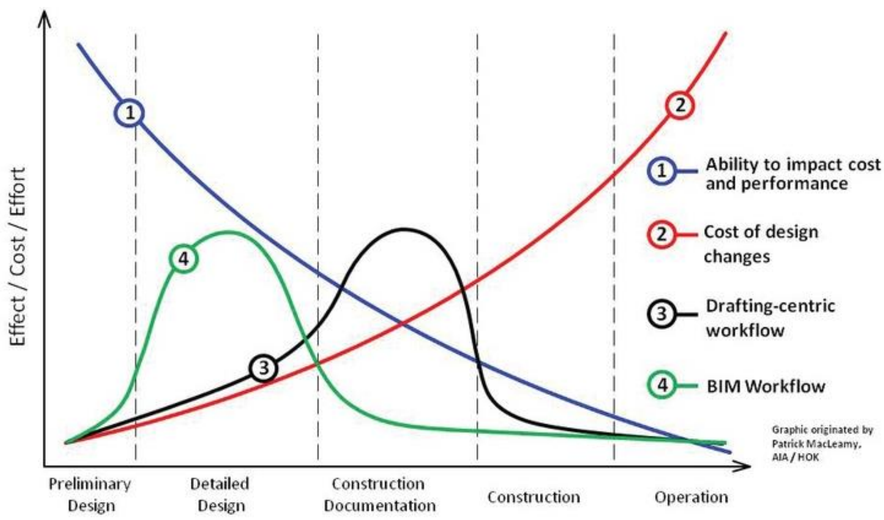

Figure 5 - BIM workflow vs Traditional workflow (MacLeamy, 2004)

Another major problem facing the construction industry is the interdisciplinary management of design information (Mokhtar et al., 1998) and critical challenges related to "effective integration and information flow management", especially in the design phase of construction (Davidson, 2004, cited in Phelps, 2012). A lack of appropriate design planning will result in a lack of sufficient information exchange among the project team (Formoso et al., 1998). This is because the design process involves collaboration that increasingly requires information exchange between multidisciplinary project teams, and if the project does not have a clearly defined design plan, then the information cannot be shared sufficiently throughout the project.

Therefore, insufficient information exchange will negatively impact the effectiveness of information flow within the design process. Improving the flow of information is critical since it significantly impacts process planning and scheduling (Chen et al., 2003; Bashir et al., 2022). Moreover, it was stated by Phelps (2012) that a construction project's success depends on 'effective information flow' due to the increasing complexity of projects. Therefore, improving the information flow precisely in the design phase of construction would benefit the overall construction project's performance and improvement.

2.2 Extensive Waste in Construction Design

It is widely believed that there is considerable waste within the design and construction processes. Waste is identified as any activity that does not add any value to the process and, therefore, impacts the project's success in terms of productivity and efficiency. It is also identified by Koskela (1992, p.17) that non-value-adding activity or waste is "activity that takes time, resources or space but does not add value", which also has negative impacts on project cost (Mossman, 2009). These non-value-adding activities or waste are considered as "main contributors to schedule delays and cost overruns" in the construction design process (Han et al., 2007). It has been estimated that waste in construction is around 55%, whereas only 5-10% of construction effort creates value, as shown in Figure 6 (Mossman, 2009).

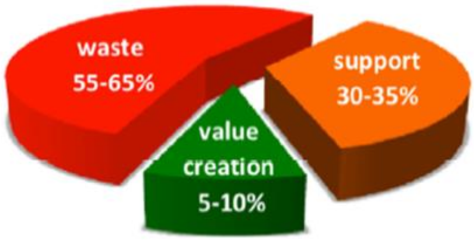

Figure 6 - Proportion of construction effort creating value (5-10%), supporting value creation (30-35%) and wasted (55-65%) (Mossman, 2009)

Based on the results of a meta-analysis of time, 49.6% of construction time was spent on wasteful or non-value-adding activities (Horman & Kenley, 2005). Moreover, a study carried out in Sweden revealed that only 15-20% of the worker's time is spent on direct work, and approximately 35% is spent on waiting, redoing errors, and disruptions which is a complete waste of time (Jongeling & Olofsson, 2007). Similarly, in a study that was conducted by Josephson and Saukkoriipi (2005), where a group of workers were observed for 22 working days, 33.4% of the worker's (labour) time was recorded as waste in activities like waiting, idle time, rework, and disruption.

It can be found that labour productivity is a critical challenge that would have significant impacts on producing waste during both the design and construction process. Likewise, Doloi (2008) stated that poor labour productivity is one of the critical significant causes of cost overruns and schedule delays. As shown in Figure 7, there is a direct link between labour productivity and the project control level. Improvement of the project control levels will improve the effective process undertaken by workers (Gugino, 2009).

Therefore, implementing effective approaches such as Lean and BIM would benefit the project in terms of improving the project control and accordingly increasing the work and worker productivity (Azhar, 2011; Talla & McIlwaine, 2022). Thus, improved worker productivity will save time/cost and reducing waste in construction design.

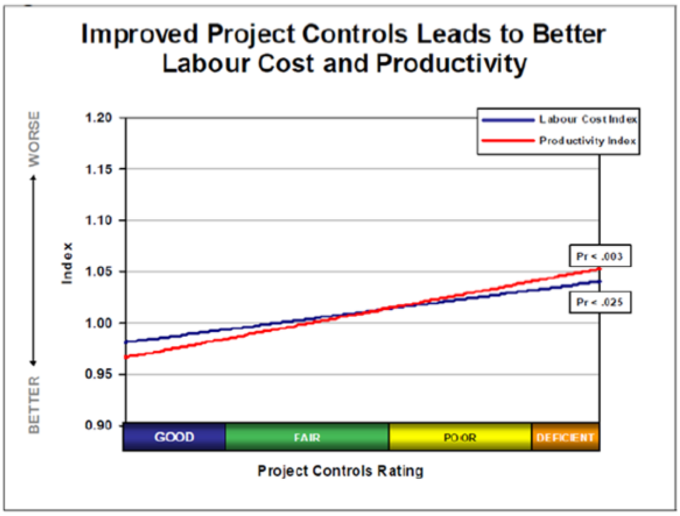

Figure 7 - Improved Project Controls Lead to Better Labour Cost and Productivity (Gugino, 2009)

The root causes of many types of construction waste can be traced back to the design phase, which has significant impacts on the overall project cost/time overruns. Non-value-adding activities during the design process are considered to be waste themselves. They would also lead to other activities that produce waste within the design and construction processes. These activities that add no value to the process can occur due to poor communication, inadequate information and documentation, lack of coordination, missing information, too much information, inefficient decision-making, and design changes (Austin, Baldwin, & Newton, 1994; Ballard & Koskela, 1998).

Consequently, all of the above problems will result in waste, such as rework, waiting, and excess inventory in the design and construction phases (Faniran & Caban, 1998; Koskela, 2000; Ningappa, 2011). The primary source of rework is considered to be caused by design changes, errors, and omissions (O'Connor & Tucker, 1986; Love et al., 1999) during the design process (love et al., 2008).

Moreover, it is argued by love et al. (2008) that design-induced rework has contributed to more than 70% of the total amount of rework in projects which is the main factor that contributes to time/cost overruns as well as schedule performance (love et al., 2008; Li & Taylor, 2011). Performance, efficiency, cost, and timeline are all affected by a project's design process (Li & Taylor, 2011; Love et al., 2011).

2.3 Information Flow Management

2.3.1 Information

Information is the fundamental source for organisations to deliver projects efficiently and effectively. In order to define information, it is important to distinguish the meaning of data, information, and knowledge. It was argued by Zins (2007) that there are debatable relations among these three as the distinction between them is not clear (Checkland & Howell, 1998).

Data

Data is defined as signs that are used to represent information (Langefors, 1993). They are symbols for a basic and simple description of things, which cannot be used to provide insight, though, can be used to generate information when meaning is added (Davenport & Prusak, 1998; Rowley, 2007; Jashapara, 2011, cited in Chatzipanagiotou, 2017). Data is useful to a computer, and for it to become information, it needs to be useful to a person. It was argued by Langefors (1993) that data needs to be interpreted in a process to turn into information. Similarly, it was stated by Warner (1996, p. 1) that "Data will need to be interpreted or manipulated to become information". Therefore, data can be found as the basis for generating information.

Information

Information has been defined in many ways. Despite the variety in definition, it is widely believed that information is data that a person has interpreted to give it meaning. A selection of quotations to define information is listed below:

"Information is data that has been interpreted and understood by the recipient of the message" (Lucey, 1991, p.5; Lucey, 2005, p.17).

"Information equals data plus meaning" (Checkland & Scholes, 1990, p.303).

"Information is data that has been processed into a form that is meaningful to the recipient" (Davis & Olson, 1985, p.200).

Therefore, systematically organised or meaningful data (Jashapara, 2011, cited in Chatzipanagiotou, 2017; Zins, 2007) that can be used to create knowledge is defined as Information (Davenport & Prusak, 1998; Rowley, 2007, cited in Chatzipanagiotou, 2017; Detlor, 2010; Zins, 2007). Also, a general definition of information was given by Floridi (2011), which considers information as well-formed, meaningful and truthful data.

Information gets created, and then it is passed on during the project lifecycle to satisfy many different purposes. Therefore, considering information in a process cycle involves different steps, and each step has input, processes and output, as shown below in Figure 8. It can be demonstrated from Figure 8 that between output and input is where the information exchange occurs, which is the key towards the efficient flow of information. This will be discussed in detail in the next section.

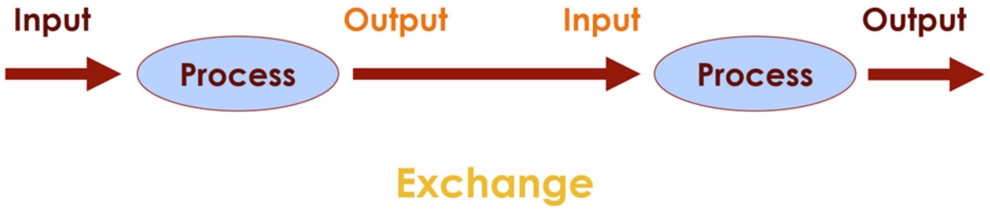

Figure 8 - Information exchange

Nowadays, the information comprises both electronic and physical forms (Mirijamdotter & Somerville, 2014) of email, report, drawing, schedule, programme, RFI, method statement, bill of quantities, cost plans, minutes, specifications, and models.

Knowledge

Knowledge is the general understanding of the knowers. As stated by Cambridge Dictionary (2017), knowledge is "the state of knowing about or being familiar with something".

Data is the raw material for generating information, and information is the raw material for creating knowledge (Zins, 2007; Silver & Silver, 1989). Contextual information that is used to indicate and direct activities and actions through assessing the information is defined as knowledge (Chatzipanagiotou, 2017). Knowledge and information cannot be equated (Chatzipanagiotou, 2017) because knowledge is one step above information (Zins, 2007). However, Chatzipanagiotou (2017) argued that there is an interplay between these two, as knowledge can also be transferred into information through lessons learned, documents and best practices. This is in contrast with Zins (2007) claiming that knowledge is non-transferable. Zins (2007) argued that knowledge cannot be transferred, but it can be communicated through information. It is widely believed that there are relations between data, information and knowledge, as shown in Figure 9. It can be demonstrated from Figure 9 that by adding context to data, it becomes information, and when meaning and insight are given to information, it becomes knowledge.

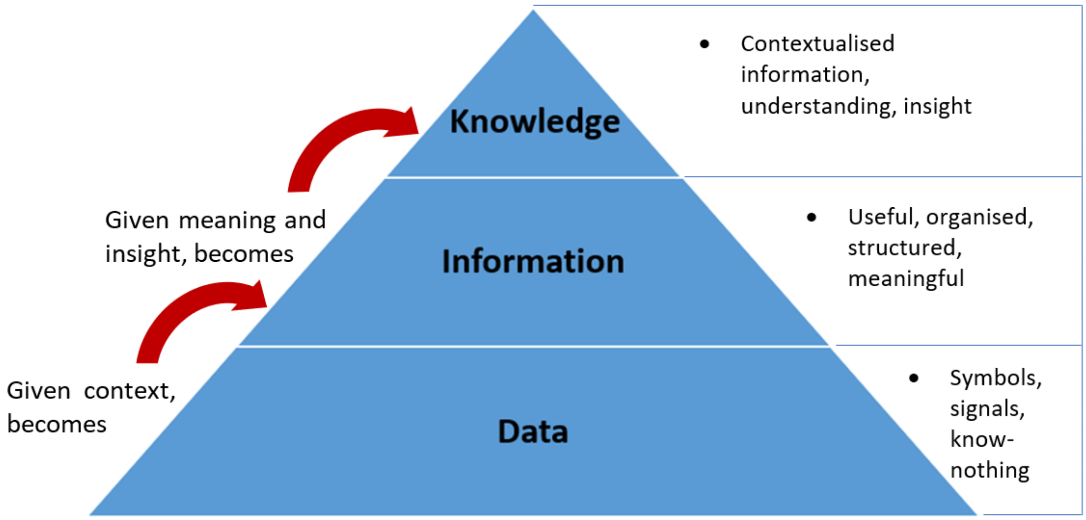

Figure 9 - Data, Information and Knowledge

2.3.2 Information Flow Management

As the amount of data and information increases, there needs to be more considerations on how to manage information successfully for efficient and effective information exchange and flow. It is widely believed that managing information is crucial for a project's success (Baldwin et al., 1999; Robertson, 2005; Detlor, 2010; Chatzipanagiotou, 2017; Talla & McIlwaine, 2022).

As information management is a broad conceptual term, it has been given various meanings and interpretations (Detlor, 2010; Chatzipanagiotou, 2017). The term is often used interchangeably with other terms, such as data management, knowledge management, etc.

As discussed before, there are relations between data, information and knowledge and hence the management of these three are somehow linked. However, it was argued by Detlor (2010) that "information management is more than just the management of data". Rather, it is the management of a diverse set of information resources, ranging from data to information (Baltzan, Philips, & Detlor, 2008, cited in Detlor, 2010). It was stated by Choo (2002) that Information management is "a continuous cycle of related activities encompassing the information value chain".

Moreover, information management is defined in relation to technology. The use of Information Technology (IT) to link and integrate business strategy and information is defined as information management (Johannessen & Olaisen, 1993). Nevertheless, information management was argued to be more about managing the information lifecycle processes rather than managing the technology (Detlor, 2010). According to Gartner (2013), Information management is a method enabled by technology to collect, store, process and manage information.

Despite the numerous definitions of information management, it is widely believed that the purpose of information management is to ensure that information is created, disseminated and delivered at the right time to the right people (Choo, 2002; Detlor, 2010; Chatzipanagiotou, 2017; Bilge & Yaman, 2021). This is in line with what Willpower Information (2005) believed to be the objective of information management, which is ensuring that “valuable information is acquired and exploited to its fullest extent” (Willpower Information, 2005, cited in Hicks, 2007). So, it can be found that the aim of information management is to ensure that the information is exchanged and shared accurately, which contains the value to improve the performance of the overall project.

Information management is not only about the information itself but also includes people, processes, and technology (Robertson, 2005; Chatzipanagiotou, 2017). Therefore, information management also focuses on managing activities that lead to changes in people and their behaviour, making the information management process more challenging (Chatzipanagiotou, 2017; Kania et al., 2021). These activities occur during the whole information lifecycle. Thus, information management concerns control over the information lifecycle (Detlor, 2010) by project participants.

There are several models of information lifecycle, but most of them include information-related processes or activities such as the creation or identification of information needs, information acquisition, information organisation, storage of information, design and development of information products, information retrieval, dissemination and distribution of information, and information use (Choo, 2002; Wilson 2003; Detlor, 2010;).

Detlor (2010) examined the different processes and activities in the information lifecycle models and proposed the following processes as the predominant information processes that need to be managed in information management:

- Information creation: the processes where individuals and organisations generate and produce new information artefacts and items.
- Information acquisition: the process where information items are obtained from external sources.

- Information organisation: the process of indexing or classifying information in ways that support easy retrieval at later points in time.
- Information storage: the process of physically housing information content in structures such as databases or file systems.
- Information distribution: the processes of disseminating, transporting, or sharing information.
- Information use: the process where individuals and organisations utilise and apply information made available to them.

If the above information processes are managed effectively, it would help to provide the right information to the right people in the right forms at the right times and at reasonable costs (Choo, 2002; Robertson, 2005; Detlor, 2010). Also, effective management of those activities and elements would add value to information and consequently to the information flow (Hicks, 2007).

Moreover, effective information management would benefit organisations in terms of reducing cost, reducing uncertainty or risks, adding value to existing services, and creating new value through the implementation of new technology and information-based services (Choo, 2008; Ozkan & Seyis, 2021). Even though the need for effective information flow management is often well understood, there are still many challenges within the flow of information that make information management problematic, especially during the design process.

In order to fully understand information flow management, it is essential to consider the three aspects of people, process and technology. Information needs managing and guiding throughout the project from start to finish. As mentioned before, information flow management is not limited to the information itself, but it also focuses on managing people, process, and technology (Robertson, 2005; Chatzipanagiotou, 2017). Thus, this makes information flow management more challenging and complicated (Chatzipanagiotou, 2017) as the focus of information flow management should be on the three aspects of people, process and technology collectively (Figure 10).

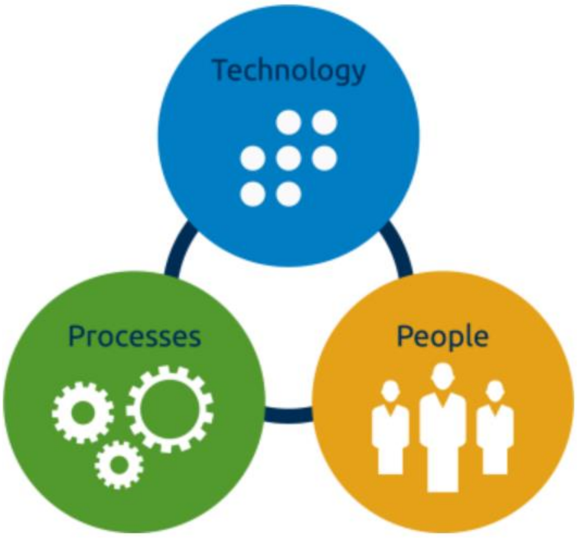

Figure 10 - People, Process and Technology

People

People play an important role in any organisation as they have a significant impact on information flow management, both positively and negatively. For information to be shared and managed, it needs to be created, exchanged and used by a person. It was stated by Phelps (2012) that in order for information to add value to a project, it needs to be shared, made available, accepted, and used by individuals and the project team. Therefore, for a project's success, it is important to understand the social phenomena which is related to individuals and the collaborative process of information (Phelps, 2012; Hickethier et al., 2013; Ibrahim et al., 2019).

Behavioural trends and their contribution to information flow were studied by Phelps (2012). The study revealed that there are four key factors which influence the information exchange and flow within a project team (Phelps, 2012):

1. Trust involves having positive expectations about another’s future actions when an individual is vulnerable to those actions.
2. Commitment is the strength of an individual’s identification with and involvement in a particular organisation.
3. Learning occurs when processing new information changes an individual’s range of potential behaviours.
4. Common understanding comes from an informal agreement regarding what is relevant to other team members and the project in general.

The first two factors, which are closely related to each other, are mostly linked to “a person’s values regarding the project” (Phelps, 2012, p.6). It was argued by Kadefors (2004) that trust is not regarded as a behaviour but as a psychological state. Interpersonal trust and building trusting relationships are essential for sustaining the effectiveness of any team (Gillespie, & Mann, 2004; Sagar et al., 2022) because when individuals trust one another, they are more likely to take risks that would benefit the team (Sagar et al., 2022). Also, it is important that trust is built in the project as soon as possible since the lack of trust prevents teams from exchanging information, and it will then lead to coordination the information management problems (Sagar et al., 2022).

A range of processes and outcomes that are related to productivity were believed to be the most influential factor for individuals’ trust, which include problem-solving and communication quality, discretionary effort, organisational behaviour, and commitment (Driks & Ferrin, 2002, cited in Gillespie, & Mann, 2004; Sagar et al., 2022). To enhance the performance of a project especially in a more cross disciplinary environment, there needs to be a higher level of trust (Kadefors, 2004). A higher level of trust would accordingly improve the flow of information as individuals are more likely to disclose and share information between project teams (Gillespie, & Mann, 2004; Sagar et al., 2022).

Moreover, the quality and the amount of information that individuals share are affected by individual's commitment to the project (Phelps, 2012; Ibrahim et al., 2019). Also, learning and understanding of the information provided by others are affected by the level of an individual’s commitment to the project and project team (Phelps, 2012). Therefore, the level of individuals’ commitment is essential to the flow of information, and it could have both negative and positive impacts on the information flow management and subsequently on the overall project success (Phelps, 2012; Ibrahim et al., 2019).

The following two factors “form an individual’s mental model”, which determines how a person: 1) evaluates new information, 2) links new information to their existing knowledge, and 3) categorises and orders information for the project (Phelps, 2012, p.6) as shown below in Figure 11. The engagement of individuals in learning would link the new information to a part of their existing mental model, which subsequently adjusts or broadens individuals’ mental model (Phelps, 2012).

The convergence of the mental model would enable individuals to develop a greater awareness of the relation of their knowledge to others and to the project as well, which is referred to as common understanding (Phelps, 2012). As a result, the more relevant information is shared considering the needs of others and the project, which subsequently impacts the information flow management (Phelps, 2012). However, it was argued by Phelps (2012) that if individuals are not willing to build on the common understanding, they do not value or trust shared information, and ignore or reject it. Thus, it would make the information flow management ineffective.

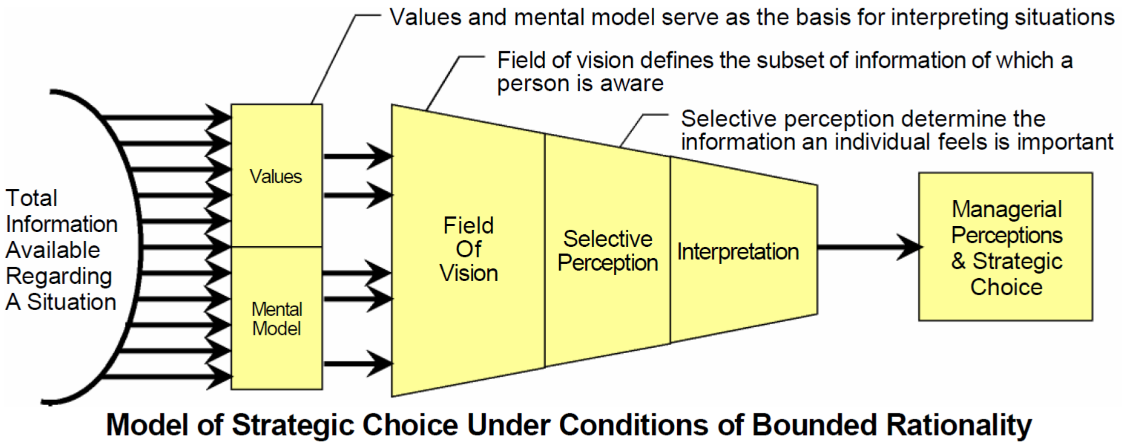

Figure 11 - Individual's Mental Model (Hambrick & Mason, 1984, cited in Phelps, 2012)

Therefore, understanding the aspect of people in terms of information flow is crucial to better manage the information flow and, thus the project success in general (Phelps, 2012; Hickethier et al., 2013). It was stated by Phelps (2012, p.9) that increasing trust and learning within project teams generate higher levels of commitment and understanding, which affect information flow effectiveness positively. This is demonstrated below in Figure 12.

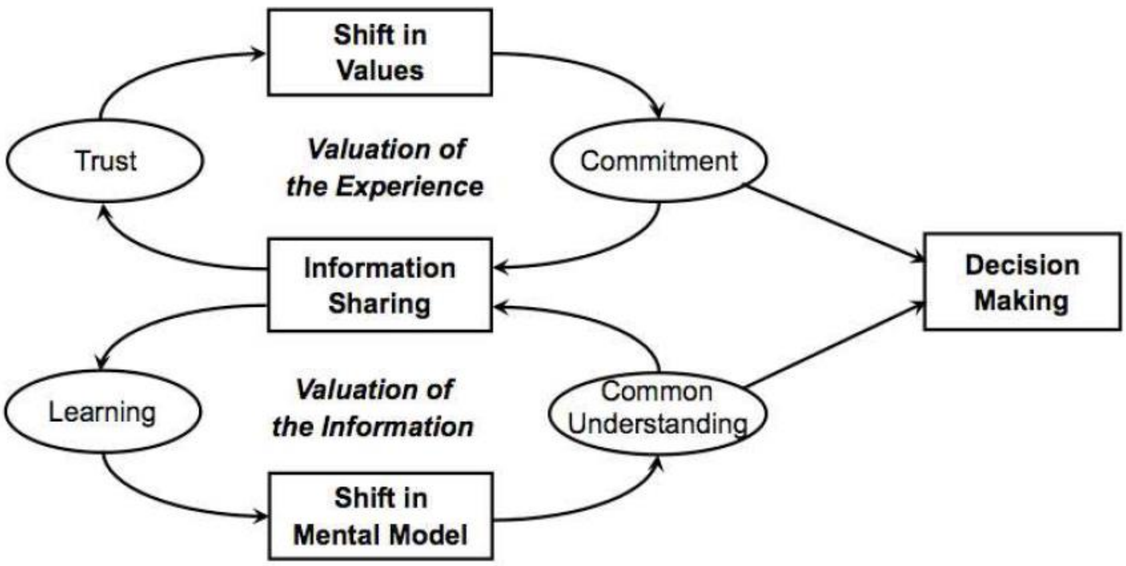

Figure 12 - The Interrelation of Trust and Learning Cycles (Phelps, 2012)

Process

As the technology matures and the amount of information increases, the process which supports this massive flow of information needs to be well managed (Hicks, 2007; Detlor, 2010; Al Hattab & Hamzeh, 2013). The process of information flow involves different activities and elements which need to be managed effectively to improve overall information flow management. According to Hicks (2007, p.1), these information-related activities "involve the creation, representation, organisation, maintenance, visualisation, reuse, sharing, communication and disposal of information". This is similar to Detlor (2010) proposed information process that was previously discussed. It was believed by Hicks (2007, p.1) that these activities and elements in the process could be considered to "involve adding value to information by virtue of how it is organised, visualised and represented, and enabling information (and hence value) to flow to the end-user through the processes of exchange, sharing and collaboration".

Therefore, a value-flow model (Figure 13) was proposed by Hicks (2007), which demonstrates that there is a fundamental value in the information (data) itself, and by virtue of the way information is organised, represented, exchanged and visualised, the further value will be generated. The value-flow model was adopted from the principles of lean thinking, which are related to information flow management in terms of adding value and reducing waste within the process (Hicks, 2007). The concept of lean and waste are discussed in more detail in section 2.4 Lean Construction.

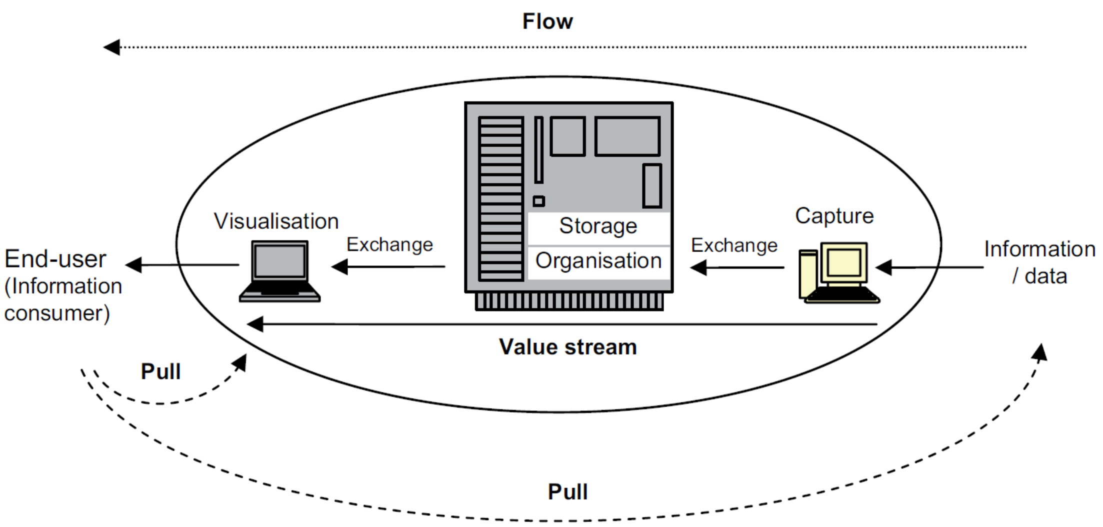

Figure 13 - The Value-Flow Model as Applied to Information Management (Hicks, 2007)

Technology

As technology is maturing, people require more information than ever before, and technology is generating more data than ever before, which results in a massive amount of information exchange during the design process (Al Hattab & Hamzeh, 2013; Leite et al., 2016; Ibrahim et al., 2019).

Introducing more technology and software enables generating and transferring more information than ever before. On the one hand, this could be helpful, but on the other hand, it can cause issues as humans cannot handle too much information at once (Leite et al., 2016). Therefore, enhanced innovative and technological tools and concepts are essential to managing information flow effectively.

Building Information Modelling (BIM) is believed to be an enabler for information flow management improvements (Azhar, 2011; Eastman et al., 2011; Al Hattab & Hamzeh, 2013; NBS National BIM Report, 2019; Ingram, 2020). BIM provides a 3D model that has many functionalities and can hold complex types of information (Eastman et al., 2011; Ingram, 2020). Also, BIM provides a collaborative environment in which people, technology and process come together to benefit the overall project performance. The BIM concept is discussed more in section 2.6 Building Information Modelling (BIM).

2.3.3 Information Flow Challenges

As technology matures, the amount of information and data generated and shared during the construction design process has rapidly increased (Al Hattab & Hamzeh, 2013; Leite et al., 2016; Ibrahim et al., 2019). Therefore, dealing with a large variety of project information and data to support decision-making efficiently and effectively has become critical (Leite et al., 2016).

Despite the rise in the amount of available information to use (Al Hattab & Hamzeh, 2013; Leite et al., 2016), the majority of information shared within the project “never ends up actually adding value to the project” (Phelps, 2012). When shared information is inaccurate, withheld, and excessive, its value will be lost, leading to significant waste (Hicks, 2007; Tribelsky & Sacks, 2010; Talla & McIlwaine, 2022). This would ultimately cause many challenges in the project.

Phelps (2012) argued that the primary cause of information waste is managing information flow ineffectively. Similarly, Al Hattab & Hamzeh (2013) also agreed that “ineffective information sharing and flow" is the major factor contributing to the waste of information. It is critically important to improving the flow of information as it has significant effects on process planning and scheduling (Chen et al., 2003; Kania et al., 2021). Also, to produce and exchange high-quality information and consequently improve the overall project performance and productivity, it is essential to manage information flow effectively (Zeng, Lou, & Tam, 2007; Kania et al., 2021).

Moreover, it was stated by Phelps (2012) that construction projects' success depends on 'effective information flow' due to the increasing complexity of projects. Therefore, Tribelsky and Sacks (2010) suggested that applying principles of lean construction to information flow management would improve the design process as well as reduce waste in this phase of the construction lifecycle.

Furthermore, BIM would also improve project information flow by providing a more flexible platform where information can be shared transparently between project teams (Al Hattab & Hamzeh, 2013; Ingram, 2020). The shared and exchanged information within the BIM collaboration platform would result in coordinated information and subsequently reduce delays, time, quality losses and cost overruns (Ozkan & Seyis, 2021).

Also, BIM provides many features which would enable effective information flow management. The technological features of BIM, such as visualisation, clash detection, detailed information asset, etc., which allow working in a collaborative environment, is widely believed to bring numerous benefits to the project, specifically in terms of information flow management (Azhar, 2011; Eastman et al., 2011; Ingram, 2020; NBS National BIM Report, 2019).

Thus, it can be found that BIM and Lean would support the information flow improvement in terms of reducing non-value-adding activities and information while increasing the value-adding activities and information. Even though the importance and beneficial role of BIM and Lean approaches to managing information flow have been understood, there are still many challenges within information flow management. Thus, the aim of this research is to study and understand these challenges and explore how BIM and Lean approaches could better enhance information flow management concerning different BIM maturity levels.

2.4 Lean Construction

2.4.1 Lean History

Lean Production was born as a result of Toyota's production system in the 1900s (Shingo, 1989). The world's first automatic power loom was invented by the founder of Toyota Motor Company 'Sakichi Toyoda' in 1902 (Toyota, n.d.). The loom had the ability to stop automatically when a broken thread was detected. This invention enabled the handling and monitoring of several machines by a single operator. Sakichi Toyoda's invention can be found as the origin of implementing 'Jidoka' (automation) principles (Toyota, n.d.). Jidoka means "automation with a human touch", which became one of the leading Toyota Production System concepts.

The other concept of the Toyota Production System is known as the 'Just-in-Time (JIT)' system, which was based on Kiichiro's production system (Toyota, n.d.). Kiichiro, the son of Sakichi, became the leader of the automobile-manufacturing operation which was established in 1936 and was the starting point of developing the Just-in-Time concept (Toyota, n.d.).

Later, Taiichi Ohno, who is considered the creator of the Toyota Production System (TPS), used the philosophies of the two concepts, Just-in-Time and Jidoka, to develop a more efficient production system (Toyota, n.d.). Taiichi Ohno is also known as the father of the Kanban System, one of the Lean manufacturing tools that are helpful not only in the manufacturing industry but also in other industries.

It was argued by Liker (2004) that Toyota Production System (TPS) "is not a toolkit"; it is "a sophisticated system of production in which all of the parts contribute to a whole" that "focuses on supporting and encouraging people to continually improve the processes they work on". TPS House, a model, developed by Toyota, represented the Toyota Production System principles (Liker, 2004). As shown in Figure 14, the model demonstrates the best quality, lowest cost, and shortest lead time by shortening the production flow by eliminating waste (Liker, 2004).

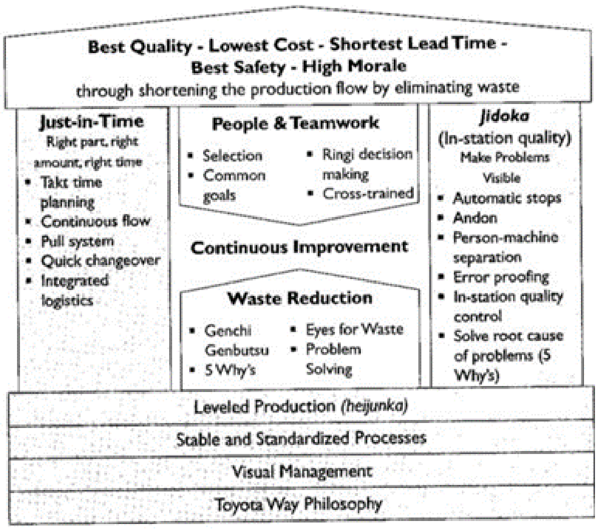

Figure 14 - The House of The Toyota Production System (TPS) (Liker, 2004)

Moreover, 14 principles were found by Liker (2004) in 'The Toyota Way'. These principles, which are divided into four main categories, can be found as the foundation of the Toyota Production System (TPS) (Liker, 2004). The four categories of Liker (2004) 14 principles are called the 4P model, as listed below;

- Philosophy
- Process,
- People/partners
- Problem-solving

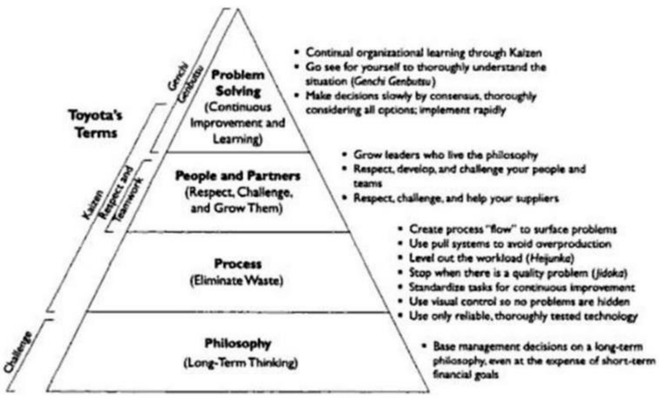

Figure 15 - The 4P Model of the Toyota Way (Liker, 2004)

As can be illustrated from Figure 15, the first P, 'Philosophy', is discussed by Liker (2004) as a long-term perspective of decision-making, even for a short-term business goal. 'Process', the second P, means that 'The Right Process Will Produce the Right Results' (Liker, 2004). The third P, 'People and Partners', is defined by Liker (2004) as 'Add Value to the Organisation by Developing Your People'. The last P, 'Problem Solving' is about 'Continuously Solving Root Problems Drives Organizational Learning' (Liker, 2004).

According to Gao & Low (2014, p.53), "the 4P model of the Toyota Way provides a picture of the values that constitute the foundation of the Toyota Production System and how these principles are applied in practice." It is also believed by Gao & Low (2014) that the 4P model can be used in any organisation as a key concept to establish their business.

2.4.2 Lean Philosophy

Lean is about making value while reducing non-value-adding activities (waste). Lean thinking is based on identifying and maximising customer value and reducing waste (Howell & Ballard, 1998). Lean thinking was first introduced by Toyota Production System (TPS), which in construction is known as 'Lean Production' system (Womack, Jones, & Roos, 1990). Lean construction can be identified as a combination of new processes and tools adopted from lean manufacturing that aims to improve the project's performance and reduce cycle time while minimising waste (Ballard & Howell, 1997; Alarcón, 1997).

Figure 16 - Five Principles of Lean (Womack & Jones, 1996)

Although there are different lean principles which several authors have identified, only particular ones are relevant and applicable in the context of this research. According to Womake & Jones (1996), there are five principles which could help to identify activities that add no value and eliminate them. The five principles which can be seen in Figure 16 are more discussed in Table 1.

Table 1 - Five Principles of Lean

1	**Value** Defining value from customers perspective	Value is the first key point of Lean thinking. The end customer will define the value because it identifies by the customers' needs. According to Womack & Jones (1996, 2010, p.353) value is a "capability provided to customer at the right time at an appropriate price, as defined in each case by the customer."
2	**Value Stream** Identifying all required steps in the value stream to eliminate waste	All the processes and the steps that produce value is value stream. "A value stream is all the actions currently required to bring a product through the main flows essential to every product from raw materials into the arms of the customer." (Rother & Shook, 1999, 2003, p.3). Also, value stream is defined by Womack & Jones (1996, 2010, p.353) as "specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer." This process along with particular activities can be recognised as the start point of eliminating waste or non-value adding activities. Highlighting root cause of waste through process mapping and eliminate them is the main purpose of value stream mapping (Rother & Shook, 2003). Similarly, Egan (1998) proposed that elimination of waste "has to be pursued throughout the whole value stream".
3	**Flow** Creating constant value flow by eliminating waste	This principle is about making the value-creating steps flow to deliver complete waste elimination. According to Womack & Jones (1996, 2010, p.348) the "progressive achievement of tasks along the value stream" is flow. 'One piece flow' which targets one piece of continuous flow is the best flow (Rother et al., 2001). However, it is argued by Koskela (2000) that creating continuous flow in construction is a major challenge as a result of fragmentation level in construction which prevents performance improvement (Egan, 1998). Nevertheless, Ballard (1997, 2000) claimed that the reliability of workflow cam be improved with the Last Planner System of Production Control (LPS).
4	**Pull** Producing based on demand	One of the main waste is known as excess inventory which will cause other waste. Therefore, it is important to produce the product by the demand of the customer and when it is needed. This means Pull which is also explained by Womack and Jones (2003) that creating and designing the customer' demand exactly as it is required and only when they need it.
5	**Perfection** Continuous improvement	The last principle of lean is perfection which plays an important role in terms of continuous improvement. This principle aims to improve the performance of projects by adoption of new value-added methods (Womack & jones 1996)

2.4.3 Lean in Construction

The construction industry has been considerably improved by adopting new approaches and principles to reduce waste and increase productivity. Lean construction plays an important role in terms of improving construction productivity and reducing waste in construction. Lean construction has been defined in many ways as it's a broad philosophy. According to Lehman & Reiser (2004), "lean construction is a project delivery system based on Lean Production Management process, originally developed by the Toyota Motor Company that is aimed at improving value by satisfying customer needs and improving performance". Similarly, lean construction is defined by Lean construction institute (n.d.) as "a production management based approach to project delivery". Lean construction is also defined by Ballard (2004) as "added value by eliminating waste".

Koskela (2004) explained three production views*; transformation, flow and value generation*. According to Koskela (2000), "The resulting transformation-flow-value generation model of production is called the TFV theory of production" since it will address critical construction issues, it can positively impact the construction industry (Koskela, 2000). Therefore, the three elements of the production system (TFV) can be found as one of the lean construction foundations. An overview of TFV theory can be seen below in Table 2.

Table 2 - TFV Overview (Koskela, 2000)

	Transformation view	*Flow view*	*Value generation view*
Conceptualization of production	As a transformation of inputs into outputs	As a flow of material, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
Main principles	Getting production realized efficiently	Elimination of waste (non-value-adding activities)	Elimination of value loss (achieved value in relation to best possible value)
Methods and practices (examples)	Work breakdown structure, MRP, Organizational Responsibility Chart	Continuous flow, pull production control, continuous improvement	Methods for requirement capture, Quality Function Deployment
Practical contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner
Suggested name for practical application of the view	Task management	Flow management	Value management

2.5 The Concept of Waste and Value in Construction

2.5.1 Waste in Construction

Non-value-adding activities (waste) are a critical goal in construction that will have significant impacts on the project's process and continuous improvement (Koskela, 1992, 2000). As shown in Figure 17, activities in a process can be categorised into three main types; value-adding (VA), essential non-value-adding activities (ENVA) and non-value-adding activities or waste (O'Connor & Swain, 2013).

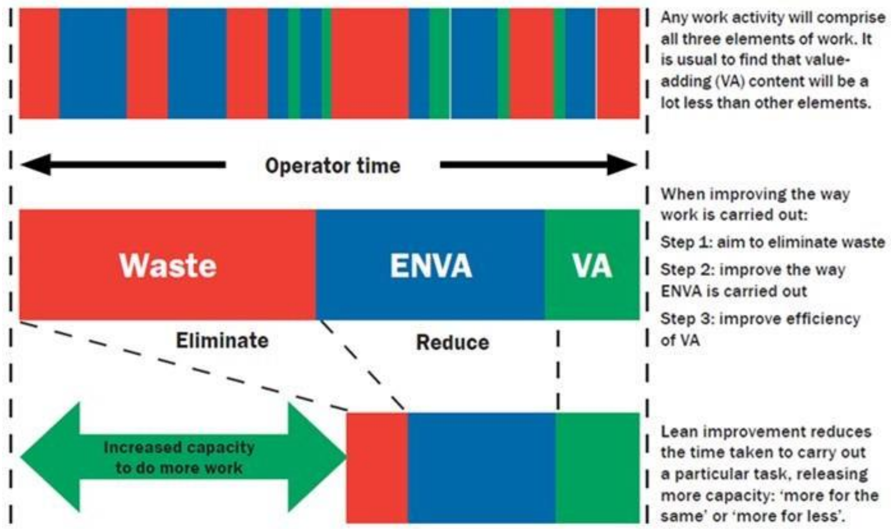

Figure 17 - Eliminating Waste (O'Connor & Swain, 2013)

As identified by Koskela (1992, p.17), non-value-adding activity is an "activity that takes time, resources or space but does not add value," which is also known as 'waste'. Likewise, Ohno (1988, p.19) argued that "if we regard only work that is needed as real work", the rest of the work that is not needed can be defined as 'waste'. Ohno (1988) identified seven major types of waste as; overproduction, time on hand (waiting), transportation, processing, stock on hand (inventory), movement, and making defective products. Later, Koskela (2000) used Ohno's (1988) definition of waste and listed seven types of waste as follows;

- Waste of overproduction
- Waste of correction
- Waste of material movement
- Waste of processing
- Waste of inventory
- Waste of waiting
- Waste of motion

The seven main types of waste were described by Rashid & Heravi (2012), as can be seen in Table 3.

Table 3 - Description of seven main groups of waste (Rashid & Heravi, 2012)

Wastes	Description
Over Production	Product that is more than required. Production much earlier than the time required (do something before it is actually needed). Manufacturing items for which there are no orders. Changes in the needs of the next delivery recipients (design changes).
Defect, Correction & Rework	Errors in the execution of required process that cause wastes in time, materials, etc., more than usual. Failure in machine tools and equipment due to incorrect use of them. Correcting incorrect and unnecessary processes. Reworks due to work interferences.
Inventory	A large number of under way processes in the construction or incomplete endeavor (or completed deliverables but not yet delivered). Possession of large and unnecessary quantities of raw materials that the capital still holds.
Transportat ion	Any mobility of materials that do not add to production values. Multiple transfers of data and information for final approval.
Waiting	Time wasted in the activities of employees and machines work due to bottlenecks and interferences, and capacity bottlenecks. Waiting for the information needs and customer requests or final approvals. Delays associated with stock-outs, lot processing delays, equipment.
Movement	Any physical movement or walking workers that keeps them from the work or causing delays in their work.
Over Processing	Additional steps in the production that is not required. Product with a number of features and quality over what the customer expected of the product. Unnecessary inspection.

Moreover, Koskela (2004) presented a new waste which is called 'Making-do'. This waste can happen when all the standard and necessary inputs of one task are not available, but the task is started (Koskela, 2004).

It is believed by Koskela (2000) that 'process' is the most important type of waste, which can be considered as the movement of the material. However, 'overproduction' or producing more and faster than is required was identified by Rother & Shook (2003) as the primary source of waste which could cause other waste.

It becomes critical to eliminate construction waste after it has been identified because it significantly improves the efficiency of the working process (Ohno, 1988; Howell & Ballard, 1998). Waste elimination is essential not only because of its role in improving project performance but also because it is essential as it will result in excessive time and cost (O'Connor & Swain, 2013). The level of waste in construction projects was found to be around 50% which reveals the importance of eliminating waste to improve project efficiency as well as minimise project cost and time (Egan, 1998). Similarly, based on the findings of Christian et al. (1995), it was reported by Zhao & Chua (2003) that only 46% of working time is spent on activities that add value, whereas 39% of the time is spent on waiting and idling.

It was claimed by Ohno (1988, p.20) that to eliminate waste, the extra manpower needs to be released as “wasteful and meaningless jobs enhance the value of work for workers” (Ohno, 1988). However, Koskela (2000) argued that eliminating each waste has a different method from one to another as there are different root causes for each waste.

According to Koskela (1992, 2000), there are three root causes of waste; the structure of the production system (design), the way production is controlled (ignorance), and the inherent nature of production. ‘The physical flow that is traversed by material and information’ is determined as the structure of the production system, which may cause or increase inspecting, moving and waiting (Koskela, 1992, 2000). Producing waste by the control principles and lack of conformity to the proposed principles are the two ways that affect waste in the way production is controlled (Koskela, 2000).

It is in the nature of production that waste (non-value-adding activities) exists; defects emerge, machines break down, and accidents happen (Koskela, 1992, 2000). These three root causes of waste would change on the subject of their structured time (Koskela, 2000). Therefore, there should be different techniques to attack these waste sources (Koskela, 2000).

2.6 Building Information Modelling (BIM)

2.6.1 BIM Concept

Building Information Modelling (BIM) as a new approach to construction design brings a new way of working in the construction industry (Hardin & McCool, 2015). Likewise, as stated by Eastman et al. (2011, p.16), “BIM is a fundamentally different way of creating, using, and sharing building information lifecycle data”. It is also believed that BIM is a current innovation which is expected to overcome the construction industry’s low productivity (NSB, 2019; Abbasnejad et al., 2021) due to its various benefits.

Many people believe that BIM is not just a tool or software but a process (Azhar, 2011; Azhar, Khalfan, & Maqsood, 2012; Hardin & McCool, 2015; Abbasnejad et al., 2021; Sampaio et al., 2022) in which all information and data are shared collaboratively by all the project participants throughout the whole lifecycle of projects as shown in Figure 18. Likewise, it was stated by Eastman et al. (2011, p.351) that “BIM is not a thing or a type of software but a human activity that ultimately involves broad process changes in construction”. BIM concept is to create a virtual building prior to physically building it, to identify problems and simulate and evaluate possible impacts (Smith, 2007) in order to resolve any issues that might occur on the construction site, such as rework, early in the design process (Eastman et al., 2011).

Figure 18 - BIM as a collaborative approach (Underwood, 2014)

BIM aims to improve construction efficiency, quality, and productivity (Arayici et al., 2011; NSB, 2019; Abbasnejad et al., 2021). Moreover, BIM seeks to change the silo mentality of the Architecture, Engineering and Construction (AEC) industry in which no information or data is shared between project participants, as shown in Figure 19. Lack of information transfer and lack of collaboration is the result of a silo mentality, which will lead to a reduction of construction project productivity and performance (Fenwick, Seville, & Brunsdon, 2009).

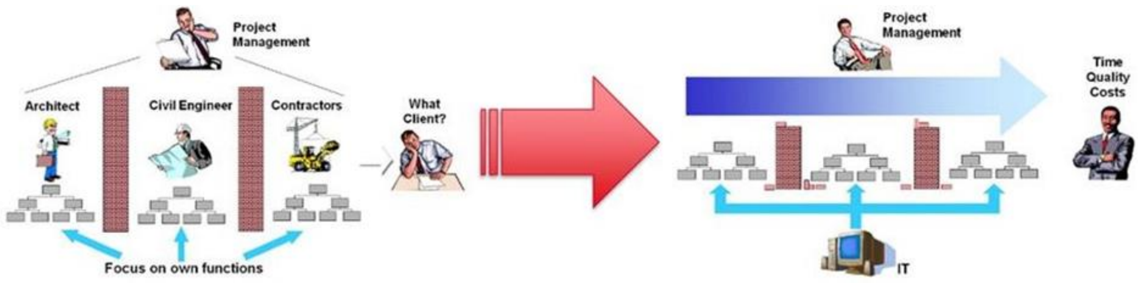

Figure 19 - Silo Mentality change by BIM (Underwood, 2014)

Even though the BIM concept is widely known, there is still a lack of implementation of this approach in the construction industry. Therefore, the government set a new target to mandate BIM in the Architecture, Engineer and construction (AEC) industry. The Government Construction Strategy (2011) reported that the "Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016".

According to Construction Industry Council (2013), the government target and "strategy for BIM implementation will change the dynamic and behaviours of the construction supply chain, unlocking new, more efficient and collaborative ways of working". However, this target only applies to government funded construction companies, which means that the rest of the construction firms are free to either adopt or not adopt the BIM concept, and this might have negative impacts on the government's target for 2016.

Nevertheless, since BIM benefits are becoming significantly understood by the construction industry, even some of the small companies that the government does not fund are still willing to adopt BIM. For example, Ben Beurgler, who is a senior engineer at EMC, expressed the opinion about BIM adoption that "we are just a small firm, doing small projects, but we see the value, and we are made the commitment" (n.d., cited in McGraw-Hill Construction, 2009).

The adoption level of BIM in companies is different due to the size or implementation level of companies. As shown in Figure 20, A 'maturity model' has been developed to identify each level towards BIM adoption, which aims to "categorise types of technical and collaborative working to enable a concise description and understanding of the processes, tools and techniques to be used" (BIM Industry Working Group, 2011, p.16). This will be discussed more in section 2.6.5 BIM Maturity Levels.

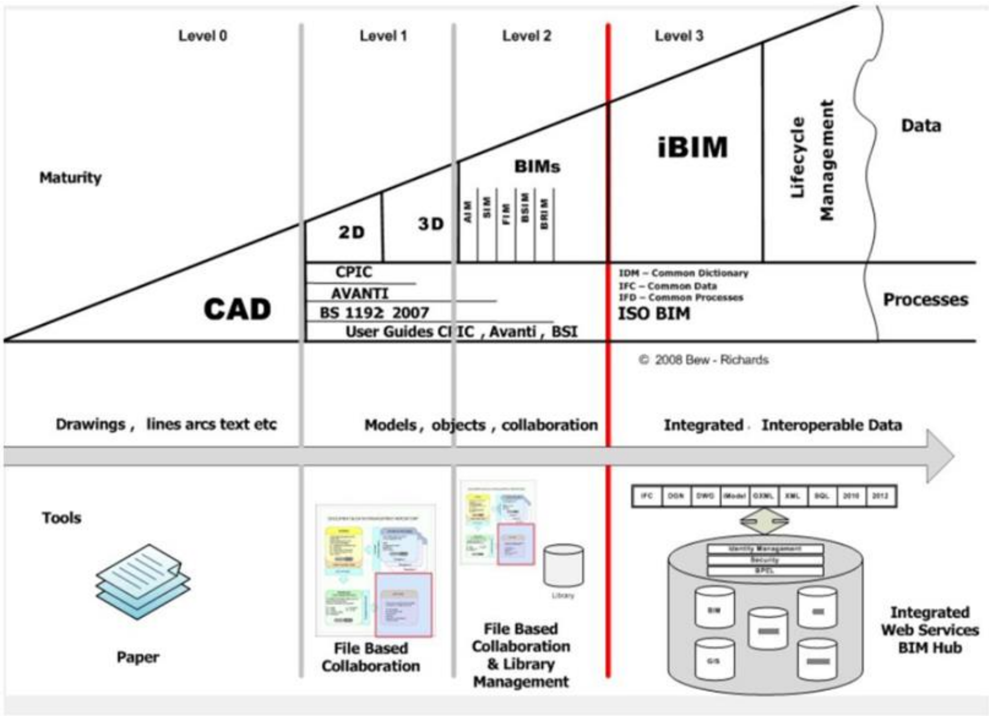

Figure 20 - BIM Maturity Model (BIM Industry Working Group, 2011)

2.6.2 BIM Model

Traditionally construction projects use paper-based methods in which data is produced only by 2D CAD drawings. However, the new approach to BIM has the capability of expanding the traditional CAD and paper-based methods by "defining and applying intelligent relationships between the elements in the building model" (Singh, Gu, & Wang, 2011, p.134).

Similarly, it is believed by Eastman et al. (2011) that BIM changes the industry from a paper-based process to "a coordinated and collaborative process that maximizes computing capabilities" through the creation and use of the BIM model. BIM model includes any information related to the actual building (e.g. physical, functional characteristics, and project lifecycle information) (Ningappa, 2011) directly from the model, and it can automatically extract 2D drawings and other building documents and data (Singh, Gu, & Wang, 2011).

Table 4 below demonstrates the traditional 2D-based method versus the Model-based process in the construction process.

Table 4 - 2D based Process vs Model based process (Ningappa, 2011)

2D Based Process		Model Based Process
Linear, Phased	Design	Concurrent, Iterative
Paper 2D	Drawings	Digital 3D Object based tied to intelligent data
Evaluated over days in 2D	Value Engineering Alternatives	Evaluated in 3D instantly
Unclear Elevations	Site Planning	Relief Contours
Slow and Detailed	Code Review	Expedited and Automated
Light Tables	Design Validation	Clash Detection with Audit Trails
2D Drawings	Field Drawings	2D Drawings and Perspectives
Assembled near completion	Closeout Documents	Intelligent models for operations and maintenance instructions; Constantly updated during construction
Stand Alone Activites	Scheduling	Activities linked to Models
Limited Scenarios evaluated	Sequence Planning	Extensive Scenarios Evaluated earlier in the process
Paper Shop Drawings	Field Coordination	Overlaying Digital Models using collision detection software
Use manuals	Operation Training	Visual

According to Azhar (2011) following are some of the purposes of using a BIM model;

- Visualisation
- Fabrication/shop drawing
- Code reviews
- Cost Estimating
- Construction sequencing
- Conflicts, interference, and collision detection
- Forensic analysis
- Facilitate management

2.6.3 BIM Benefits in Construction Design

The use of Building Information Modelling (BIM) provides numerous benefits to the whole project's lifecycle from the design stage to the operation stage, as shown in Figure 21. Azhar (2011) and Azhar et al. (2008) listed some of the BIM benefits to the project lifecycle, which are briefly described in Table 5 below.

Table 5 - BIM Benefits (Azhar et al., 2008; Azhar, 2011)

BIM Benefits	Brief Description
Faster and more effective processes	Information is more easily shared and can be value-added and reused.
Better design	Building proposals can be rigorously analysed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions.
Controlled whole-life costs and environmental data	Environmental performance is more predictable, and lifecycle costs are better understood.
Better production quality	Documentation output is flexible and exploits automation.
Automated assembly	Digital product data can be exploited in downstream processes and used for manufacturing and assembly of structural systems
Better customer service	Proposals are better understood through accurate visualization
Lifecycle data	Requirements, design, construction, and operational information can be used in facilities management.

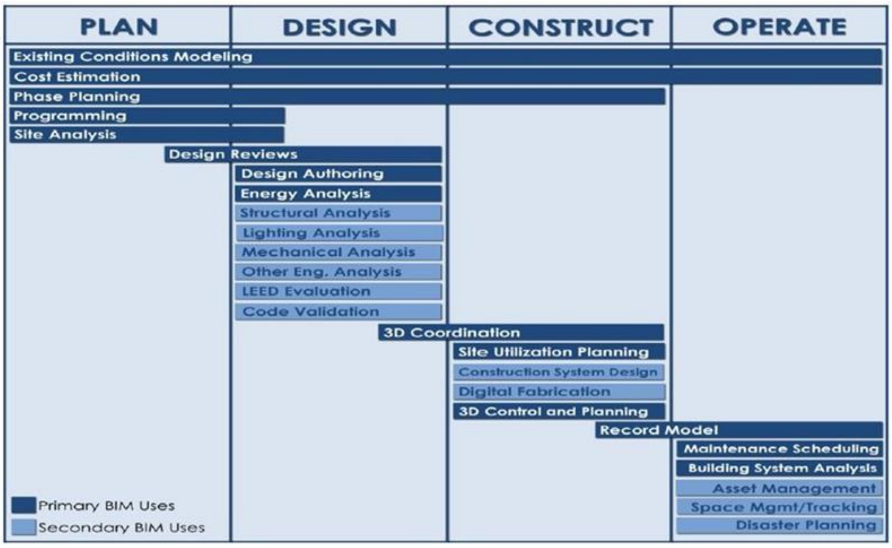

Figure 21 - BIM uses throughout Building Lifecycle (The computer integrated construction research program, 2011)

Eastman et al. (2011) stated that "BIM facilitates a more integrated design and construction process that results in better quality buildings at lower cost and reduced project duration" due to the benefits that BIM provides. Similarly, McGraw-Hill Construction (2009) and NBS (2019) reported that BIM users gained many benefits, which include improvement in productivity, enhanced quality, increased opportunities for new business and also achieving better outcomes in projects.

Another research on the benefits of BIM revealed fifteen top benefits of BIM, which can be seen in Figure 22. The research of McGraw Hill Construction (2013) reported that the most beneficial impact of BIM is on 'reducing errors and omissions', and 'collaboration with owners/design firms' scored as the second top benefit of BIM. Likewise, Singh, Gu, & Wang (2011, p.134) stated that BIM applications "provides constraints that can reduce modelling errors and prevent technical flaws in the design, based on the rules encoded in the software provides opportunities for enhanced collaboration and distributed project development".

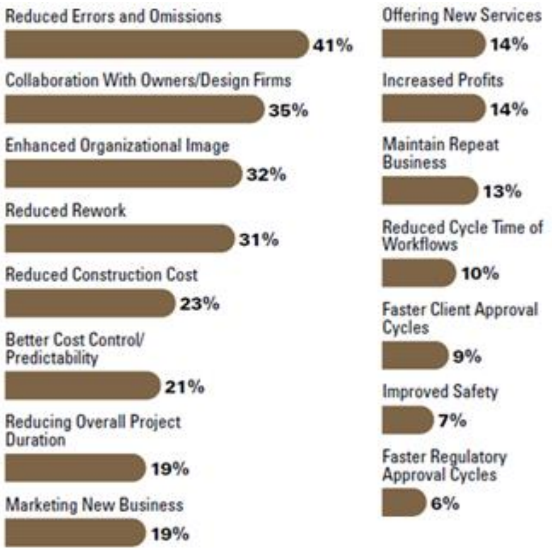

Figure 22 - Percentage of BIM benefits (McGraw Hill Construction, 2013)

Even though BIM has many benefits to the construction industry, only particular potential benefits of it will be discussed within this research as they are more related to lean construction and would enhance information flow management in terms of reducing non-value-adding activities and information in the design process.

As can be illustrated in Figure 23 design process, including preliminary and detailed design, has the most significant impact on the cost and performance of the project. According to MacLeamy Curve, 2004 shown in Figure 23, it is important to make decisions in the early stage of a project because this would increase the opportunity for positive outcomes and reduce the cost of change (MacLeamy, 2004; Guo, Wang, & Xiong, 2022).

The early decisions in the design process can influence the overall cost, functionality, and project outcomes (Eastman et al., 2011; Guo, Wang, & Xiong, 2022). Thus, BIM workflows can significantly improve information flow and, thus, project performance because they have their most significant benefits to the design process (Eastman et al., 2011). The benefits BIM provides to the design process will increase the project performance and efficiency and reduce the project cost through its tools and process approach.

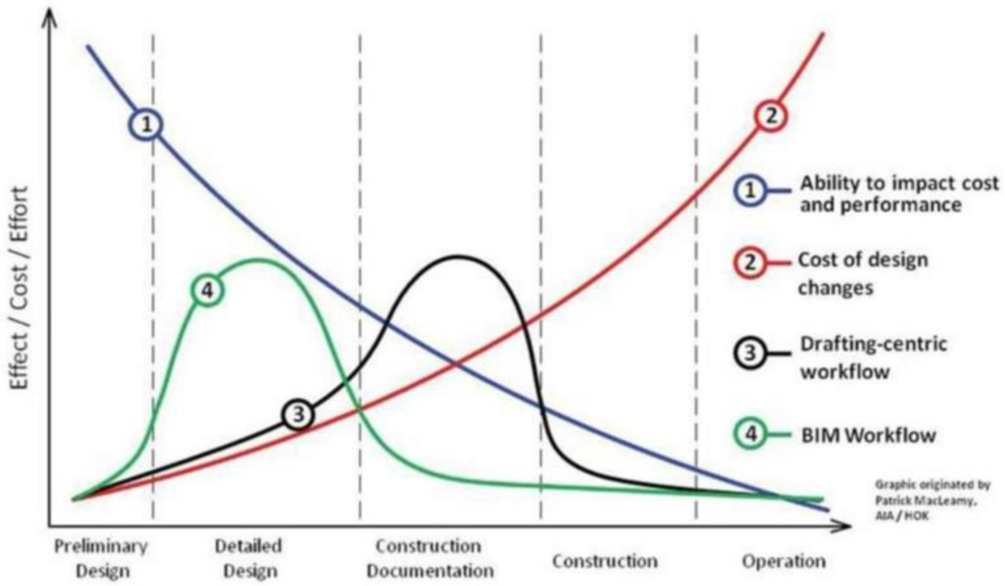

Figure 23 – BIM workflow vs Traditional workflow (MacLeamy, 2004)

Some of the design benefits of BIM are discussed by Eastman et al. (2011) which are as follows;

- Earlier and more accurate visualisations of a design

The 3D BIM model which is generated by the BIM software, allows visualisation of the design from different viewpoints at any phase of the project process.

- Automatic low-level corrections when changes are made to design

The 3D model of the project will be free of geometry, alignment, and spatial coordination errors as the objects are controlled by parametric rules in the design, which ensure proper alignment. Thus, the user's need to change the design and manage the changes will be reduced.

- Generation of accurate and consistent 2D drawings at any stage of the design

Accurate and consistent 2D drawings can be extracted from the model. Therefore, the significant amount of time and number of errors related to the construction drawings will be reduced. Also, fully reliable drawings can be produced if any changes to the design are required.

- Earlier collaboration of multiple design disciplines

BIM technology facilitates simultaneous work by multiple design disciplines in a collaborative environment. This enables the project participants to check the design problems in the early stages, which will help them to identify any solutions to improve the design. Also, the design time will be shortened as well as reducing design errors and omissions.

- Easy verification of consistency to the design intent

BIM provides earlier 3D visualizations and quantifies the area of spaces and other material quantities, allowing for earlier and more accurate cost estimates.

- Extraction of cost estimates during the design stage

An accurate bill of quantities that can be used for cost estimation can be extracted from the BIM model at any design stage. This makes it possible to make better decisions in terms of cost early in the design stage.

- Improvement of energy efficiency and sustainability

BIM tools provide an energy analysis to evaluate the energy use of the building during the early design stage, which will offer many opportunities in terms of improving building quality and increasing sustainability.

Although many authors explained various benefits that BIM offers in the design process, only four BIM features that are mainly beneficial in relation to lean construction in terms of improving information flow in this context are selected;

- Visualisation
- 4D Scheduling
- Clash detection
- Construction sequence planning
- Collaboration and communication

Each above-listed BIM feature can add value to the projects in terms of improving the flow of information and, therefore, generating value and reducing waste, as each one of them provides many benefits to the project.

Visualisation

Visualisation, as the best BIM tool, provides a three-dimensional virtual view of the building (Eastman et al., 2011; Hergunsel, 2011; Talebi, 2014; Andersen & Findsen, 2019). It is stated by Talebi (2014, p.6) that "visualisation promotes planning and sequencing the construction components". Any specific components or objects of the 3D model can be viewed, which will help the designers to identify any missing information, duplicated information, or wrong information to make changes to the model early in the design process. Project managers can use walk-throughs, rendering and construction sequencing to provide a better understanding of the final building to all project participants (Azhar, 2011; Hergunsel, 2011; El Ammari & Hammad, 2019). By virtually visualising the BIM model, any information design errors can be detected, which helps to improve the information quality and, thus, the efficiency and reliability of the design.

4D Scheduling

One of the BIM's beneficial features is the ability to provide 4D models and simulations throughout the design process. By using 4D simulation tools, which include not only the 3D model but also time and cost scheduling, design can be easier discovered, and it will be economically practicable (Eastman et al., 2011; Andersen & Findsen, 2019). 4D models can provide a "big picture" view of the project's condition (Eastman et al., 2011), enabling all project participants to access and view the information available in the model and make any changes if needed early in the design process. This type of tool can play a significant role in the design process, as it links the 3D model with the time and cost scheduling, allowing the team members to know the details about the exact construction schedule as well as information about materials and costs (Wang et al., 2004).

Additionally, by using 4D, the reliability of information within the schedule planning will be improved as well as improving the collaboration and communication in projects (Koo & Fischer, 2000; Hartmann, Gao & Fischer, 2008; Brito & Ferreira, 2015). Figure 24 demonstrates the 4D process in which some of the construction waste can be recognised early in the design phase and reduced by the tools that 4D simulations provide. Through 4D scheduling and visualisation, the information reliability would be improved alongside the enhanced collaboration and communication in the project (Koo & Fischer, 2000; Hartmann et al., 2008; Brito & Ferreira, 2015; Andersen & Findsen, 2019).

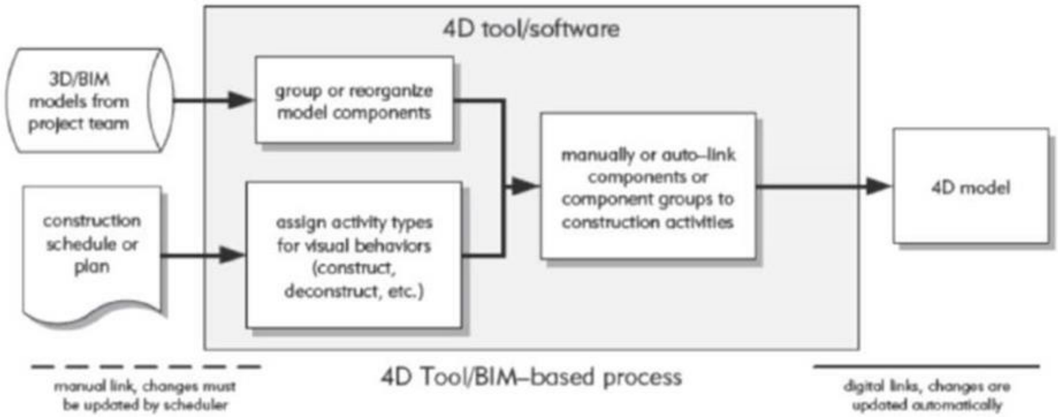

Figure 24 - Typical Process Steps for a 4D BIM-based workflow (Eastman et al., 2011)

Clash Detection

One of the most beneficial processes of BIM is clash detection, which allows project owners to save time and money (McGraw Hill Construction, 2009; NBS, 2019). According to Jackson (2010), "clash detection allows for the effective identification, inspection, and reporting of unintended material or system interferences in a 3D project model". Similarly, Eastman et al. (2011, p.) stated that "Automatic detection of conflicts is an excellent method for identifying design errors, where objects either occupy the same space (a hard clash) or are too close (a soft clash)".

BIM enables clash detection and design coordination which helps to check any interfaces between all the components of the building (Jackson, 2010). The process of clash detection can be performed across all building systems (e.g. mechanical system vs structural system) at any stage of the project process, as shown in both Figure 18 and Figure 19 (Eastman et al., 2011). Also, any human error during the design of the building can be inspected through clash detection, which will result in reducing time and the cost of discovering clash issues late in the project process (Jackson, 2010; Azhar, 2011; Khudhair et al., 2021).

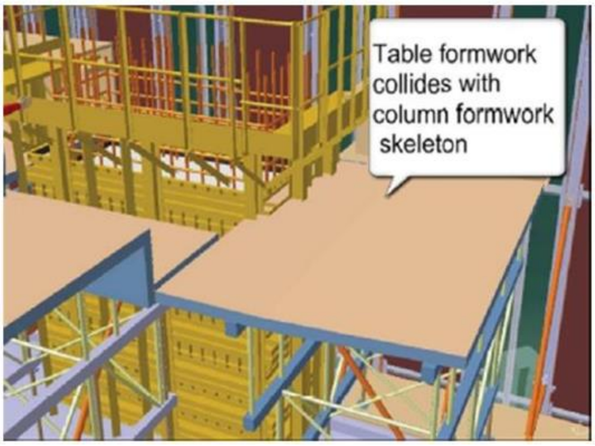

Figure 25 - BIM Structural System Clash Detection

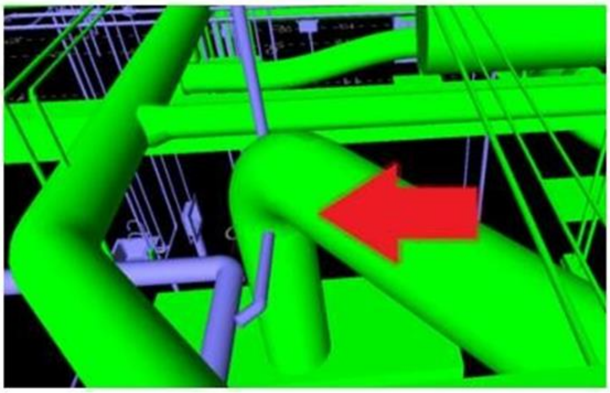

Figure 26 - BIM MEP System Clash Detection

Construction sequence planning

"Construction planning and scheduling involve sequencing activities in space and time, considering procurement, resources, spatial constraints and other concerns in the process" (Eastman et al., 2011, p.281). According to Azhar (2011), The BIM model can coordinate material ordering, fabrication, and delivery schedules for all building components. In order to achieve the best feasible construction schedule planning, 4D models and tools are used within the BIM model. More reliable and enhanced schedules can be implemented by creating, viewing and editing 4D models, which is enabled by BIM (Eastman et al., 2011).

Additionally, 4D tools enable the construction sequence plan to be simulated and evaluated by the project team, which will help the project participants "to ensure that the plan is feasible and as efficient as possible" (Eastman et al., 2011). Therefore, this would improve information flow as the information related to planning and scheduling is being checked and analysed regularly.

Collaboration and communication

Collaboration and communication can be found as the key fundamental aspects of BIM. According to Singh, Gu, & Wang (2011), “the scope of BIM is expanding from current intra-disciplinary collaboration through specific BIM applications to multi-disciplinary collaboration through a BIM- server”. Earlier collaboration between project participants is enabled through BIM, which will have many benefits to project improvement, especially in terms of exchanging information. BIM-enabled collaboration and communication provide effective and efficient information management within a digital model, establishing a reliable foundation for decisions during the building lifecycle (Bradley et al., 2016, Cited in Machado et al., 2020). Communication improvement can also reduce failure and increase project and information management efficiency (Thomas, Tucker, & Kelly, 1998).

Moreover, it is believed by Brow and Barret & Baldry that the use of BIM for effective collaboration and communication in the early design process can have significant impacts on the information quality and, therefore, project quality (2002, 2009, cited in Talebi, 2014; Ozkan & Seyis, 2021).

2.6.4 BIM Challenges in Construction Design

2.6.5 BIM Maturity Levels

It is widely believed that BIM provides many benefits by adding value to the overall process of the construction project lifecycle. However, BIM implementation did not directly result in a better construction process in terms of time, cost, or quality (Smits et al., 2016). This is due to the lack of using integrated information modelling technologies with the organisational processes of a project (Davies & Harty, 2013; Hartmann et al., 2012; Sackey, Tuuli, & Dainty, 2014).

Moreover, it was argued by Smits et al. (2016) that, to reap the actual benefits of BIM adoption, individuals, along with organisations, should learn how to use the new technology first. Additionally, the adoption level of BIM in companies and organisations is different due to the size or implementation level of the companies. Therefore, it is vital that organisations build up their BIM maturity by using the existing developed BIM maturity models (Succar, 2009; Sebastian & Van Berlo, 2010; Mom & Hsieh, 2012; Giel et al., 2012; CICRP, 2013; Chen et al., 2014).

According to Succar (2010), “a collation of process maturity levels from ‘immature’ to ‘highly mature’ is typically referred to as a ‘Maturity Model’”. A BIM Maturity Matrix (model) was developed by Succar (2010), which was influenced by the existing maturity models and numerous Business Performance, Excellence and Quality Management models (see Appendix A). This BIM Maturity Index comprises five levels:(a) Initial, (b) Defined, (c) Managed, (d) Integrated and (e) Optimised (Succar, 2010). Each of these five levels is explained according to three identified interlocking BIM Fields of activity: Technology, Process and Policy (Succar, 2009, see appendix B).

Moreover, a ‘BIM Maturity Model’ was developed in the context of the UK to identify each level towards BIM implementation. This ‘Maturity Model’ aims to “categorise types of technical and collaborative working to enable a concise description and understanding of the processes, tools and techniques to be used” (BIM Industry Working Group, 2011, p.16). Table 6 describes the definition of each level of the Maturity model.

This research will focus only on three BIM Maturity levels: defined, managed and integrated, as explained and determined based on BIM capability stages and organisational scales in Figure 28. In the context of this research, the ‘Defined’ BIM level refers to projects that are still in the Level 1 of the BIM maturity model, as shown in Figure 27. The BIM level ‘Managed’ refers to the projects that are in the Level 2 of the BIM maturity model in Figure 27. Finally, the ‘Integrated’ BIM level refers to the projects that are presented in the highlighted section in Figure 27.

In the context of this research, ‘Integrated’ BIM level refers to the projects that are using the ‘Integrated Project Delivery’ (IPD) approach. According to the American Institute of Architects (AIA), integrated project delivery is “a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.” (AIA, 2007).

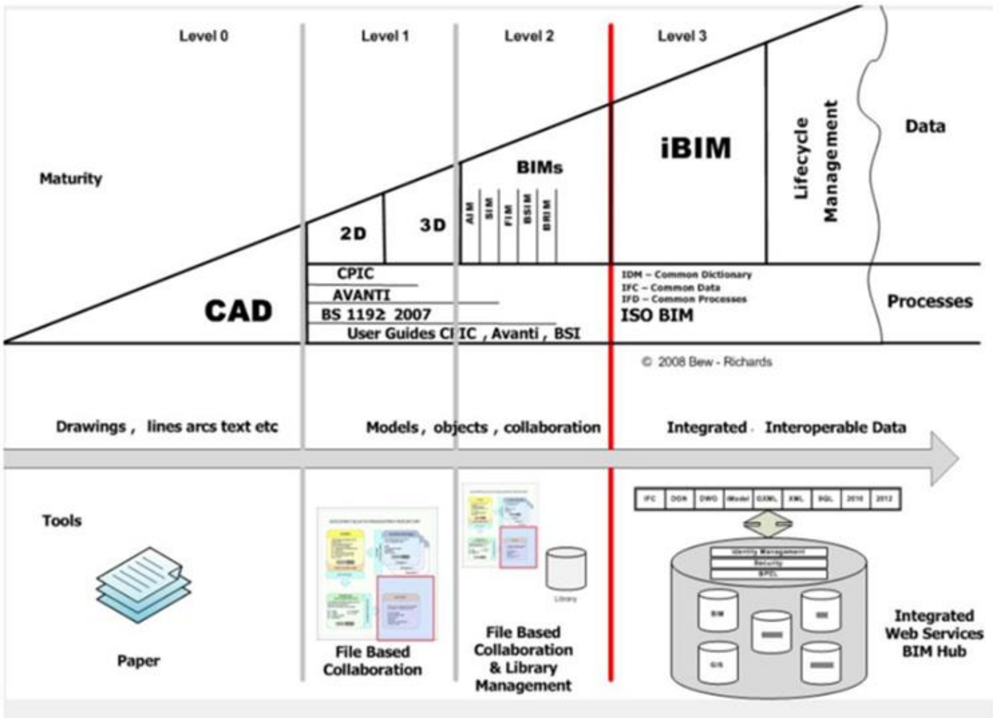

Figure 27 - BIM Maturity Model (BIM Industry Working Group, 2011)

Table 6 - Maturity Level Definition (BIM Industry Working Group, 2011)

Level	Definition
0	Unmanaged CAD probably 2D, with paper (or electronic paper) as the most likely data exchange mechanism.
1	Managed CAD in 2 or 3D format using BS1192:2007 with a collaboration tool providing a common data environment, possibly some standard data structures and formats. Commercial data managed by standalone finance and cost management packages with no integration.
2	Managed 3D environment held in separate discipline "BIM" tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as "pBIM" (proprietary). The approach may utilise 4D programme data and 5D cost elements as well as feed operational systems.
3	Fully open process and data integration enabled by "web services" compliant with the emerging IFC/IFD standards, managed by a collaborative model server. Could be regarded as iBIM or integrated BIM potentially concurrent engineering processes.

			a	b	c	d	e
			INITIAL	DEFINED	MANAGED	INTEGRATED	OPTIMISED
BIM CAPABILTY STGAES	STAGE 1	**Object-based Modelling**: single-disciplinary use within a Project Lifecycle Phase	Implementation of an object-based tool. No process or policy changes identified to accompany this implementation.	Pilot projects are concluded. BIM process and policy requirements are identified. Implementation strategy and detailed plans are prepared.	BIM processes and policies are instigated, standardised and controlled.	BIM technologies, processes and policies are integrated into organisational strategies and aligned with business objectives.	BIM technologies, processes and policies are continuously revisited to benefit from innovation and achieve higher performance targets.
	STAGE 2	**Modelling-based Collaboration**: multi-disciplinary, fast-tracked interchange of models	Ad-hoc BIM collaboration; in-house collaboration capabilities incompatible with project partners. Trust and respect between project participants may be lacking.	Single-thread, well-defined yet reactive BIM collaboration. There are identifiable signs of mutual trust and respect among project participants.	Multi-thread proactive collaboration; protocols are well documented and managed. There are mutual trust, respect and sharing of risks and rewards among project participants.	Multi-thread collaboration includes downstream players. This is characterised by the involvement of key participants during projects' early lifecycle phases.	Multi-thread team included all key players in an environment characterised by goodwill, trust and respect.
	STAGE 3	**Network-based Integration**: concurrent interdisciplinary interchange of nD models across Project Lifecycle Phases	Integrated models are generated by a limited set of project stakeholders - possibly behind corporate firewalls. Integration occurs with little or no pre-defined process guides, standards or interchange protocols. There is no formal resolution of stakeholders' roles and responsibilities.	Integrated models are generated by a large subset of project stakeholders. Integration follows predefined process guides, standards and interchange protocols. Responsibilities are distributed and risks are mitigated through contractual means.	Integrated models (or parts of) are generated and managed by most project stakeholders. Responsibilities are clear within temporary project alliances or longer-term partnerships. Risks and rewards are actively managed and distributed.	Integrated models are generated and managed by all key project stakeholders. Network-based integration is the norm and focus is no longer on *how* to integrate models/ workflows but on proactively detecting and resolving technology, process and policy misalignments.	Integration of models and workflows are continuously revisited and optimised. New efficiencies, deliverables and alignments are actively pursued by a tightly-knit interdisciplinary project team. Integrated models are contributed to by many stakeholders along the construction supply chain.
ORGANISATIONAL SCALES	MICRO	**Organisations:** dynamics and BIM deliverables	BIM leadership is non-existent; implementation depends on technology champions.	BIM leadership is formalised; different roles within the implementation process are defined.	Pre-defined BIM roles complement each other in managing the implementation process.	BIM roles are integrated into organisation's leadership structures.	BIM leadership continuously mutates to allow for new technologies, processes and deliverables.
	MESO	**Project Teams** (multiple organisations): inter-organisational dynamics and BIM deliverables	Each project is run independently. There is no agreement between stakeholders to collaborate beyond their current common project.	Stakeholders think beyond a single project. Collaboration protocols between project stakeholders are defined and documented.	Collaboration between multiple organisations over several projects is managed through temporary alliances between stakeholders.	Collaborative projects are undertaken by inter-disciplinary organisations or multidisciplinary project teams; an alliance of many key stakeholders.	Collaborative projects are undertaken by self-optimising interdisciplinary project teams which include most stakeholders.
	MACRO	**Markets:** dynamics and BIM deliverables	Very few supplier-generated BIM components (virtual products and materials representing physical ones). Most components are prepared by software developers and end-users.	Supplier-generated BIM components are increasingly available as manufactures/ suppliers identify the business benefits.	BIM Components are available through highly accessible/searchable central repositories. Components are not interactively connected to suppliers' databases.	Access to component repositories are integrated into BIM software. Components are interactively linked to source databases (for price, availability, etc...).	Dynamic, multi-way generation and interchange of BIM components (virtual products and materials) between all project stakeholders through central or meshed repositories.

Figure 28 - BIM Maturity Matrix (Succar, 2010)

2.7 Interaction of Lean and BIM

2.7.1 Synergy between Lean and BIM

Lean is about making value while reducing non-value-adding activities. Identifying and maximising customer value and reducing waste can be found as the main key aspects of lean thinking (Howell & Ballard, 1998). Lean thinking was first introduced by Toyota Production System (TPS), which in construction is known as the 'Lean Production' system (Womack, Jones, & Roos, 1990).

Lean construction can be identified as a combination of new processes and tools adopted from lean manufacturing that aims to improve the project's performance and reduce cycle time while minimising waste (Ballard & Howell, 1997; Alarcón, 1997). Although there are different lean principles that several authors have identified, only particular ones are relevant and applicable in the context of this research.

It is widely believed that lean principles can better contribute to eliminating waste if adopted with another concept that facilitates waste reduction. The benefits that Building Information Modelling (BIM) provides can be recognised as a valuable concept for reducing construction waste by providing a variety of features (Sacks et al., 2010). It is believed by Dave, Boddy, & Koskela (2013) that "Lean construction and Building Information Modelling (BIM) have significant synergies and can bring benefits if implemented together". Likewise, according to Eastman et al. (2011, p.298), "there is a strong synergy between lean construction and BIM" as some of the principles of lean construction can be fulfilled by using BIM, and it will also enable the achievement of other principles (Eastman et al., 2011; Sacks et al., 2010). Also, BIM "improves workflow in the construction process", which helps to the reduction of construction waste (Eastman et al., 2011, p.298).

Table 7, which is adapted from the 'Interaction Matrix of Lean Principles and BIM functionalities' (Sacks et al., 2010), demonstrates the interaction between lean principles and some of BIM capabilities which will accordingly result in reducing construction waste. However, it is argued by Dave et al. (2013) that besides the benefits of BIM and Lean construction itself, a "careful management of the information model" is also needed.

Integrated BIM and Lean can have major effects in improving information flow and, therefore, project performance by making changes in information and material processes. However, it is argued by Sacks et al. (2010) that these changes should not only be based on BIM and Lean but should also "be rooted in conceptual understanding of the theory of production in construction" (Sacks et al., 2010, p.16).

As can be illustrated in Figure 29, the integration of Lean construction principles with Building Information Modelling (BIM) can benefit the construction industry through the support and good understanding of the theory of production in construction (Sacks et al., 2010).

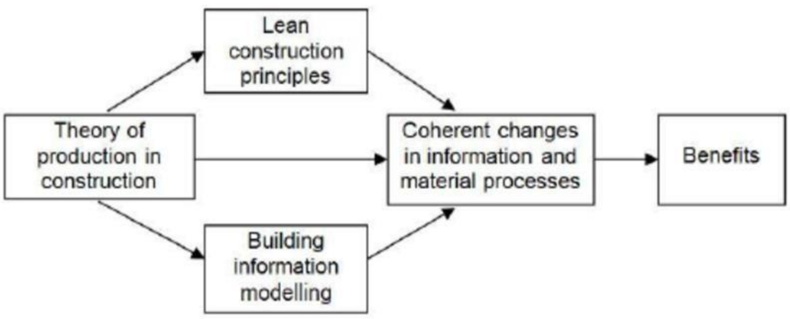

Figure 29 - The Dependence of benefits realisation through process change in construction on lean construction principles, BIM, and a theoretical understanding of production in construction (Sacks et al., 2010)

Building Information Modelling (BIM) is about people, processes and technology (tools) (Arayici et al., 2011), as shown in Figure 30. However, there is a lack of theoretical evidence on the BIM concept which could support and ensure its implementation. On the other hand, the

Lean construction foundation is based on the theory of production (Koskela, 2000), and it is very people and process-focused. Although, there is a lack of technological measures for Lean construction adoption to be fully effective.

Tribelsky and Sacks (2010) suggested that applying principles of lean construction to information flow management would improve the design process as well as reduce waste in this phase of the construction lifecycle. BIM would also improve information flow by providing a more flexible platform for the transparent sharing of information between project members (Al Hattab & Hamzeh, 2013). Therefore, BIM, with its technology feature and Lean, with its theoretical foundation, can complement each other for better information flow management and, thus, project efficiency. This integration of Lean and BIM is shown in Figure 31, which is an advanced form of Figure 29.

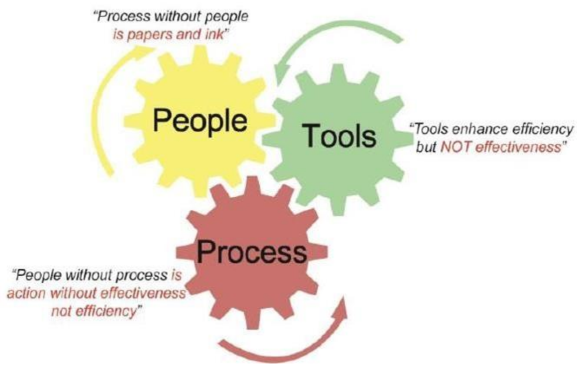

Figure 30 - People, Process and Tools (Technology)

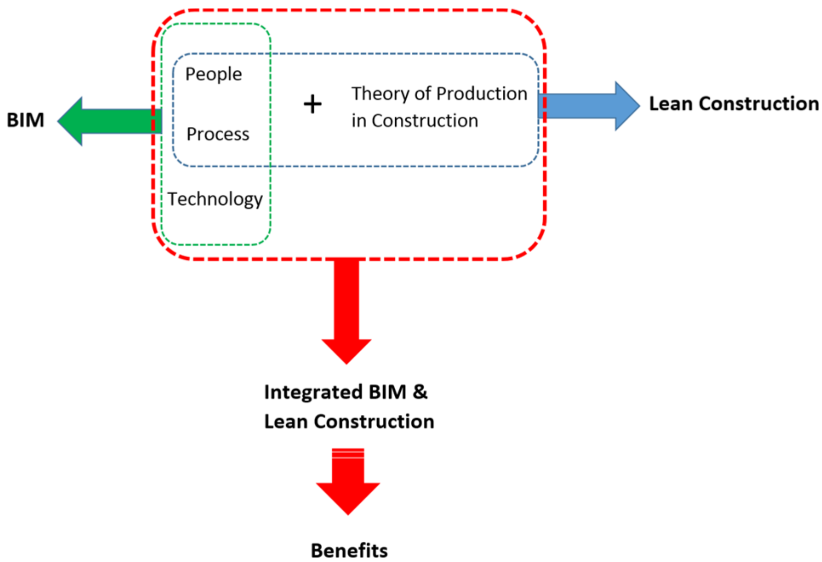

Figure 31 - Integration of BIM and Lean Construction (Mollasalehi et al., 2016)

In addition to improving the efficiency of the whole project lifecycle, BIM provides various features that will reduce the time and costs of the project as well as reduce waste (Eastman et al., 2011). As listed in Table 7, some of the BIM features that have the most positive interactions to lean construction are aesthetic and functional evaluation, multi-user viewing of merged or separate multi-discipline models, 4D visualisation of construction schedules, and online communication of product and process information (Sacks et al., 2010) which will be discussed more within the next sections. The following are four main areas of interaction by (Eastman et al., 2011);

- Use of BIM reduces variation
- BIM reduces cycle time
- BIM enables visualization of both construction products and processes
- BIM supports a number of lean principles in the design stages

Table 7 - Interaction of Lean principles and some of BIM functionalities

BIM functionalities / Lean Principles	Aesthetic and functional evaluation	multi-user viewing of merged or separate multi-discipline models	4D visualisation of construction schedules		online communication of product and process information	
	Visualisation	Clash Detection	4D-Scheduling	Construction Sequence planning	Collaboration and coordination	Communication
Reduce Variability	✓	✓		✓		✓
Reduce cycle time	✓	✓	✓	✓	✓	✓
Reduce batch sizes	✓	✓				
Increase flexibility	✓			✓	✓	✓
Select an appropriate production control approach				✓	✓	✓
Standardise				✓		✓
Institute continuous improvement						✓
Use visual management	✓			✓		✓
Design the production system for flow and value	✓	✓		✓	✓	
Ensure comprehensive requirements capture	✓	✓			✓	
Focus concept selection		✓		✓		
Ensure requirements flow-down	✓				✓	✓
Verify and Validate	✓		✓	✓	✓	✓
Go and see for yourself	✓					✓
Decide by consensus consider all options	✓				✓	✓
Cultivate an extended network of partners					✓	✓

2.7.2 The Relation between Integrated BIM and Lean Approaches with Waste and Value concepts

There is a strong synergy between BIM and Lean principles, so the BIM approach is suitable for reducing waste (Eastman et al., 2011; Sacks et al., 2010). Figure 32 demonstrates the interaction between Lean and BIM in four major mechanisms. These mechanisms aim to achieve the lean goals, reduce waste and increase value.

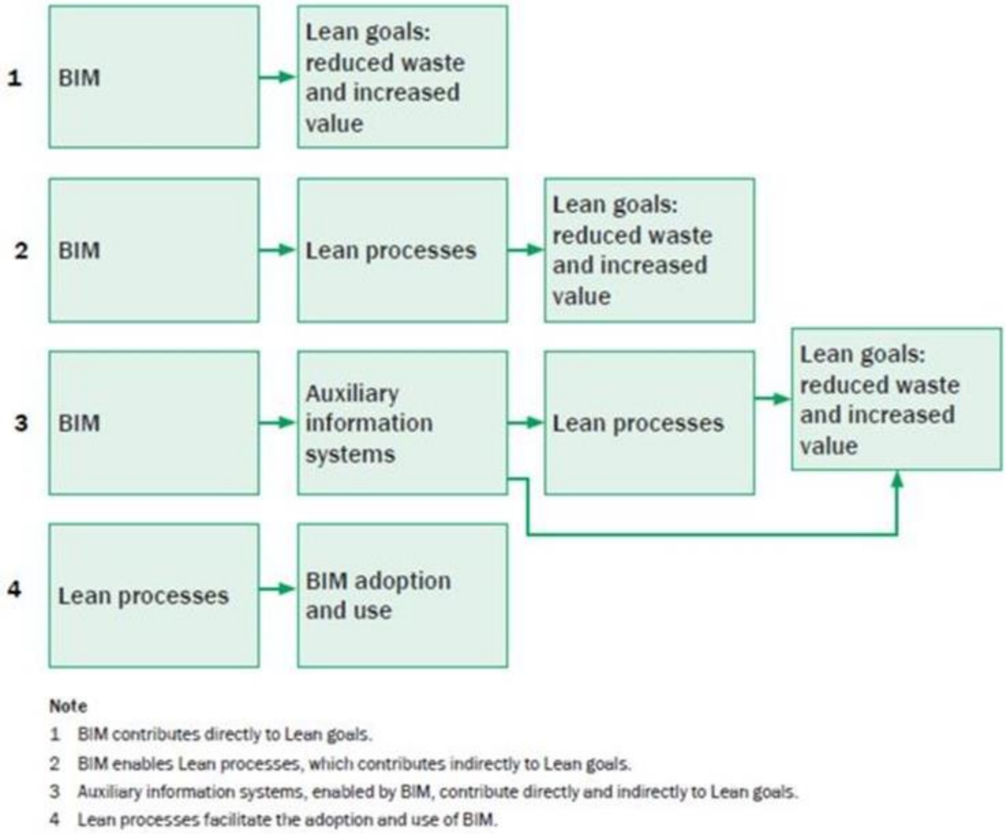

Figure 32 - Conceptual connections between BIM and Lean (Dave et al., 2013)

The following are these mechanisms that were discussed by Dave et al. (2013);

1. BIM contributes directly to Lean goals: clash detection can be found as an example of this contribution. Finding clashes in the 3D model enable designers to correct the problems, which will save a significant amount of time and money that would otherwise be wasted through rework or delay. Therefore, this BIM feature will help to reduce waste of waiting, defects and unnecessary movement. Also, visualising a coordinated model by separate disciplines in the early design stage allows end users (clients) to provide their inputs and the client's requirements will be better understood by designers. Thus, both principles of Lean construction, waste minimisation and value generation will be better achieved through this function.
2. BIM enables Lean Processes and contributes indirectly to Lean goals: the use of BIM for collaborative planning in Lean construction is an example of this contribution. Gaining a deeper understanding of the planned activities in advance is the main feature of collaborative planning, which can be achieved by using BIM tools such as 4D planning. 4D planning enables Lean construction to overcome problems that might be realised late in

the project, which will contribute to reducing major construction waste such as waiting, defects, and unnecessary movement.

3. Auxiliary information systems, enabled by BIM, contribute directly and indirectly to Lean goals: cost management and carbon footprint analysis can be found as examples of this input which will benefit the project by carrying out useful and value-adding calculations.
4. Lean processes facilitate the introduction of BIM: the implementation of BIM and its effectiveness will be relieved by the Lean construction environment.

Koskela (1992) proposed the cycle time approach to shorten cycle times by eliminating non-value-adding activities, leading to a reduction in construction waste. Koskela (1992) listed some practical approaches which will help to reduce the cycle time based on the explanations of several authors, and these can be achieved through integrated BIM and Lean construction (for example, Hopp et al., 1990; Plossl, 1991; Stalk & Hout, 1990);

- Eliminating work-in-process
- Reducing batch sizes
- Changing plant layout so that moving distances are minimised
- Keeping things moving
- Reduce variability
- Changing activities from sequential order to parallel order
- Isolating the main value-adding sequence from support work
- In general, solving the control problems and constraints preventing a speedy flow.

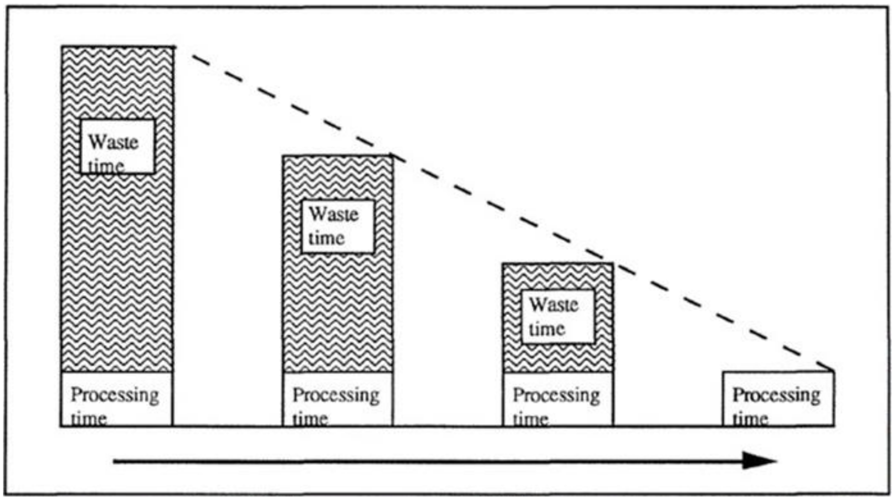

Figure 33 - Cycle time can be progressively compressed through the elimination of non-value-adding activities and variability reduction (Berliner & Brimson 1988, Cited in Koskela, 1992)

This 'lead time' or 'cycle time' approach can be considered as a benchmarking principle to eliminate waste throughout the project process, mainly in the design process. It is believed that there is a need for applicable methods and approaches to address the issues that might result in adding to the cycle time. However, these approaches must be in parallel to the lean principles in order to reduce waste. As mentioned before, Building Information Modeling (BIM) and Lean principles have a strong synergy, making the BIM approach an appropriate method to reduce waste (Sacks et al., 2010; Eastman et al., 2011).

According to Koskela (2000), lack of communication sometimes causes infinite cycle time, which results in producing more waste. Therefore, implementing BIM as a collaborative and communication-based approach will improve the communication between the project participants (Eastman et al., 2011). This will have positive impacts on reducing the cycle time and, as a result, reducing wastes that are related to lack of communication.

As BIM provides a 3D model available among all the project participants and everyone can have access to it at any time that is required (Eastman et al., 2011) it can be realised that the waiting time was wasted for the information sharing can be eliminated. Further, the time it takes to correct information design errors and solve problems will also add to the cycle time (Koskela, 2000) and accordingly increase construction waste.

As can be demonstrated from Table 7, Sacks et al. (2010) argues that some of BIM functionalities, such as 4D visualisation of construction schedules and automated clash checking, will help to reduce the cycle time as well as other lean principles, which consequently results in improvement of information flow and reduction of waste within the information flow.

By understanding BIM and Lean principles and their applications, it can be found that using a BIM model and integrating it with lean principles will help to recognise many activities and information that add no value to the design process. These two approaches can improve information flow in terms of reducing non-value-adding activities and information while increasing the value-added information and activities.

Even though all stages of construction contribute to producing waste (Osmani, Glass, & Price, 2008), the most significant cause of waste is related to design changes (Faniran & Caban, 1998) due to a lack of effective information flow management which happens in the design process (Phelps, 2012). The design stage of the construction process can be defined as the most important stage which has significant influences on the outcome of the project (Freire & Alarcón, 2002). Therefore, it is crucial to understand the benefits of Lean and BIM approaches in terms of reducing non-value-adding activities and information (waste) to improve information flow.

Some of the benefits of using BIM and Lean in the design stage of construction were summarised by Dave et al. (2013); reducing design development life cycle, effective capture and flow-down of intent, reducing rework, increasing iteration for value improvement, improving the predictability of investment and lifecycle costs (4D scheduling), and enhancing ability to engage with stakeholders. One of the BIM's beneficial features is the ability to provide 4D models and simulation, which includes not only the 3D model but also the time and cost schedule throughout the design process (Eastman et al., 2011). Therefore, if there are any conflicts, errors or confusion in the provided information, these issues can be resolved in the design process, which will help to eliminate the waste of processing, correction and waiting (Sacks et al., 2010).

Moreover, Formoso et al. (1998) listed three principles for waste elimination in the design process based on the findings of Huovila et al. (1997):

1. Reduce uncertainty, which can be found as one of the main causes of rework. By clearly defining the project restrictions and the requirements of internal and external clients, this can be accomplished;
2. In order to reduce waiting time, the design tasks should be decomposed adequately so that they can be properly planned, and the transfer of information should be done in smaller batches;

3. Reduce the effort needed for information transfer through teamwork and by rearranging the design tasks.

All these three principles can be achieved through the Lean and BIM concept. Through BIM, early involvement of all participants in the design stage will allow project goals and boundaries to be identified in advance, enhancing information flow and thus would help reduce waste of rework (defects), waiting, and unnecessary movement.

Additionally, as all the information is available in a BIM model which can be collaboratively shared between all projects team, the effort for information transformation will be reduced, and this will contribute to reducing waste of waiting, unnecessary movement, defects and excess inventory. Implementing BIM and Lean together would provide many benefits to the project's performance and productivity as the synergies between these approaches have many benefits to the project's entire lifecycle (Nguyen & Akhavian, 2019; Machado et al., 2020).

Thus, the BIM and Lean approaches can improve information flow by reducing non-value-adding activities and information (waste) and increasing value-added information and activities.

2.8 Chapter Summary

This chapter reviewed the literature on the construction design process, information flow management, Building Information Modelling (BIM), Lean Construction, and the interaction of BIM and Lean construction in order to examine how information flow management could be improved through the usage of BIM/Lean concept and also to identify the relevant knowledge gap.

The construction industry has suffered from poor productivity for decades, and the need for change in the industry has been recognised long since. Therefore, the number of construction projects adopting new innovative and technological processes such as BIM and Lean construction has rapidly increased over the last decade to improve construction productivity.

The chapter revealed that despite the increased BIM/Lean adaption level, there are still many problems associated with the construction industry. Major construction issues seem to be related to the design process and the design information exchange. It has been highlighted that, as the technology matures, the amount of information generated and shared between project teams is increased rapidly whether this information adds any value to the process or not.

Therefore, it is critically important to improve design information management as major design problems are related to a lack of information management, including information exchange and information flow.

Subsequently, the chapter focused on the importance of information flow management and the challenges associated with this. Further review of BIM and Lean construction and their interaction emphasised the lack of theoretical and practical knowledge related to the role of BIM/Lean in improving information flow management and in relation to different BIM maturity levels.

The literature showed that BIM is identified as the rising information management system in construction, which would bring more benefit to projects when integrated with Lean construction. However, the chapter revealed that there is a lack of research on the practical role of BIM/Lean to effective information flow management and how information flow management could be improved in different BIM maturity levels. These key findings inform the necessity of understanding effective information flow management, the challenges associated with exchanging information and the role of BIM/Lean in tackling those challenges.

Therefore, this chapter has identified the gaps in knowledge and developed three main areas that need to be addressed in the context of this research to meet the research aim and objectives. These areas, which form the basis for the research data collection and analysis, include the 'Effective Exchange of Information', 'Challenge of Effective Information Flow Management', and 'The Role of BIM/Lean in Relation to Effective Information Flow Management'. These areas that emerged from this chapter will be explored and discussed in detail throughout the research process.

The next chapter explains the process, plan and design for the research project presented in this study.

Chapter 3. Research Methodology

3.1 Methodology

To conduct research and achieve the aim and objectives of the research effectively, a systematic approach is required to be conducted by the researcher (Fellows & Liu, 2003). Generally, the research methodology is the way that the research will be conducted on various levels, from the philosophical position through to the method of research, research approach, research strategy, research techniques and procedures. It is important to understand the available research methodologies and then select the most suitable method for the research (Dawood & Underwood, 2010). The "Research Onion" (Saunders et al., 2016) methodology model, as shown in Figure 34, is adapted to provide a better explanation of the philosophical position and methodological choice of this research.

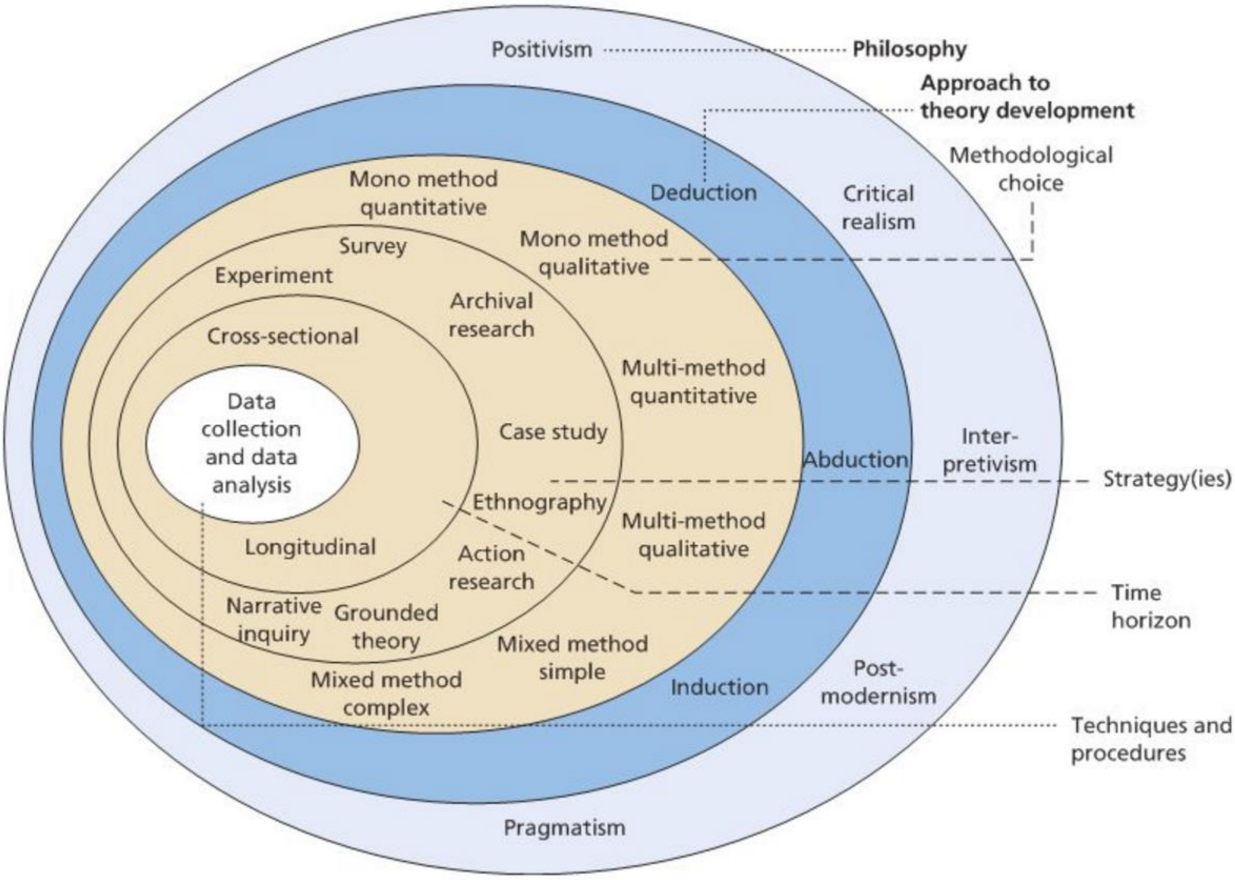

Figure 34 - The research 'onion' (Saunders et al., 2016)

3.2 Research Philosophy

The research philosophy "contains important assumptions about the way in which you view the world" (Saunders et al., 2007, p.121), and it also refers to assumptions about knowledge development (Saunders et al., 2016). Philosophy can be considered the foundation of any research that contributes to the development of knowledge by choosing research strategy and methods that best suit the research. Understanding the research philosophy is critically important as it supports research design decisions by providing different research approach guidelines (Easterby-Smith et al., 2002). Moreover, it was stated by Easterby-Smith et al. (2002) that knowledge of philosophy could also help to identify and clarify research designs which would enable the researcher to resolve the research questions. According to Saunders et al. (2007, 2016), there are three major aspects of research philosophy: epistemology, ontology, and axiology. Each of these three key ways of thinking about research is important and discussed respectively in Figure 35, Figure 36, and Figure 37.

3.2.1 Epistemology

Epistemology, as a fundamental element of research philosophy, studies the nature of knowledge. This aspect of research philosophy is explained below in Figure 35.

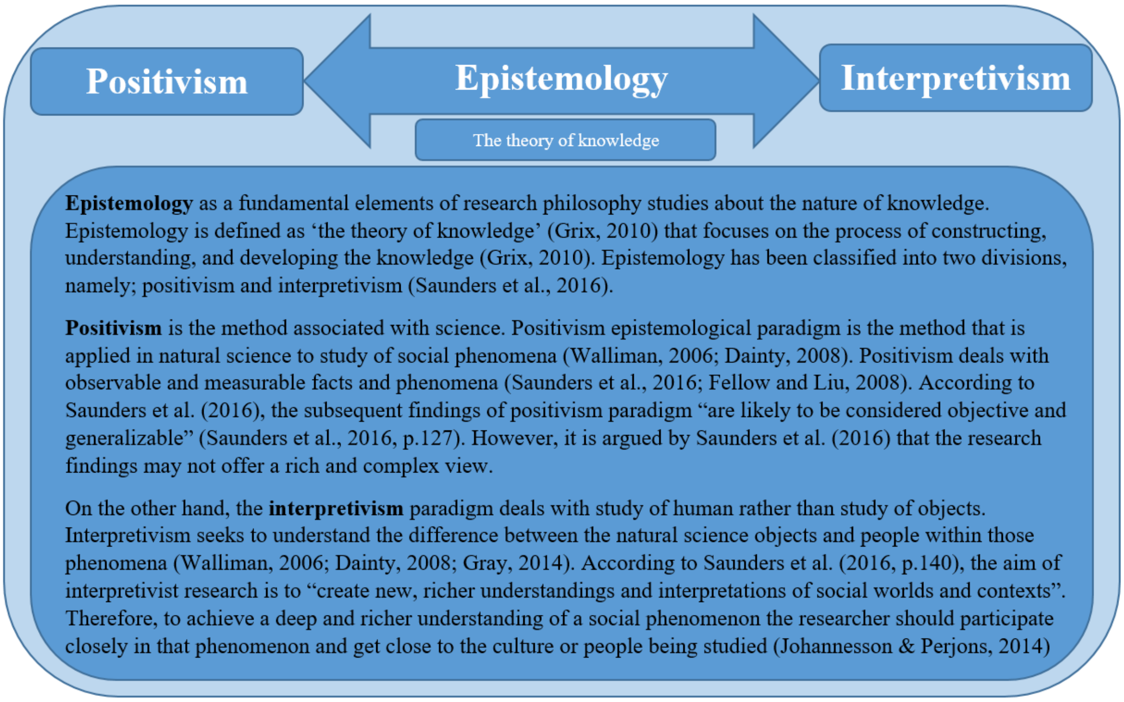

Figure 35 - Epistemology

3.2.2 Ontology

Ontology is one branch of philosophy that studies the nature of existence and what constructs reality (Grix, 2010; Gray, 2014). An explanation is given below in Figure 36.

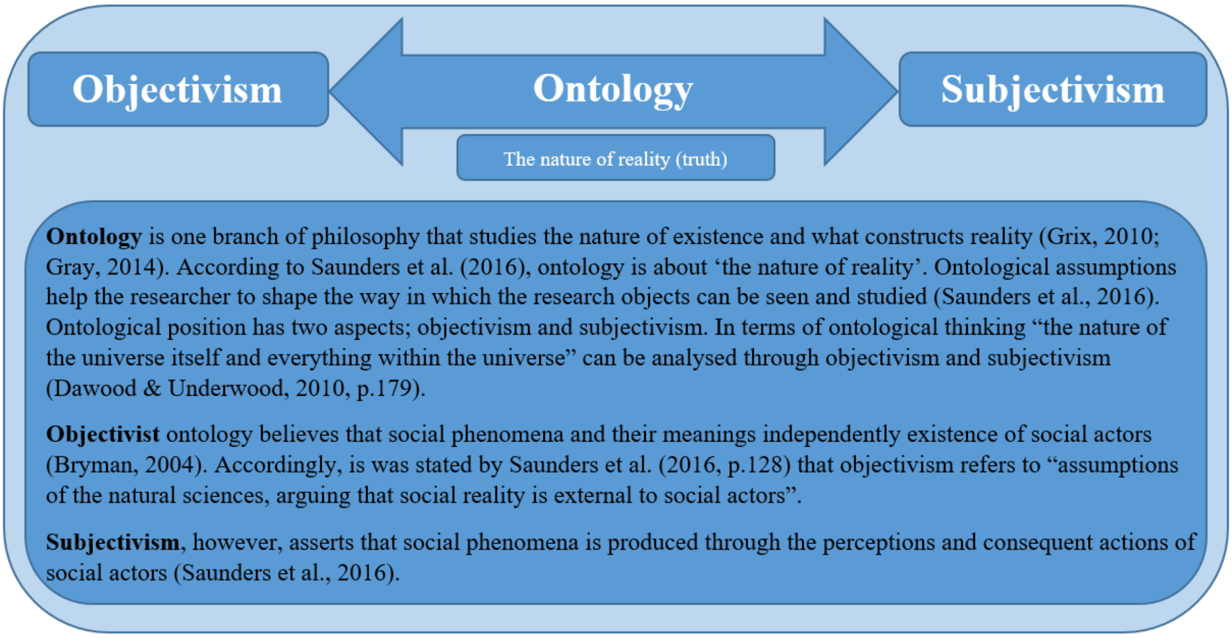

Figure 36 – Ontology

3.2.3 Axiology

Axiology is about how much value is placed on knowledge and explained further below in Figure 37.

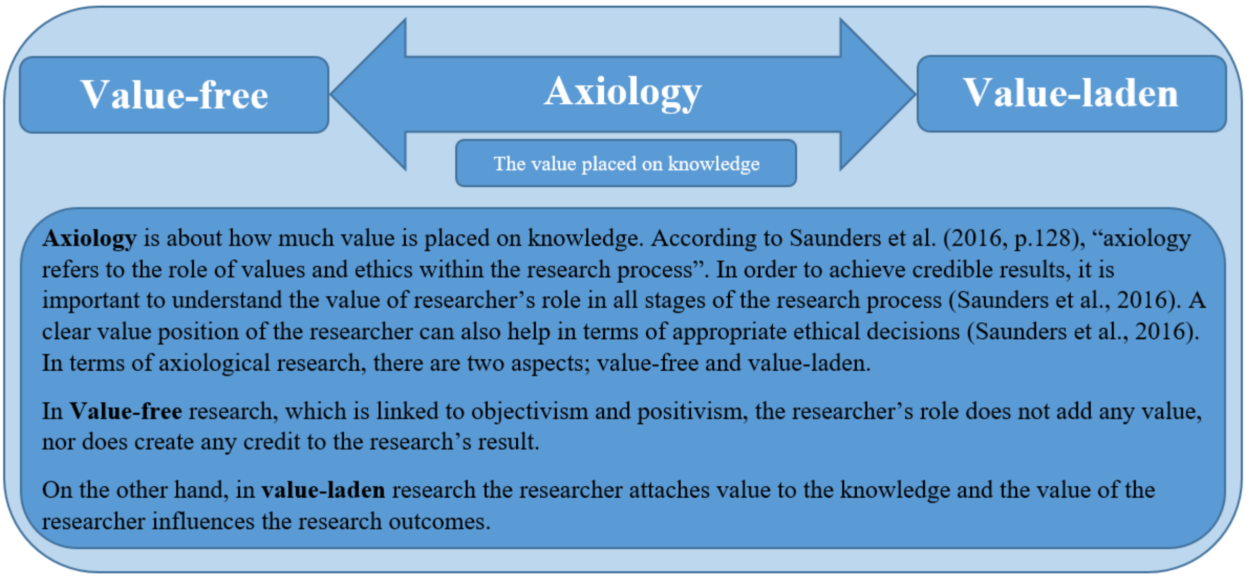

Figure 37 - Axiology

3.2.1 The Philosophical Stance of This Research

This research focuses on information flow as a phenomenon which is influenced by the actors (project participants in the design process, such as designers and design managers). The researcher and the research participants' views that will add to the research knowledge are assumed to be dependent on their interpretations. The benefits of BIM/Lean approaches to enhance information flow in terms of value and non-value-adding information/activities are interpreted by people (project participants in the design process) differently.

Also, the researcher will look at the information flow challenges in the design process from the different perspectives of different groups of people by actively participating in their daily practices and meetings and observing their processes (Saunders et al., 2016). This will help the researcher to achieve a deep and richer understanding of the phenomenon (Johannesson & Perjons, 2014; Saunders et al., 2016), which is information flow in the context of the research.

Therefore, this research has been structured using the interpretivism philosophy in terms of the epistemological paradigm. In this research, information flows are considered phenomena which are generated and carried out by project participants and, as such, the environment could influence their activities when generating and carrying out the phenomenon.

Consequently, in terms of ontological position, this research is more subjectivist in nature. Also, as discussed above, this research is close to interpretivism, which is explicitly subjectivist (Saunders et al., 2016).

Moreover, this study leans towards having a value-laden axiological position because the researcher conducts interviews. Interviews, as a chosen data collection technique, reflect the researcher's values which indicate that the researcher's values and beliefs play an important role in the research process for the interpretation of the phenomena and research data and analysis (Saunders et al., 2016).

As discussed, the philosophical paradigm adopted in this research is highlighted in Figure 38.

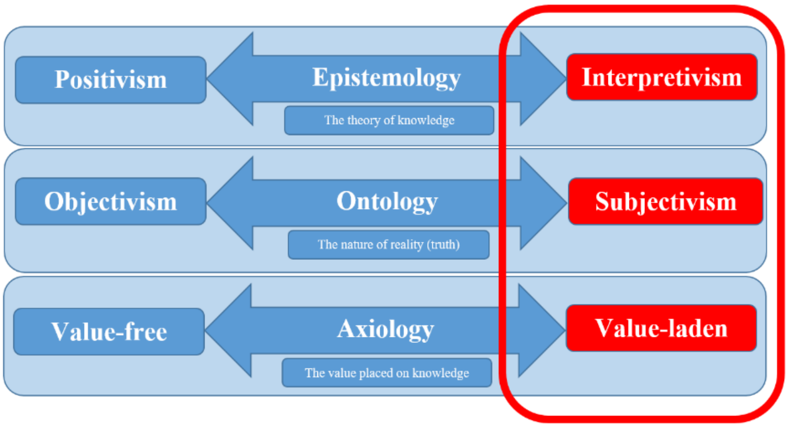

Figure 38 - The philosophical position of this research

3.3Research Approach

In order to design the research, it is important to understand the approaches to theory development at the beginning of the research (Saunders et al., 2016). There are three contrasting approaches to theory development: deductive, inductive and abductive (Saunders et al., 2016). These three main approaches are discussed below in Table 8.

Table 8 - Deduction, induction and abduction: from reason to research (Saunders et al., 2016)

	Deduction	Induction	Abduction
Logic	In a deductive inference, when the premises are true, the conclusion must also be true	In an inductive inference, known premises are used to generate untested conclusions	In an abductive inference, known premises are used to generate testable conclusions
Generalisability	Generalising from the general to the specific	Generalising from the specific to the general	Generalising from the interactions between the specific and the general
Use of data	Data collection is used to evaluate propositions or hypotheses related to an existing theory	Data collection is used to explore a phenomenon, identify themes and patterns and create a conceptual framework	Data collection is used to explore a phenomenon, identify themes and patterns, locate these in a conceptual framework and test this through subsequent data collection and so forth
Theory	Theory falsification or verification	Theory generation and building	Theory generation or modification; incorporating existing theory where appropriate, to build new theory or modify existing theory

As can be illustrated in Table 8, inductive research theory is developed and built through data analysis (Grix, 2010; Saunders et al., 2016). With inductive approaches, the research starts with specific observations to explore and understand the nature of the problem to broader generalisations and generate theories (Creswell, 2014; Saunders et al., 2016). In this type of research, generalisations are sought from the specific to the general (Grix, 2010; Saunders et al., 2016), and theory is generated based on the collected data. It is widely believed that an inductive research approach is associated with a qualitative research methodology (Grix, 2010; Creswell, 2014; Saunders et al., 2016). The induction approach through qualitative research is shown in Figure 39.

Deductive research, on the other hand, is used for testing an existing theory as opposed to inductive research, which is used for theory building. The origin of the deduction is in the natural sciences, where the basis of explanation is presented through natural laws (Saunders et al., 2016).

Deductive research generally starts from general to specific, and a theory will be tested or verified by examining hypothesises (Creswell, 2014). Similarly, it was stated by Saunders et al. 2016, p.152) that in deduction research, “a theory and hypothesis are developed, and a research strategy designed to test the hypothesis” (Saunders et al., 2016, p.152). Figure 40 outlines the deductive approach, which is usually used in quantitative research.

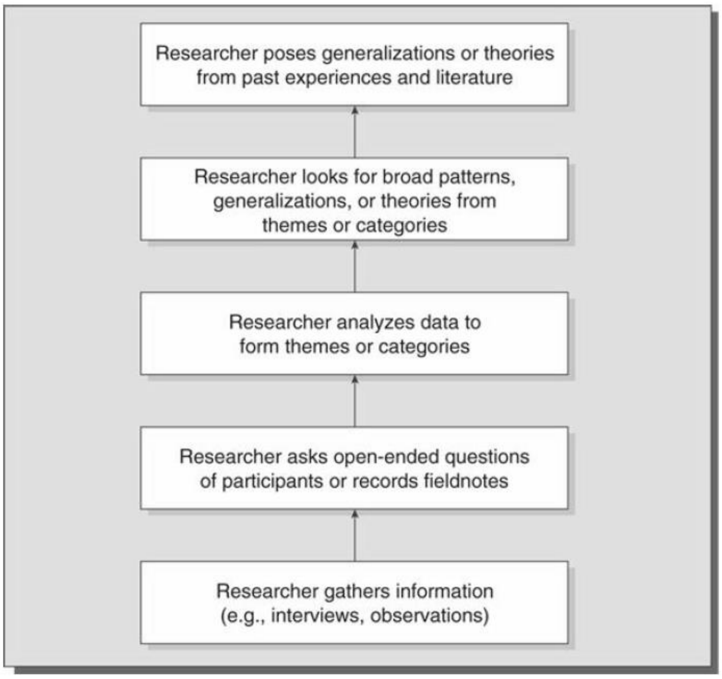

Figure 39 - Inductive Approach (Creswell, 2014)

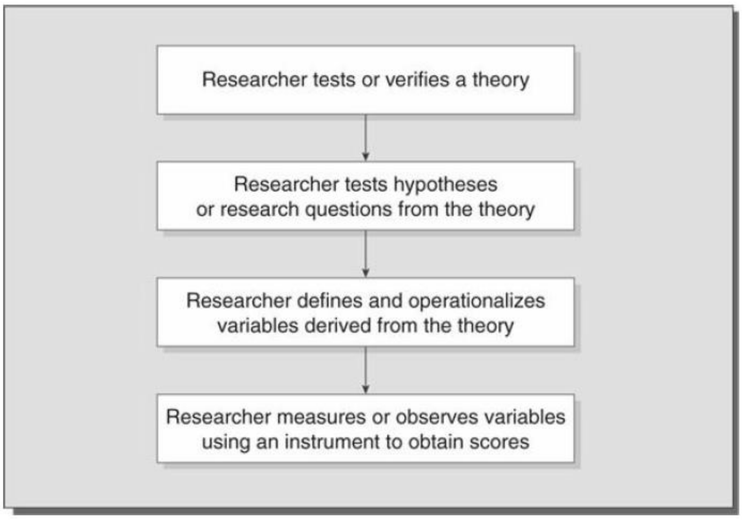

Figure 40 - Deductive Approach (Creswell, 2014)

Moreover, abductive research, as the third approach to theory development, is the combination of both inductive and deductive. Instead of starting from data to theory (as in inductive research) or theory to data (as in deductive research), abductive research moves back and forth (Saunders et al., 2016). Therefore, in abductive research, generalisations are sought from the interactions between the specific and the general (Saunders et al., 2016).

3.3.1 Research Approach Justification

This research conducts the abductive approach to theory development. Initially, this research includes determining the issue and studying the current solutions by reviewing the literature review to provide an in-depth understanding of the problem. Based on the comprehensive study of the literature, an initial theoretical graph is developed. Thus, the research first leans towards a deductive research approach. Secondly, more information will be gathered through interviews to formulate the theory which is close to the inductive research approach. Therefore, based on the collected data analysis, the initial theoretical graph which was designed based on the literature review, will be refined and explored comprehensively. Hence, this research will adopt an abduction research approach.

There is a wealth of information in the research area of BIM and Lean approaches and information management but far less in the context of this research which focuses on the role of BIM/Lean in enhancing information flow. Therefore, this research leans towards an abductive approach which enables moving back and forth between theory and data (Saunders et al., 2016).

This research requires an in-depth study of the phenomenon that is information flow to identify the key challenges associated with this phenomenon and then explain how information flow can be improved using BIM and Lean approaches in terms of adding value and reducing non-value adding information/activities in relation to the different BIM maturity levels through data collection. This will be obtained through a critical review of the literature on information flow management and the role of BIM/Lean in enhancing information flow which would result in developing an initial theory (deductive).

As a literature review and a rigid methodology associated with the deduction approach "does not permit alternative explanations of what is going on" and what is the nature of the problem (Saunders et al., 2016, p.147), this approach is not used independently in this research. So, to obtain a better understanding of the nature of the problem (Saunders et al., 2016), which is the information flow challenges in this context, data will be collected through interviews, and the analysis of the collected data will formulate a theoretical and practical exploration (inductive).

The data collected from interviews needs to be linked to the initially developed theory to address the aim of this research. Therefore, the initially designed theory from the literature review (deductive) with the detailed exploration of the information flow which was obtained through the data analysis (inductive) will be integrated into an overall detailed explorational and theoretical study which would be validated through existing data and new data (abductive) (Saunders et al., 2016). Consequently, an abduction research approach is found to be the most relevant approach to address the objectives of this research.

3.4Research Methodology

Research methods are broadly categorised into three types: quantitative, qualitative, and mixed-method research (Saunders et al., 2016). The choice of research methodology highly depends on the purpose of the research and the information type and availability (Naoum, 2007). It is important to choose the right research methodology to achieve the objectives of the research. Table 9 demonstrates the difference between qualitative and quantitative research methodologies.

3.4.1 Quantitative Research

Quantitative research is based on measuring numerical data and analysing the data using statistical and graphical techniques to study the relationships between variables (Grix, 2010; Saunders et al., 2016).

In quantitative research, variables or concepts that can be measured are developed and then converted into specific data collection techniques (Grix, 2010). Quantitative research is mostly associated with positivism and a deductive approach (Creswell, 2014; Saunders et al., 2016). However, it can also work with an inductive approach if data are used to build a theory (Saunders et al., 2016).

The strategies that are generally used in quantitative research are experimental and survey research strategies which are usually conducted through specific data collection techniques such as questionnaires (Saunders et al., 2016). According to Ragin (1994, cited in Grix, 2010), "the quantitative techniques include identifying general patterns and relationships among variables, testing hypotheses and theories, and making predictions based on these results". Quantitative methods are conducted using a '*large'* number of cases, and the researcher is detached from the study object (Grix, 2010; Zikmund et al., 2013).

3.4.2 Qualitative Research

In contrast to quantitative research, qualitative research uses non-numerical data. According to Saunders et al. (2016, p. 168), "qualitative research studies participant's meanings and the relationships between them, using a variety of data collection techniques and analytical procedures, to develop a conceptual framework and theoretical contribution". In this type of research, social phenomena will be studied to make sense of subjective and socially constructed meanings to interpret the phenomenon (Denzin and Lincoln, 2003; Saunders et al., 2016). Therefore, qualitative research is generally associated with an interpretivist philosophical position (Grix, 2010; Denzin and Lincon, 2011, Cited in Saunders et al., 2016).

Many qualitative research commences with an inductive approach to developing theory (Creswell, 2014; Saunders et al., 2016). However, it was argued by Yin (2014) that some qualitative research starts with a deductive approach, where the focus is on testing an existing theory using approaches related to qualitative research.

Moreover, Saunders et al. (2016, p. 168) stated that the abductive approach is used in practical qualitative research for theory development where "inductive inferences are developed, and deductive ones are tested iteratively throughout the research". In qualitative research, the researcher is intimately involved and not detached from the object of the study (Grix, 2010; Zikmund et al., 2013).

The positive interaction of the researcher with the study object enables rich findings which is not likely to be produced by statistical data as in quantitative research (Grix, 2010). There are wide varieties of strategies to be conducted in qualitative research, such as action research, case study research, ethnography, narrative research and Grounded Theory (Saunders et al., 2016).

Table 9 - Comparing Qualitative and Quantitative Research (Zikmund et al., 2013)

Qualitative Research	Research Aspect	Quantitative Research
Discover Ideas, Used in Exploratory Research with General Research Objects	Common Purpose	Test Hypotheses or Specific Research Questions
Observe and Interpret	Approach	Measure and Test
Unstructured, Free-Form	Data Collection Approach	Structured Response Categories Provided
Researcher Is Intimately Involved. Results Are Subjective.	Researcher Independence	Researcher Uninvolved Observer. Results Are Objective.
Small Samples—Often in Natural Settings	Samples	Large Samples to Produce Generalizable Results (Results That Apply to Other Situations)
Exploratory Research Designs	Most Often Used	Descriptive and Causal Research Designs

3.4.3 Mixed Methods Research

A mixed method is a combination of quantitative and qualitative research. As a result of this combination, mixed methods research is associated with a variety of strategies and many different techniques of data collection (Creswell, 2014; Saunders et al., 2016). Also, different approaches may be used for theory development in this type of research. Using mixed methods research may strengthen the research as it helps to explore and understand the research problem from multiple world view (Creswell, 2014). However, due to the complexity of mixed methods research, there are also some challenges in conducting this type of research, such as time consumption, sufficient resource availability, and clear understating of both qualitative and quantitative research (Creswell, 2014).

3.4.4 The Methodological Choice of This Research

As can be illustrated from earlier discussion and Table 9, there are many differences between qualitative and quantitative research methodologies. This research has adopted a qualitative research method due to the many advantages that it provides, in the context of this research, compared to the quantitative research method. As it was pointed out by Creswell (2007), qualitative research is conducted when a problem or issue needs to be explored. In this research, the information flow challenges as a phenomenon need to be explored to address the research aim and objectives.

This research needs a complex and detailed understanding of the information flow challenges which can only be established by speaking directly to project participants, through interviews, in the design process and by understating the contexts in which they address the information flow challenges using BIM and Lean approaches (Creswell, 2007; Madondo, 2021). Such an in-depth understanding of the information flow challenges and the role of BIM/Lean approaches to enhance this phenomenon can only be achieved by directly collaborating and interpreting with project participants through interviews as in qualitative research methodology. It is unlikely to achieve such an in-depth understanding and rich findings by numerical data through questionnaires as in quantitative research methodology (Grix, 2010).

Also, the findings and responses from questionnaires or other statistical data in a quantitative method do not provide the true participants' meanings and the deeper thoughts that governed their responses (Creswell, 2007). Therefore, as discussed in earlier chapters, the epistemological and ontological positions of this research lean towards interpretivism and subjectivism, which are associated with a qualitative research methodology.

Moreover, in this study, the researcher intends to directly get involved in the research and interact with project participants personally in the design process by interviewing them, which places the research in a value-laden axiological position that is in relation to qualitative research. Whereas in quantitative research, the researcher does not physically get involved in the research process, and the research leans towards a value-free axiological position.

The statistical data analysis and findings from quantitative research are not appropriate in the context of this research to understand the key challenges of information flow and the role of BIM/Lean in addressing those identified challenges in terms of value-adding and none-value adding information/activities. Therefore, qualitative research, which is "a better fit for the research problem", is chosen in this research as the most appropriate research methodology to address the aim of this research (Creswell, 2007, p. 40).

3.5 Research Strategies

Research strategy is defined as "a plan of action to achieve a goal" in which "a researcher will go about answering the research questions" (Saunders et al., 2016, p. 177). The choice of research strategy depends on the philosophies, approaches, and methods used to meet the objectives of the research and answer the research questions. Therefore, in order to choose an effective strategy, research questions need to be considered and designed carefully to determine the data that is required and indicate appropriate research methods, which will lead to the understanding of research objectives (Fellow and Liu, 2008).

Saunders et al. (2016) outlined different research strategies that are mainly linked with quantitative, qualitative and mixed methods research design. The first two research strategies are exclusively linked to a quantitative research design, and the next two may be used in qualitative or quantitative, or mixed-methods research (Saunders et al., 2016). The final four strategies are exclusively linked to a qualitative research design (Saunders et al., 2016). The strategies are listed below:

- Experiment
- Survey
- Archival and Documentary Research
- Case Study
- Ethnography
- Action Research
- Grounded Theory
- Narrative Inquiry

3.5.1 Experiment

According to Saunders et al. (2016, p.178), "experiment is a form of research that owes much to the natural sciences, although it features strongly in psychological and social science research". It was stated by Creswell (2014, p.156) that an experimental design intent to "test the impact of an intervention on an outcome, controlling for all other factors that might influence that outcome". Likewise, an experiment aims to "study the probability of a change in an independent variable causing a change in another, dependent variable". (Saunders et al., 2016, p.178). Therefore, rather than using research questions, predictive hypotheses are used in an experimental strategy (Saunders et al., 2016).

3.5.2 Survey

Survey strategy tends to answer questions of "what, who, where, how much, and how many" (Saunders et al., 2016). According to Creswell (2014, p.155), a survey strategy "provides a numeric description of trends, attitudes, or opinions of a population by studying a sample of that population". A survey enables a large collection number of standardised quantitative data. This type of strategy generally adopts questionnaires to collect standardised data. However, it was argued by Saunders et al. (2016) that a questionnaire is not the only technique to collect data for this strategy, and structured interviews can also be used.

3.5.3 Archival and Documentary Research

This type of research uses online archives of organisational, governmental, university-based, and media documents and other data (Saunders et al., 2016). As outlined by Saunders et al. (2016), there are different types of documentary sources that can be used in this research strategy, including communications between people (emails, letters, social media postings), individual records (diaries, notes), organisational sources (administrative records, agendas, agreements, contracts, reports, strategy documents and plans), government sources (publications, reports, national statistics), and media sources (printed and online articles). Archival or documentary research effectiveness depends on the nature of the research questions and finding suitable documents to achieve the research outcomes (Saunders et al., 2016).

3.5.4 Case Study

A case study is an in-depth inquiry to investigate a case or phenomenon within its real-life context (Yin, 2014; Saunders et al., 2016). The fundamental aspect of a case study is to understand the context in which the boundaries of the study are determined (Saunders et al., 2016). A case study strategy would "generate insights from intensive and in-depth research into the study of a phenomenon in its real-life context", which will lead to "rich, empirical descriptions and the development of theory" (Saunders et al., 2016, p.185). An in-depth inquiry can be used for the identification of 'what is happening' and 'why' (Saunders et al., 2016).

Therefore, a case study as an in-depth inquiry seeks to answer 'how' and 'why' questions. According to Yin (2014), there are two types of case study research strategies: single case study and multiple case studies. A single case study is generally used for an in-depth study of a critical case or an extreme or unique case, whereas multiple case studies focus on the possible replication of findings across cases (Yin, 2014; Saunders et al., 2016).

3.5.5 Ethnography

Ethnography studies the social world and culture of an entire group of people who interact with each other over time (Creswell, 2007; Saunders et al., 2016). This strategy, which aims to determine how the culture works, requires the researcher to physically get involved in the project being studied. As stated by Creswell (2007, p.68) ethnography process involves "extended observation of the group in which the researcher is immersed in the day-to-day lives of people" to understand and produce detailed cultural meanings of their shared behaviours, beliefs, language, and the interactions between each other (Creswell, 2007; Saunders et al., 2016). Therefore, ethnography is qualitative research as the researcher interprets and clarifies the shared behaviours, beliefs, and language of the studied group who share the same space (Creswell, 2007; Grix, 2010; Saunders et al., 2016). This type of strategy is relevant for modern organisations and other business and management research areas (Saunders et al., 2016).

Moreover, this strategy provides the opportunity to challenge and extend conventional understanding and to create new insights into social behaviour (Easterby-Smith et al., 2008). However, it was argued by Creswell (2007) that using this strategy is challenging due to different reasons. For example, the data collection time is extensive, and there are many issues within a fieldwork study, such as getting involved in an unfamiliar culture group or organisation (Creswell, 2007).

3.5.6 Action Research

Action research studies a change process of a social phenomenon in which the researcher is part of this process of change (Easterby-Smith et al., 2008). This strategy provides a problem-solving process that incorporates different forms of knowledge transfer (Saunders et al., 2016) and implementation among project participants.

The purpose of this strategy is "to promote organisational learning to produce practical outcomes" through issues identification, planning action, taking action, and evaluating action (Saunders et al., 2016, p.190). It was stated by Coghlan and Brannick (2014, cited in Saunders et al., 2016, p. 190) that action research is about "research in action rather than research about action" as this research strategy focuses on "addressing worthwhile practical purposes" (Reason, 2006, cited in Saunders et al., 2016, p. 191) and resolving real organisational problems. Therefore, this strategy helps to answer not only 'what we know' question but also 'how we know' question.

3.5.7 Grounded Theory

Grounded Theory focuses on developing a theory that is grounded in data (Creswell, 2007; Easterby-Smith et al., 2008; Saunders et al., 2016). This strategy provides a systematic approach to undertake qualitative research in which a theoretical explanation of a process and social actions or interactions is developed (Creswell, 2007; Saunders et al., 2016). Grounded Theory can apply to both inductive and abductive approaches (Saunders et al., 2016). Grounded Theory is a useful research strategy. However, this strategy challenges researcher in terms of data collection, the use of existing theory, the identification of a core category, and its time consuming (Saunders et al., 2016).

3.5.8 Narrative Inquiry

Narrative Inquiry focuses specifically "on the stories told by individuals" (Creswell, 2007, p.54), which may enable the researcher to gain insights into organisational realities that are linked closely to the experiences of members (Easterby-Smith et al., 2008; Saunders et al., 2016).

In-depth interviews are used as the method of data (stories) collection in this strategy. However, other methods, such as observation, may also be used to collect stories (Easterby-Smith et al., 2008; Saunders et al., 2016). It was argued by Saunders et al. (2016) that Narrative Inquiry might be used as the main research strategy or in conjunction with another strategy.

3.5.9 Research Strategy Justification

To choose an appropriate strategy for this research, all mentioned research strategies are summarised in Table 10, which demonstrates their different characteristics.

As this research requires an in-depth qualitative study of the information flow challenges and the role of BIM/Lean to enhance information flow in the design process of a real-life project, a Case Study research strategy is chosen for this research.

This research aims to explore 'how' the information flow in the design process could be improved in terms of adding value and reducing non-value-adding activities/information that contribute to waste using BIM/Lean approaches in relation to different BIM maturity levels. To address the aim of this research and answer 'how information flow could be improved' question, the case study research strategy, which is designed to answer 'how' and 'why' questions (Yin, 2014), is chosen.

Although other research strategies, such as Grounded Theory and Narrative Research within qualitative research design, seek to answer 'how' question but they are not appropriate in the context of this research. For example, Narrative Research focuses on the exploration of an individual's life, which requires a clear understanding of the context of each participant's life

(Creswell, 2007). However, this research does not focus on the life of individuals but focuses on the perspective of individuals based on their experiences to study the challenges of information flow and the role of BIM/Lean to enhance those challenges.

Also, this study requires multiple qualitative sources, such as interviews and observations, whereas Narrative Research uses mainly interviews and documents. Moreover, other research strategies, such as Experiments and Surveys, are not appropriate in the context of this research as they are associated with the Quantitative Research method, whereas this research has adopted the Qualitative Research methodology.

This research will study multiple cases which have substantial analytic benefits that would provide rich and in-depth findings (Yin, 2014). Multiple case design enables the investigation of the research objectives critically and comprehensively. To first identify the information flow challenges and then critically analyse the role of BIM and Lean to enhance those challenges, it is important to study multiple cases in which different levels of BIM maturity have been adopted. Selecting the cases requires establishing a rationale based on the aim and objectives of the research (Creswell, 2007; Yin, 2014). Therefore, three cases will be selected based on their levels of BIM and Lean implementation that can be categorised into: Defined, Managed, and Integrated projects.

These selected cases involve individuals, activities, and processes that will be investigated to obtain rich and reliable data. This data will be collected by interviewing individuals who are involved in daily activities and information flow processes in the design phase of the project. As each case will involve different information flow challenges due to their different levels of BIM and Lean adoption, the findings would help the researcher to gain a comprehensive insight into the role of BIM and Lean in enhancing information flow.

Moreover, the findings from three different cases provide an exploration and understanding of information flow in terms of value and non-value-adding activity and information through using BIM and Lean approaches in relation to different BIM maturity levels.

Table 10 - Summary of Different Characteristics Research Strategies Adopted from Creswell (2007) and Saunders et al. (2016)

Associated Research Design	Research Strategies	Overall Definition	Focus	Data Collection Forms	Unit of Analysis (sample size)	Form of Research Question
Quantitative Research	**Experiment**	Studying the probability of a change in an independent variable causing a change in another, dependent variable	Testing the impact of an intervention on an outcome, controlling for all other factors that might influence that outcome	Laboratory experiments	Testing variables	What, how, why
	Survey	Providing numeric description of trends, attitudes, or opinions of a population by studying a sample of that population	Collecting large number of standardised data from a sizable population	Questionnaire and structured interviews	Studying a sample of a population more than 10 individuals	What, who, where, how much, how many
Quantitative, Qualitative, and Mixed methods Research	**Archival and Documentary Research**	Using online archives of organisational, governmental, university-based, and media documents and other data	Using secondary sources to gain access to sufficient numbers of suitable documents	Secondary sources	Secondary data	Who, what, where, how many, how much
	Case Study	An in-depth inquiry into a topic or phenomenon within its real-life setting	Developing an in-depth description and analysis of a case or multiple cases	Interviews, observations, documents and artifacts	Studying an event, a program, an activity, more than one individual	How, why
Qualitative Research	**Ethnography**	Studying the culture and social world of an entire group of people who interact with each other over time	Describing and interpreting a culture-sharing group	Observations and interviews	Studying a group that shares the same culture	Why
	Action Research	Studying a change process of a social phenomenon in which the researcher is part of this process of change	Addressing worthwhile practical purposes and resolving real organisational problems	Observations, interviews and available data	Studying a change process, more than one individuals	What, how
	Grounded Theory	Focusing on developing a theory that is grounded in data	Developing a theory grounded in data from the field	Interviews	Studying a process, action, or interaction involving many individuals	How
	Narrative Inquiry	Focusing specifically on the stories told by individuals	Exploring the life of an individual	Interviews and documents	Studying one or more individuals	How, what, why

3.6 Time Horizon

For research to be successful, it is important to consider the time that the research is to be completed. This research is a cross-sectional study in which a particular phenomenon will be studied at a particular time (Saunders et al., 2016). This is because longitudinal studies involve the study of change and development over a long period of time (Saunders et al., 2016). Therefore, as a PhD study is time-constrained, it needs to be completed over a short period of time. Thus, this research aims to finish within the expected PhD period.

3.7 Data Collection Methods

To meet the objectives of this research, both secondary and primary data will be collected. There are different types of secondary and primary data, which are discussed in this chapter to justify the chosen data collection methods of this research.

3.7.1 Secondary Data

As can be illustrated in Table 11, there are three different types of secondary data: documents, surveys, and multiple sources (Saunders et al., 2016). This research will use a combination of all three secondary data types in which data is gathered through literature reviews on published work such as books, journals, government surveys, government publications and reports.

Table 11 - Types of Secondary Data Adopted from Saunders et al. (2016)

Secondary Data						
Document		**Survey**			**Multiple source**	
Text	**Non-text**	**Censuses**	**Continuous and regular surveys**	**Ad hoc surveys**	**Snap shot**	**Longitudinal**
• Books • Journals • articles • Notices • reports etc.	• voice and video recordings • pictures • drawings • films etc.	• Governments' Censuses • Censuses of population • Censuses of employment	• Government surveys • General purpose market research surveys etc.	• Academics' surveys • Organisations' surveys • Government' surveys etc.	• Data compiled in reports • Government publications • Big data sets • Journals etc.	• Government publications • Newspaper • reports • Big data sets • Journals etc.
Data that endure physically as evidence, allowing data to be transposed across both time and space.		Existing data that originally collected for other reasons using a survey strategy such as questionnaires.			Combination of different data sets to form another data set.	

3.7.2 Primary Data

There are three main primary data collection methods which are: interviews, questionnaires, and observations (Saunders et al., 2016). As this research adopted a qualitative research method, qualitative data collection will be conducted through interviews. Some of the advantages and limitations of interviews and observations as qualitative data collection methods are listed in (Creswell, 2014).

3.7.2.1 Interviews

Interviews, as a widely used data collection method, enable the identification of variables and their relations and allow testing theories or suggestions (Cohen & Manion, 1997, cited in Gray, 2004). This research has adopted interviews to gather valid and reliable data which are relevant to the research aim and objectives (Saunders et al., 2016). It is widely believed that there are three types of interviews which are: structured, semi-structured, unstructured, and focus groups (Creswell, 2007; Easterby-Smith et al., 2008; Grix, 2010; Saunders et al., 2016).

Semi-structured interviews will be conducted in this research which allows flexibility in the questions' structures and orders depending on the interview's conversation flow (Grix, 2010; Saunders et al., 2016). As this research has adopted the interpretivism philosophy, it is important to understand the participants' actual meanings and, if necessary, to investigate their explanations of their responses (Saunders et al., 2016).

Semi-structured interviews enable asking questions to explore the key challenges of information flow and the role of BIM and Lean to improve information flow from different project participants' viewpoints in the design process and in relation to the different BIM maturity levels. This will be obtained through a series of semi-structured interviews conducted for each case study. The process will include interviewing five individuals from each case study who are key people involved in the design process of the three selected cases. It is important to understand and investigate the project participants' views on information flow and its challenges. Therefore, Participants in the interviews will be chosen based on their job description and the key roles that they have within the design process of the project, which include:

1. Project manager
2. Design manager
3. Document controller
4. BIM implementation manager
5. Lead design manager

So, a total number of 15 interviews will be conducted to achieve the aim and objectives of this research. To ensure that a rich and detailed set of data is collected, the researcher will use good manners in interacting with the interviewees in a friendly environment (Saunders et al., 2016).

3.8 Data Analysis Methods

There are different analytical techniques to analyse qualitative data, which are all listed below in Table 12. However, only one type of data analysis has been adopted in this research which is believed to be the most appropriate data analysis method for this research.

Table 12 - Data Analysis Types and Techniques (Saunders et al., 2016)

Data Analysis Types and Techniques	Definition	Procedure
Thematic Analysis	Thematic Analysis as a foundational method for qualitative analysis aims to search for themes or patterns across a data set such as interviews and observations through coding techniques.	• Becoming familiar with the data • Coding the data • Searching for themes and recognising relationships • Refining themes and testing propositions
Template Analysis	Template Analysis is a type of Thematic Analysis however, the researcher codes a proportion of the data items before developing an initial list of codes and themes which is knows as a coding template.	• Becoming familiar with the data • Initial coding • Developing coding template
Explanation Building and Testing	There are three techniques associated with this type of data analysis which are Analytic Induction, Deductive Explanation, and Building and Pattern Matching.	• Number of repeated steps to find a valid explanation of the phenomenon being studied (Analytic Induction) • Building an explanation by testing and refining a predetermined theoretical proposition (Deductive Explanation) • Matching patterns for dependent and independent variables (Pattern Matching)
Grounded Theory Method	Grounded Theory Method provides a holistic approach that guides from inception through the process of data collection and analysis to completion.	• Initial coding or open coding • Focused coding • Axial coding • Selective coding
Narrative Analysis	Narrative Analysis is a collection of analytical approaches to analyse different aspects of narrative.	• Thematic Narrative Analysis to identify analytical themes within narratives • Structural Narrative Analysis which analyses the way in which a narrative is constructed
Discourse Analysis	Discourse Analysis explores how discourses construct or constitute social reality and social relations through creating meanings and perceptions.	• Text which analyses the use of language • Discursive practice which explores the nature of the discourse • Social practice which examines the social setting and structures
Content Analysis	Content Analysis is an analytical technique that codes and categorises qualitative data in order to analyse them quantitatively.	• Sampling • Devising analytical categories • Defining the unit of analysis • Conducting coding • Undertaking quantitative analysis
Data Display and Analysis	Data display and analysis enables recognising relationships and patterns in the data as well as drawing conclusions and verifying these.	• Data condensation • Data display • Drawing and verifying conclusions

Thematic Analysis has been chosen for data analysis of this research due to its flexible systematic and logical way of qualitative data analysis, which will be "leading to rich descriptions, explanations and theorising" (Saunders et al., 2016, p.579).

As this research leans towards an interpretivism epistemological paradigm, Thematic Analysis is an appropriate analytical technique to explore different interpretations (through different project participants' viewpoint) of the phenomenon, which is the information flows. As can be illustrated in Table 12, there are different procedures for undertaking Thematic Analysis. One of the main procedures of this approach is coding the data, which "involves labelling each unit of data within a data item, such as a transcript, with a code that symbolises or summarises that extract's meaning" (Saunders et al., 2016 p.580).

Chapter 4. Data Analysis and Findings – Case Study A

4.1 Chapter Overview

The previous chapter presented the methodology adopted in this thesis which included conducting qualitative data collection and analysis. It has already been pointed out in the previous chapter that three case studies were investigated by interviewing relevant participants in each case study.

The purpose of this chapter is to explore and analyse the findings from the qualitative study based on semi-structured interviews that were conducted for Case Study A. In order to discuss the results of this case study, certain key themes, as shown in Figure 41, were identified to form the basis of the presentation and analysis of the data. This includes the exploration of identified themes and issues, which have been structured into a number of superordinate themes and associated subordinate themes. The relation to themes explored as part of the interview design will be noted in the sections of the themes where appropriate.

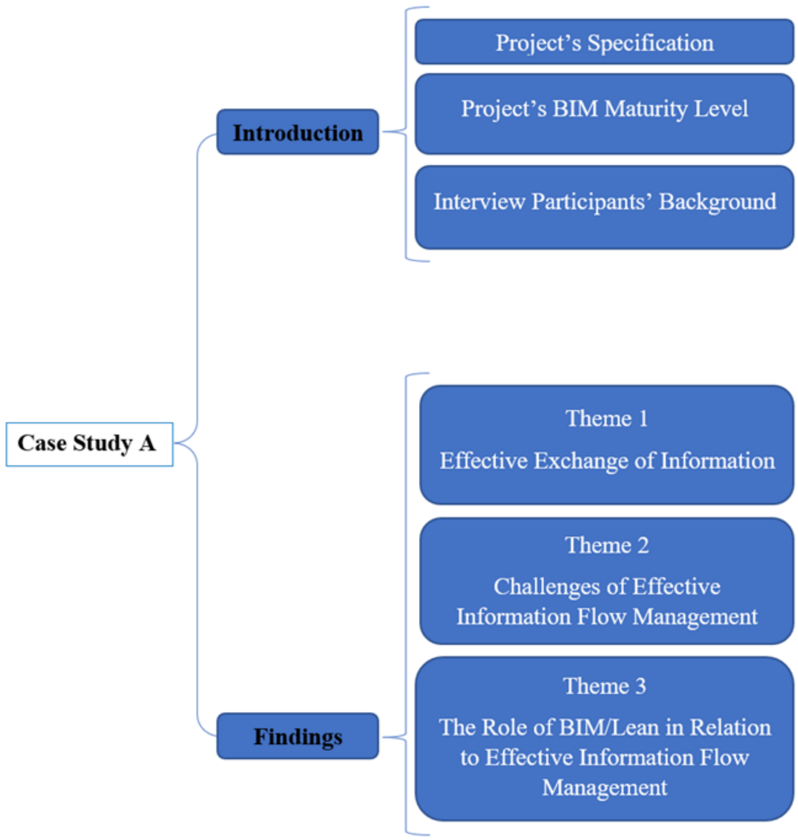

Figure 41 - Chapter 4 Overview

The early part of this chapter gives an introduction to the Case Study A project. The second covers the presentation of the findings which are categorised into three superordinate themes. The structure of this chapter is shown in Figure 41, which depicts that the project is first described in terms of its nature and type of project, size, location, etc. The level of BIM maturity in this project is then discussed, followed by an explanation of the interview participants' backgrounds. This will then be followed by a complete exploration and analysis of the findings through superordinate and associated subordinate themes that emerged from the data/interview verbatim transcript.

The chapter summary is presented at the end (4.7 Chapter Summary).

4.2 Introduction to Case Study A – Defined Project

4.2.1 Project Specification

Case Study A is the construction of 101 high-specification residential one-, two-, and three-bed apartments. The new-build scheme involved a concrete frame arranged over fixed floors around a central courtyard garden and formed phase three of a multi-phase development in the heart of the York city centre. This project, which had a value of £21 million, was started in August 2017 and was due to finish in 2019, and it was constructed by one of the leading UK construction and regeneration groups.

4.2.2 Project's BIM Maturity Level

Case Study A, a residential building project, was chosen as a case because of its level of BIM implementation in the project. Due to the client's requirements, this project was classified as a Defined project (BIM Maturity Level 1/Stage 1). This project follows the requirements set out in BS 1192:2007 standards for its BIM implementation, which included a mixture of 3D design for concept work and 2D for drafting and storing statutory approval documentation and Production Information and use of common data environment (CDE) to carry out electronic sharing of information and data.

The level of BIM implementation in this project can be defined as "BIM Level 1 maturity encompasses the management of digital, indexed construction information, including that generated by 2D or 3D CAD systems within a common data environment. Disciplined design and information management policies for collaboration and a specified naming policy shall be used." (SFT, 2019).

All of the interview participants indicated that this project was a Defined project in which only some of the aspects of the BIM approach had been implemented, such as using a “cloud-based system”, which refers to the common data environment (CDE) as part of BIM Level 1/Stage 1 implementation requirements to share information and collaborating with all project participants effectively.

According to the BS 1192:2007 and BS 19650-1:2018, as part of the BIM approach requirements, for managing the information during the project, a CDE solution and workflow should be used, and the modification of each information container should follow three states of work in progress, shared, and published in the CDE as shown in Figure 42.

The required workflow of information in the CDE can be illustrated in Figure 42, which has been adopted in this project. The actual workflow that occurs in this project (based on the required CDE workflow) can be illustrated in Figure 47 in this chapter.

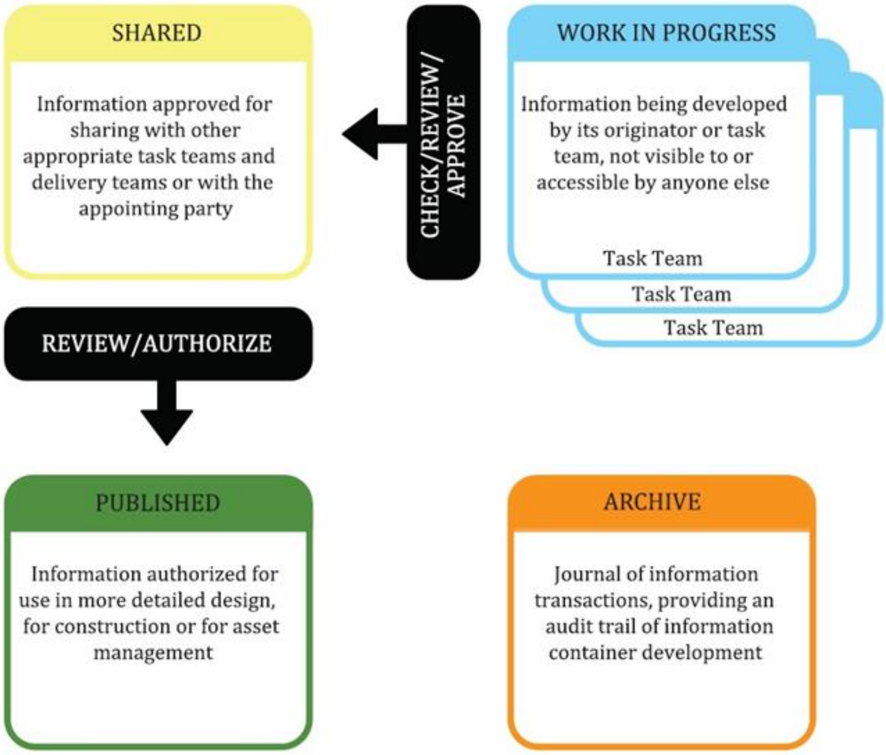

Figure 42 - The CDE Workflow

CDE workflow can be spread through various computer systems or technology platforms using information container-based collaborative working (BSI, 2018). In the context of this project, this workflow is being followed using specific software, which allows the flow of information in the CDE system.

As part of the requirements, this project would consist of managed CAD, with an expectation of having a good level of collaboration and coordination using the CDE. The use of 3D modelling contains producing 3D model information such as electronic drawings, basic visualisation based on the model and producing concept development models. The mandatory requirements of this project are based on the standards of BS 1192:2007 that require collaboration using standard methods and procedures such as adopting the CDE approach to allow information to be exchanged between all project teams, adopting naming conventions, defined naming conventions and a suitable information exchange plan to support the concepts of the CDE. (BSI, 2007)

4.2.3 Interview Participants' Background

To achieve the purpose of an in-depth exploration of Case Study A in regard to the research aim and objectives, five (5) semi-structured interviews were conducted. The interviews aim to examine the factors that influence information flow management in relation to the project's BIM maturity level. To achieve this, key project members were identified in terms of their role and their level of participation in the project because in designing interviews, it is important to target people who are directly involved with the case study to enable the development of a detailed insight into the research aim and objectives (Knight & Ruddock, 2008).

Likewise, in qualitative interviews, it is essential to choose the participants based on the depth of their knowledge and experience about the research phenomenon under investigation (Robson, 2002). Therefore, this research targeted participants who are knowledgeable about the entire project scope, the project team and resources, the project schedule, and the success or failure of any tasks throughout the project as they are involved in day to day using information management systems, so they are well informed about the challenges in terms of information flow management in the context of this research. These participants include:

- Project Manager,
- Design Manager,
- Lead Designer,
- Document Control Manager, and
- BIM Implementation Manager

The above-mentioned participants have sufficient experience and background in the construction industry and in their specific field of expertise, which enables the researcher to first achieve useful insight in terms of how the information flow is managed and what challenges have been encountered in this project in the context of this chapter.

The participants' background would also enable the researcher to understand how their experience influence and motivate the process of information flow management in relation to the project's BIM maturity levels which will be discussed further in the discussion chapter later on (Chapter 7. Cross-Case Analysis and Discussions).

Furthermore, the interview participants were labelled A1, A2 … A5 in accordance with ethical considerations of the use of anonymous quotes. Table 13 below presents a summary of sampled participants of the semi-structured interviews in Case Study A (CSA), providing details of the interviewee's position, background, years of experience and level of understanding of BIM.

Table 13 - Summary of Interview Participants Information (CSA)

Case Study A (CSA) Defined Project – BIM Maturity Level 1/Stage 2				
Participant Code	**Position**	**Field of Expertise and Background**	**Years of Experience**	**Level of Understanding of BIM** (Low, Medium, High)
A1	Project Manager	Construction Project Management	35	Low
A2	Design Manager	Architectural Engineering, Design management	28	Medium
A3	Lead Designer	Architectural Engineering	9	Medium
A4	Document Control Manager	Administration	8	Low
A5	BIM Implementation Manager	Architectural Engineering, BIM Manager	13	High

4.3 Outline and Structure of Findings to be Discussed

4.3.1 Introduction to the Themes

The areas of analysis of CSA will now be outlined. As discussed in the previous chapter (Chapter 3. Research Methodology), through thematic analysis, three superordinate themes and associated subordinate themes emerged from the data analysis, which will be discussed in this section. The first section of findings to explore, which refers to the first main theme, is the 'Effective Exchange of Information' (4.4 Theme 1 - Effective Exchange of Information). This section pertains to the importance of managing information flow effectively (Baldwin et al., 1999; Chatzipanagiotou, 2017; Detlor, 2010; Robertson, 2005), which will be discussed under two associated subordinate themes of 'Adaption of Digital Tools' and 'Roles and Responsibilities', as shown in Figure 43.

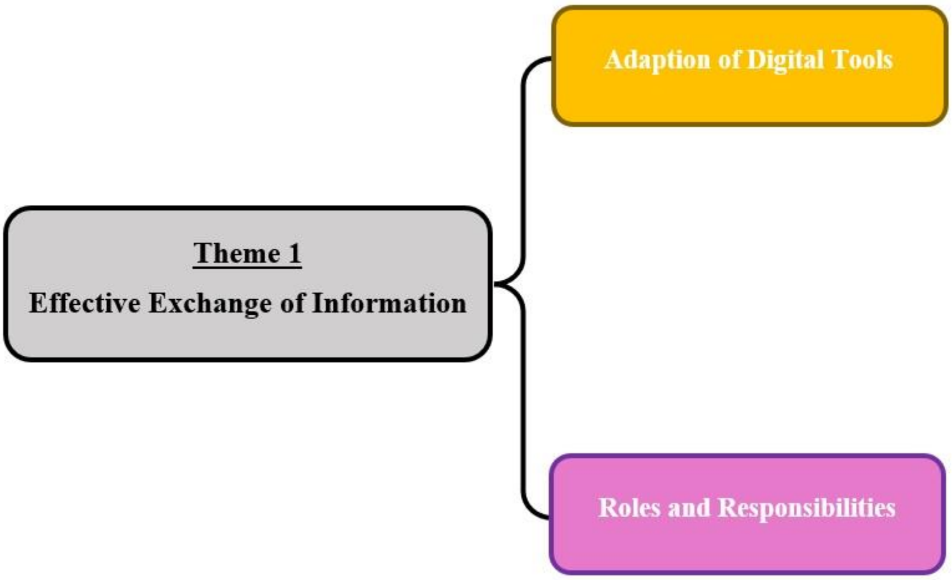

Figure 43 - Case Study A Theme 1 Outline

After discussing effective information flow management and understanding the project's practices to manage information flow, it is then essential to explore the challenges facing the project in terms of managing the flow of information, which creates the research's second superordinate theme. Therefore, the next section of findings to explore, which refers to the second superordinate theme, is the 'Challenges of Effective Information Flow Management' (4.5 Theme 2 – Challenge of Effective Information Flow Management). This section which is the core research analysis of this case study, is divided into three subordinate themes, and under each subordinate theme, a number of factors/issues have emerged from the data related to that subordinate theme which will be explored and discussed accordingly. The overview of this section, which presents theme 2 is outlined in Figure 44.

Finally, the role of BIM/Lean in enhancing information flow management will be explored under the third theme of 'The Role of BIM/Lean in Relation to Effective Information Flow Management'. Due to the nature of this project as a Defined project in which BIM implementation was limited (as explained in 4.2.2 Project's BIM Maturity Level), it was found that there are no noticeable advantages and factors in this context to explore under this theme. Therefore, this final theme can be considered the shortest theme amongst all themes in this Case Study, which will be discussed under two sub-themes of 'The Common Data Environment (CDE)' and 'The Absence of BIM/Lean Adaption' as shown in Figure 45.

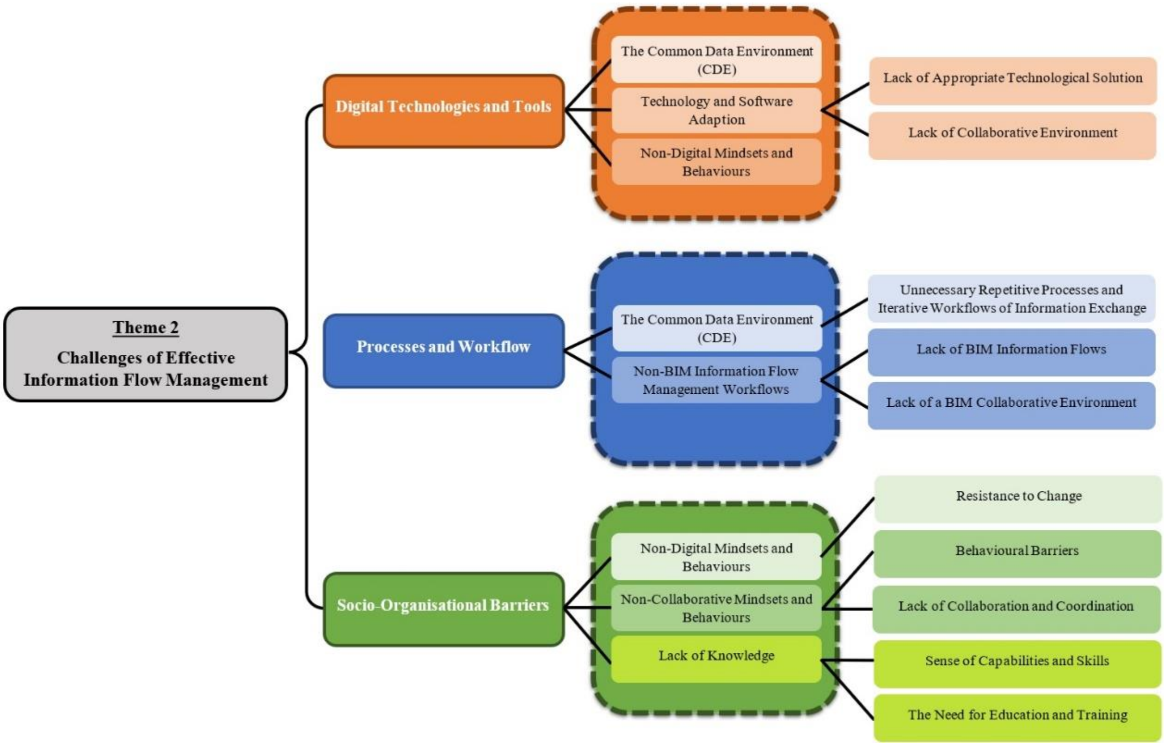

Figure 44 - Case Study A Theme 2 Outline

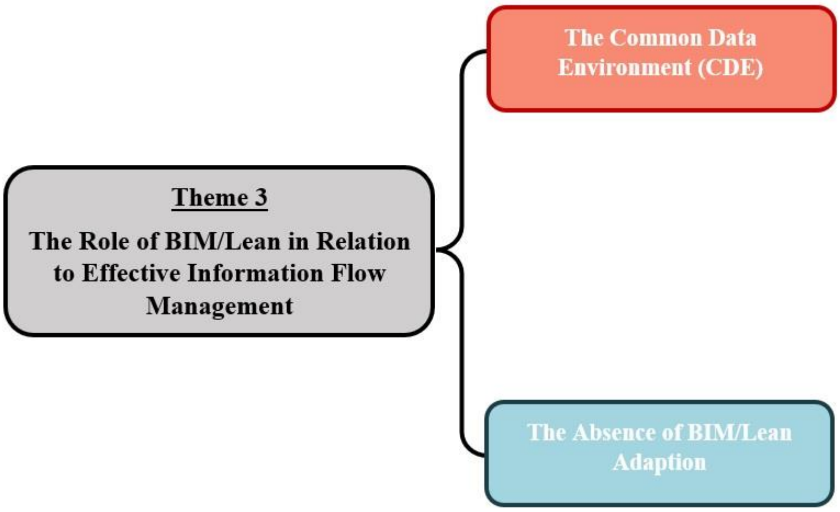

Figure 45 - Case Study A Theme 3 Outline

4.4 Theme 1 - Effective Exchange of Information

It is widely believed that due to the increased level of information exchange, it is critically important to manage information effectively (Baldwin et al., 1999; Chatzipanagiotou, 2017; Detlor, 2010; Robertson, 2005). The importance of managing the information flow was also indicated by all the interviewees. It was believed by most of the participants that projects rely heavily on information, and thus, sufficient information flow and effective management are vital for project success.

The majority of participants held the view that effective information flow management could enhance the quality of information and, subsequently, the overall project productivity. This is because information management aims to ensure that project teams can retrieve, process, and use information effectively and efficiently (Deltor, 2010). Therefore, information flow management is essential in delivering high-quality information between project participants and therefore improving the overall project performance and productivity (Zeng, Lou, & Tam, 2007).

Hence, it is important to understand how the information flow is managed to identify the opportunities and challenges of the information flow management in the context of this case study project. So, based on the interviewee's responses and the main themes, two sub-themes have emerged under this theme which aims to explore how and by whom the information flow is effectively managed in this project. Firstly, it was mentioned several times by all interviewees that some digital tools have been adapted in this project to manage and exchange the information effectively in a systematic way which will be explored under the 'Adaption of Digital Tools' sub-theme. Secondly, it was found that for the information flow management system and the digital tools that have been adapted in this project, there are particular responsibilities under a specific role that enable the efficient management of the overall information flow. This will be discussed more under the second sub-theme of 'Roles and Responsibilities' in this section.

4.4.1 Adaption of Digital Tools

To manage information flow, all interviewees reported using a digital system that enables effective information management. Therefore, an online cloud-based platform was used in this project which allowed the flow of information between all project teams as A2 stated that

"information flow comes through software called Viewpoint, which is a cloud-based system".

Even though this project was a defined project, in which the level of BIM implementation was very limited, an online-based cloud system was used to share information between different project teams. This system which was referred to as *"an online cloud-based"* platform by all participants, is considered to be the Common Data Environment (CDE) which was part of the client's requirements to be used in this project. The CDE is described by BSI (2007) as a *"single source of information for any given project, used to collect, manage and disseminate all relevant approved project documents for multi-disciplinary teams in a managed process"*.

BIM Level 1/Stage 1 projects need to adopt a CDE approach to enable sharing of information between all project members to enhance the information flow management (SFT, 2019; BSI, 2007). Because *"using the traditional method of sharing information where the flow of information between the project team and the project phases is jumbled"* (A3), all information was exchanged using the cloud system (CDE) that was adopted as part of the BIM Level 1/Stage 1 requirement in line with BS 1192:2007.

Also, it was believed by A4 that this system encourages people to be more team players *"rather than waiting for an email to come in, and then forward it on and then have any coming back and then you just going backwards forwards all day"*. Even though A4 believed that *"the system is trying to get people away from the email system"*, A2 argued that emails were still being sent to the project's team to notify them of any updates to the system and sometimes the number of notifications emails that each person receives is so overwhelming. On the other hand, as this project was not considered a Managed (BIM Level 2) project, there was still some information not being shared through the system as A4 claimed that *"they are not pulling all the details from everywhere because we don't have BIM fully in place"*. Therefore, after checking the information in the system, *"somebody physically checks all information"*, including some 2D drawings that are not in the system (A1). This is due to a lack of full BIM implementation and limited requirements based on that because there are a number of BIM features not being used in this project, such as full 3D modelling, visualisation, clash detection and etc., which result in a poor exchange of information on the CDE system. Also, during the interviews, it was found that other factors are causing these issues of not sharing information throughout the system, which will be discussed further in the next section under the second theme (4.5 Theme 2 – Challenge of Effective Information Flow Management).

It was interesting to know that although the project team are required to upload all the information in the system, A3 revealed that there were still hard copies being used in the project, whether they have been uploaded in the system or not. This is because either the consultant and contractors still issue physical pdf drawings, or they only upload the first version of a drawing, and once it gets rejected or needs some amendments, they do not upload it back again. To understand why this is happening, it can be found that even though the system is in place, some of the project team members do not fully understand the workflow that needs to be followed thoroughly, and sometimes they find it challenging to keep uploading files on the system whereas they can send that piece of information via email or hand it in, in-person.

Nevertheless, it was pointed out by A4 that the system is useful for managing information and that *"by being online, everything is recorded in that one place"*, which helps to manage the information flow easier. The majority of the participants agreed that using this system to identify the information that is needed is easy because *"everybody who gets involved in the project, from the first day, they are given some information on how to use this system to enable them to work with it throughout the whole project."* (A4).

The way that the system of managing information flow works was clear to all participants as A3 explained that *"we get notified every day when a consultant or someone else uploads information onto Viewpoint, telling us whether it is a piece of information or whether we have to comment on it"* so, *"there are notifications sent out to people who are involved in this job"* informing an update to the system (A2). Also, all participants reported that every detail about the information which was uploaded, such as the person who uploaded it, the date that it was uploaded, the purpose of that upload, etc., is identifiable.

The process of managing information flow was further explained by A2 that once the information gets uploaded, there are different statuses applied to that piece of information, so *"we have an A, B and C status for the drawings. A and B are approved, B is approved as well but with some comments providing the details and C states for reject."*. The majority of participants believed that by having this information status system, it is easier to track and understand the flow of information throughout the project. For this mentioned status system and the whole information exchange system to work successfully, there is a management side to control and manage the processes.

It was mentioned by some of the participants that the management side of this information flow system is an essential part of this system to work effectively. Therefore, the next sub-theme discusses this role with its responsibilities in terms of the effective exchange of information.

4.4.2 Roles and Responsibilities

To ensure that the cloud system (CDE) system works properly and to manage the process of flowing information within the system, a Document Control Manager manages the whole process. As stated by A4, the leaders of the system are the design managers, yet the actual management of the system and ensuring that all the file names and all information are up to standard and up to date is with the document control managers.

It was highlighted by A5 that under The Construction Industry Council (CIC) Building Information Modelling Protocol, the information manager will manage the common data environment, but A5 argued that *"we do not think so, we think the document controller will manage the common data environment because it is just documentation"*. Even though the document controller manages the whole process within the system, A4 stated that *"we all work as a team"*, and thus, everybody needs to be involved in making sure that the system works.

A4 pointed out that *"it is like any system that if people do not use it properly, there is no point of having it"* therefore, it was found that it is essential that all project teams work collaboratively together to enable managing information flow effectively and help the document control manager to manage the CDE system in a way that the system of flowing information works smoothly and efficiently.

4.5 Theme 2 – Challenge of Effective Information Flow Management

Like any other management process, managing the information flow may face challenges. The challenges of information flow management may vary from one project to another as the level of exchanged information and the amount of information differ.

In this project, it was assumed that there might be many challenges with the information flow management due to the context of a Defined project in which BIM implementation is limited. The assumption was made based on the literature findings that in traditional projects where BIM is not fully implemented up to Level 2/Satege 2, inadequate information flows between project teams are the leading cause of significant information flow challenges because the flows of information are jumbled and overlapped. (Rathnasinghe et al., 2020; Park & Lee, 2017; Zoubeir et al., 2014; Al Hattab & Hamzeh, 2013).

However, most participants held the view that they do not face any critical information flow management challenges. This is mainly because of the usage of the online cloud-based information flow management system (CDE), which was explained previously. Nevertheless, when the researcher discussed the use of CDE concerning the information flow, most participants claimed that there are some minor issues concerning information flow management that are mainly associated with the use of the CDE as the primary digital technology and tool in this project.

The processes and workflows that are being used to manage the flow of information were argued to be time-consuming due to their lengthy workflows, which caused reworks and delays at some points in the project. Furthermore, some participants were unsure whether the right tools and software were used in the project or not and if the technology was one of the contributing factors for having issues with managing the information flow.

Additionally, all project participants believed that there were socio-organisational barriers in the project, which resulted in poor information flow management. So, based on all interviewee's responses, people within the project can be considered as the main cause of issues within the information flow management because when people do not follow the process and do not use the technology as required, the effectiveness of information flow management would be at risk.

These issues within the management of the information flow were further explored, and three sub-themes emerged based on the interviewee's responses and research findings. The findings showed that these challenges are related to 'Digital Technologies and Tools', 'Processes and Workflows', and 'Socio-Organisational Barriers', which refer to the sub-themes under this theme. So, this section which refers to the 'Theme 2 - Challenge of Effective Information Flow Management', presents the findings that have emerged from the interviews under the following sub-themes.

4.5.1 Digital Technologies and Tools

In the context of this project, it was found that the level of technologies and tools used to manage information was not very advanced. The project team relies on various software applications, including drafting, modelling, analysis, parametric, drawing, and BIM software. But the level of usage of BIM software is not very advanced and is limited to 2D drawings and some 3D modelling with a very basic level of information attached to the 3D Models, as indicated by several participants.

It was revealed by A1 that Revit Software is being used in this project *"only for basic 3D modelling, which is like early stages of BIM"*. Similarly, A3 argued that even though they have done some 3D models but "*the 3D models do not have that much of information in them. And nothing has been taken from them such as any construction information"*. This is all because of the level of BIM implementation and the project's and client's requirements in this project which was explained previously.

Therefore, based on the interviewees' responses, three main factors have been elicited in regard to the 'Digital Technologies and Tools' sub-theme, which was found to cause the information flow management challenges in this project. These factors which will be discussed in this section are as follows:

- The Common Data Environment (CDE)
- Technology and Software Adaption
- Non-Digital Mindsets and Behaviours

4.5.1.1 The Common Data Environment (CDE)

In this project, the primary technological tool that was used to manage the flow of information was the cloud-based system (CDE). Participants believed that the use of this system is straightforward due to the basic level of requirements concerning information flow management. Likewise, it was believed by the majority of participants that considering this system (CDE) as a technology that is being used in this project; it is working towards its aim, which is enabling the exchange and sharing of information in a better organised and coordinated way. However, A1 believed that there are some challenges due to the lack of innovative and technological processes like BIM, which could have enabled features to boost managing the flow of information, specifically in relation to technology and tools.

It was believed by A1 that the technology and tools within BIM adoption could have improved the information flow management in this project in terms of having a fully 3D model in which all information was available and attached to that model to enable visualisation and collaboration effectively. Communication between project teams would be facilitated through visualization as part of BIM tools which would also allow a continuous flow of information (Al Hattab & Hamzeh, 2013) and, thus, overcome challenges within information flow.

By being able to visualise the BIM model, any information related to design errors could be detected early in the design process, which ultimately helps to improve the quality of information as well as the effectiveness of the information flow management. This was further explained by A1 "*if the information flow management system was live and people could work on it live where the first instance review of any drawings or information could have been done live on the screen with key project teams in the room then the whole process could have been done quickly and with fewer errors*". A2 held the same view in terms of the benefits that BIM tools provide, which enable effective collaboration among the project team.

Additionally, by using BIM technology and tools, information is always up to date because sharing and exchanging information between project teams is enabled at any time needed through the BIM model, allowing real-time design adjustments and development (Al Hattab & Hamzeh, 2013). However, A2 did not totally agree with the idea that BIM tools would certainly improve the challenges within the flow of information as he argued that *"this is not so much the improved circulation of information, it's more the method in which things are coordinated"*.

The collaborative aspect of BIM may help in terms of improving the challenges within the information flow management because the process of sharing and exchanging information is more coordinated and not being shared in isolation like in this project, A2 believed. It was further explained by A2 that in this project, BIM tools would not improve the technological challenges that the information flow management system face. Because, apart from the BIM protocols, this project has implemented a "cloud-based system (CDE)" that works quite similarly to what a BIM Level 2/Stage 2 project may have. But BIM tools would improve the processes of managing the flow of information because *"a lot of information is fully coordinated"* in a BIM collaborative environment (A2).

Moreover, it was revealed by some of the participants that as this project did not fully implement BIM and its tools to develop a 3D base model with all the information attached to it, almost all detailed drawings were produced in 2D design and were shared in the cloud system in separate PDF formats. Therefore, there were some challenges in terms of managing the exchange of information related to the drawings. For instance, A2 explained that when the drawings are done in 2D, it is very difficult to highlight the information on the drawings to identify some possible clashes and design errors. Thus, this results in rework and makes information flow management more challenging. Similarly, A3 indicated that by having a 2D environment, the project team *"are not able to do coordination"*, and that makes the management of information flow complicated as well.

These arguments from A2 and A3 support the views of several authors in the literature that claim fully integrated design and information flow management can not be guaranteed through BIM adoption if the traditional workflow and 2D environment are still followed by the project participants to share and exchange information (Kocaturk, 2013 & Kerosuo et al., 2013, cited in Zoubeir et al., 2014).

4.5.1.2 Technology and Software Adaption

When it comes to the technological aspect of the information flow management challenges, different factors can impact the "effectiveness of exchanging the information". Choosing the wrong software and not using it adequately can be considered one of the critical factors that can cause challenges in managing information flow.

It was stated by A4 that *"the actual piece of technology and software that we are using is whether the wrong system to use or could be improved"*. This showed the uncertainty about choosing and adapting the wrong system to use, which can slow down the process of managing the information flow and it can also stop the process. Different aspects can be discovered from this statement that explains the rationales behind this point of view. It can be seen that the CDE as a standalone tool in this project could complicate the flow of information because of some issues that it has in terms of both its technological aspect and its lack of collaborative processes/workflows in place.

Lack of Appropriate Technological Solution

The technological element of the CDE could be perceived to not be fully enhanced as it requires an internet connection to function. The "Internet" as technology is widely believed to benefit projects as it provides a platform for sharing and exchanging information (information flow), ease of planning information, coordination, visualization and communication (Yu, Gao, & Ren, 2016; Zeng, Lou, & Tam, 2007), which enable collaborative working and real-time management between project teams (Zeng & Wang, 2020).

The Internet is also viewed as a communication platform that facilitates an effective information flow throughout the project lifecycle (Chen et al., 2018; Zeng, Lou, & Tam, 2007). Despite the benefits of the Internet as technology within the BIM environment, an argument was made by several participants that stressed the negative aspect of using the Internet as a platform for the CDE.

When the Internet is used as a platform for the CDE to share and exchange information between project members, major issues may arise in terms of security (Khudhair et al., 2021) and Internet access and connectivity. In this regard, there was an example where the whole system crashed because of a failure in the internet connection, A4 revealed. It was highlighted by A4 that when the internet connection fails, the whole system is inaccessible, and therefore, nobody can get access to any of the information that is on the system *"so no one can upload or download anything from the system, and this is an issue with the technology side that we experienced a few weeks ago"*.

So, in this project, when the internet connection failed, all the information in the CDE was inaccessible, and the system was unavailable to use. As a result, the whole project team had to go back to the old traditional methods of sharing the information via emails and all the documents, drawings, and information had to be shared through emails (A4). As the system was down for about three days, there were delays in information delivery and in the overall process of information flow management, as highlighted by A4. Because late information exchange would result in extreme delays and issues downstream in the design phase and subsequently in construction (Al Hattab & Hamzeh, 2013), the Internet as a platform for the CDE to work was considered to cause issues in terms of the information flow management in this project.

Similarly, A3 stated that *"all these online collaborative software does have its issues"*. This issue, of course, would have negative impacts in terms of information flow management because the CDE system *"is not an offline system"* and when the system goes offline, then project members have to *"go back to the old school way of emailing through documents"* and revert to using traditional methods of information exchange (A4). As mentioned by some of the participants, this would result in unnecessary delays of waiting for a document to be emailed to them to process with the work, reworks due to the design changes, duplicated information sharing, missing information, and waste of time.

The internet as a platform for the use of the CDE is considered to be a challenge in terms of facilitating effective information flow management because if it fails, then the whole system would stop, which interrupts the flow of information and disable the project team to access the information in the system. Therefore, in this project, there is a lack of an appropriate technological solution to solve the internet issue when using the current in-use system, which causes some challenges in terms of the overall software adoption and the digital technologies and tools used in this project. Also, when there is a lack of appropriate technological solutions that do not support collaborative working where project members can actively collaborate without interruptions due to internet connection, there would be some issues related to this lack of collaborative-enabled software. This is discussed more in the following section.

Lack of Collaborative Environment

In addition to the issues concerning the 'Digital Technologies and Tool' in terms of the 'Software Adaption', it was found that the selection of the software that is being used in this project has other impacts on the project as well in terms of collaborative information flow management.

It was revealed by some of the participants that there is a lack of a collaborative environment in this project. This was further studied to understand the relation between this issue and the software adaption. It was found that another aspect of the view of uncertainty about choosing the wrong system to use that was mainly raised by A4 and declared by other participants can be that the CDE becomes an issue itself because it does not fully support the collaboration in the project. This is because of the nature of this project, which is not a fully BIM project, and the level of collaboration and coordination is therefore limited. Using "only" the technology side of BIM, that is, the online-based system (CDE), in this project would not support the collaboration throughout the project (Al Hattab & Hamzeh, 2018), which not only make the information flow slower but also may complicate the process.

The literature also highlights that it would be much more difficult to resolve any fault or errors within the CDE if BIM is not fully implemented with all required protocols and standards (Rathnasinghe et al., 2020). This is mainly because other features of BIM are not implemented in the project to support the collaboration through the CDE and enhance the information flow management, which includes producing 3D models and using BIM tools and processes to enable visualization, clash detection, faster and more effective processes, better design (Khudhair et al., 2021; Meganathan & Nandhini, 2018; Eastman et al., 2011; Azhar, 2011).

4.5.1.3 Non-Digital Mindsets and Behaviours

Another factor that was found to impact the effectiveness of information flow management related to the 'Digital Technologies and Tools' is the lack of digital mindsets and behaviours of the project teams. This factor was highlighted by some of the participants specifically concerning the technology used in this project.

Some arguments discussed earlier in the previous section argued that technology is the main issue. But A1 did not agree with the previous arguments in terms of the technology being the main issue because it was believed by A1 that the system is working very well if "people" who use the system use it properly. Some of the issues within the system are caused because people do not share the right information, or the information is not shared at the time that is needed (A1). This is due to their lack of digital mindsets and behaviours, which impede the effective utilising of digital technology and tools.

Therefore, it was argued by A1 that if the information flow was more automated with fewer human beings involved in terms of sharing information and adjusting the flow, then the management side of it would have been much better. This argument supports the importance of people's role as the key factor of a project's success concern several authors in the literature because all members of the project team need to adopt the technological and collaborative process of information exchange and commit to that process to better manage information flow (Hickethier et al., 2013; Phelps, 2012).

Furthermore, it was widely believed that some of the technical issues are not directly related to the software or the technology itself but rather related to the people who use the system. It was revealed by A3 that it is important to ensure that *"everyone in the project knows how to use the technology"* because if they do not know that, then the technology becomes a barrier in the process. Although the majority of interviewees believed that the technology side of the system is working reasonably well, and the number of challenges in terms of the information flow management is very limited (such as the issues related to the CDE), one thing that all the participants agreed on was that the main factor that can make the technology and process work successfully or unsuccessfully is the people. So, people with non-digital mindsets and behaviours would also act as socio-organisational barriers and cause challenges in terms of information flow management; this will be explored and discussed more in the context of 'Socio-Organisational Barriers' later in this chapter (4.5.3 Socio-Organisational Barriers).

The above-identified factors in this section were found to affect the 'Digital Technologies and Tools' directly or indirectly, which results in poor information flow management. As mentioned previously, the process of sharing and exchanging information in the system (CDE) was considered to be time-consuming and, in some cases, challenging. Also, the role of people and their non-digital mindsets and behaviours in using this system was considered to be challenging in terms of information flow management.

So, it is vital to understand the other factors affecting the management of information flow, i.e. processes and workflows and socio-organisational barriers, as information flow management is not only limited to the information itself but also focuses on managing the digital technologies and tools that are being used, the processes and workflows of sharing the information, and people who exchange the information and use the technology and process (Chatzipanagiotou, 2017; Robertson, 2005).

4.5.2 Processes and Workflows

Based on the previous discussion under the first sub-theme of 'Digital Technologies and Tools', it was revealed that there are other factors that impact effective information flow management, specifically in regard to the 'Processes and Workflows' in the project, which will be explored more in this section.

From the participants' point of view, the process and workflows of information flow management in this project were initially considered to be straightforward and not complicated. However, during the interviews, when the details of the stages of the process and the workflows of information exchange were reviewed and discussed deeper, some of the participants expressed opposite views to their initial opinions. This is because when the details of the process of information flow management were discovered, the findings provided more profound thoughts and insights that governed their responses.

The findings indicated that there were some issues concerning the processes and workflow of managing the information flow, which resulted in rework, idle time, and delays in the project. Therefore, based on the interviewees' responses, two main factors have been elicited in regard to the 'Processes and Workflow' sub-theme, which was found to cause the information flow management challenges in this project. These factors which will be discussed in this section are as follows:

- The Common Data Environment (CDE)
- Non-BIM Information Flow Management Workflows

4.5.2.1 The Common Data Environment (CDE)

The first factor that was revealed by the majority of participants as a contributor factor of poor effective information flow management that concerns the 'Processes and Workflow' of the information management was the CDE used in this project. Even though this project adopts a cloud-based system (CDE) to comply with the BIM Level1/Stage2 requirements, in which all information is shared and stored, the process of information flow management remains the same as a non-BIM project, and it is done traditionally. This is because of several factors which have been explained previously, such as the issues associated with the technological side of the system and other factors which will be explained below and later that are related to the iterative loops of information exchange using the current system and also the people who use the system.

Unnecessary Repetitive Processes and Iterative Workflows of Information Exchange

It was found that, in this project, the team members need to upload and submit their information on the system for architects' and owners' decisions and, based on the results, acceptance or rejection, which may take some time to be completed by the project teams have to then make the adjustments and go back through the submitting process again until the design gets accepted. Therefore, there are unnecessary repetitive processes in this project which result in poor information flow management (the workflow of this process is shown in Figure 3). This process of information flow between project teams includes several iterative loops that result in idle time, rework, and delays in the project until the architects and owners approve the design (Al Hattab & Hamzeh, 2013). So, the process can be considered a challenge in terms of information flow management.

All of the project participants believed that the process of exchanging information is relatively slow due to the lengthy workflow and the requirements of the approval process of information (shown in Figure 3). However, A2 believed that this workflow works well because *“it saves the company from printing off hundreds of drawings to send out to people and having them manually marked and approved”*. When further explored, it was found that this opinion comes from the background of working in a traditional environment where there is no online cloud-based system available. Because everything was done electronically previously and in a non-BIM project, this way of working and processing information in a cloud-based system (CDE) was seen to be more beneficial than challenging to some participants. However, this is in contrast to what A3 pointed out as the issue of managing the information flow in this project; it seemed that the consultants still issued the drawings by email before uploading them on the cloud-based system. This has a negative impact on managing the flow of information as the amount of information being produced on different platforms increases as well as the increased level of the process of checking and approving the information.

Also, although A2 acknowledged the fact that the process was done electronically, A3 did not consider that this automated process was working efficiently. Due to this automated process, even the lead designer had to comment on his own drawings as part of the process requirements. As part of the requirements for the process of information flow, the Lead Designer has to comment on all drawings and check all the information shared in the system that is related to the design. Therefore, when the Lead Designer uploads and shares the drawings that were produced by him, as part of the required process in the system, they have to comment and check their own drawings as well so that a piece of drawing can proceed in the system. Hence, this can be considered an unnecessary repetitive process that causes delays, rework, and idle time, resulting in poor information flow management in this project.

Moreover, while A1 was explaining the details of the information flow management process, it was clear that the process of information approval is very long in this project. This contrasts with what A4 believed, that the *“workflow of the process is very short”* compared to a BIM project workflow. It may be seen that both participants’ views were correct in some respect because the outlined workflow of the process seemed to be short in terms of its different outlined stages of processing information (Figure 46) and not a lengthy process but the actual process of following that workflow and meeting its requirements for each stage was very long (Figure 47).

Figure 46 shows the workflow that was explained by A4, whereby the workflow seems to be short and straightforward. However, the actual processes of that workflow can be found in

Figure 47, which illustrates the detailed and long journey of processing a piece of information. This demonstrates that even if the workflow seems to be straightforward, in terms of its overall few work packages, short processes, and apparent simple information flow, because of many factors that have been discussed already and will be discussed in the next section concerning humans being involved in this process, and a lack of technological process and tools, the information goes through several iterative loops before the design finally gets approved.

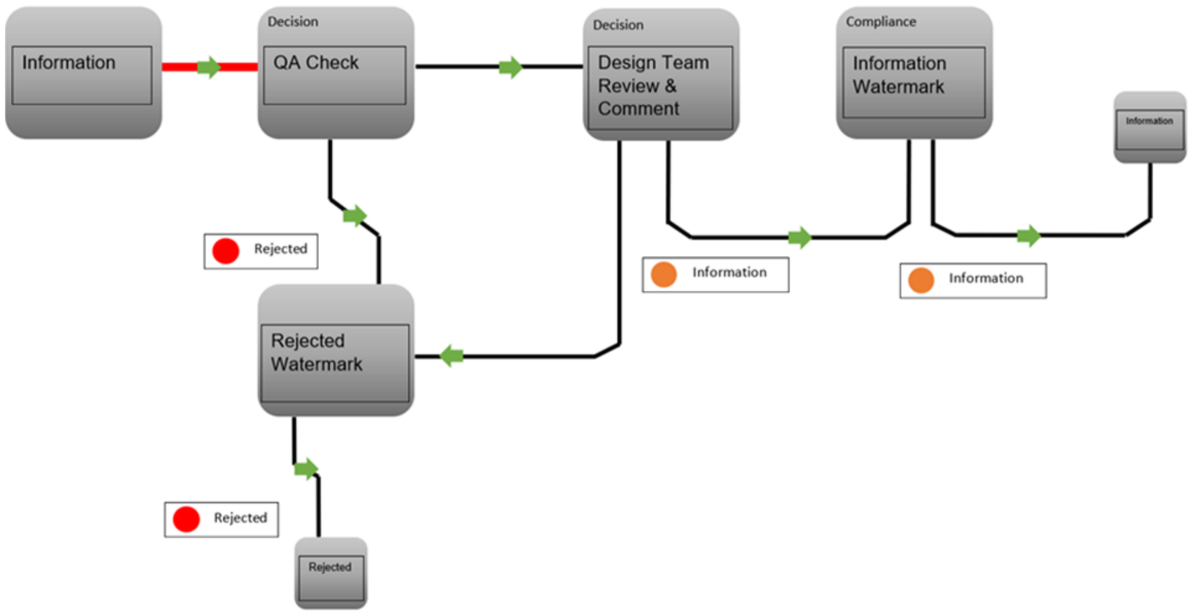

Figure 46 - CDE Overall Workflow (CSA)

Figure 46 shows the overall work packages and the general required information flows in the CDE. This means that for the overall information flow process to work like that depicted in Figure 46, it would need everything in the project to be conducted perfectly, i.e. with very limited design changes and only a few rejection points throughout the workflow to prevent the iterative loops in the process. However, in fact, this does not happen in projects such as this due to the information flow challenges explained in this section.

Also, in reality, there would rarely be only a few rejection points in the actual workflow of the process. Therefore, the existing workflow of the information flow processes in this project is better represented in Figure 47, which shows the lengthy process of information flow due to the challenges facing the project. The overall process seemed to be working well, but due to the potential design iterations, rework, delays, and unnecessary repetitive processes, some challenges were facing the information flow management.

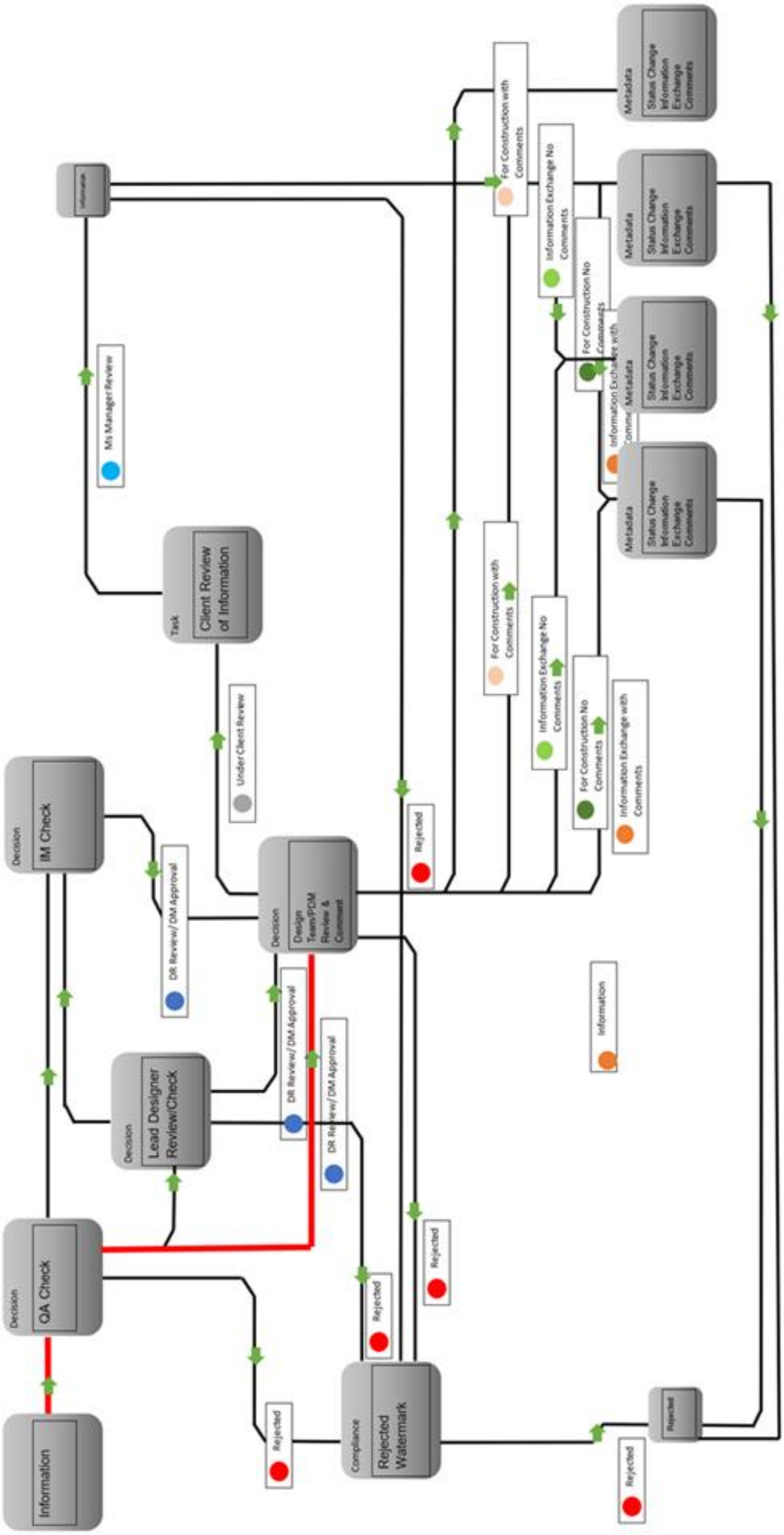

Figure 47 - CDE Detailed Workflow (CSA)

4.5.2.2 Non-BIM Information Flow Management Workflows

In addition to the previous factor, the findings from interviewees' responses elicited another factor which results in poor information flow management in regard to the 'Processes and Workflow'. The Non-BIM Information Flow Management Workflows were found to impact effective information flow management due to a lack of BIM Information Flows and a Lack of a BIM Collaborative Environment. These issues will be discussed more in the following sections.

Lack of BIM Information Flows

It was mentioned several times by some of the participants that there is a lack of BIM information flows in the processes of information flow in this project. A3 believed that because of the lack of a full technical system and processes such as BIM, the current automated information exchange process and workflow slows down the process of managing the information as well as the whole progress of the entire project itself.

The first time of creating the BIM model and issuing the first set of drawings, there is a slower process compared to issuing 2D drawings in a BIM Level 0/Stage 1 or BIM Level 1/Stage 1 process due to there being a lot of information that needs to be built into the BIM model. However, after that, *"the flow of information would be faster"* (A3) because *the "information is aggregated and shared transparently between the different users"* (Al Hattab & Hamzeh, 2013), which would subsequently speed up the process of information flow management (A3). This is in contrast to what is currently being done in this project. As the information has to go back and forth between project teams in iterative loops throughout the process, this results in a lot of rework and delays in managing the information flow (Al Hattab & Hamzeh, 2013). Yet, the checking and coordination of the information would be quicker in a fully BIM-adapted environment because there is a 3D BIM model that all project teams can refer to, issue their information based on that model, comment and receive feedback on drawings without having to go through the whole process of the current CDE where there are so many unnecessary repetitive processes of approval and coordination in a collaborative environment.

It was suggested by A3 that if this automated process were done using a federated model with BIM process and protocols, then the whole process would have worked more effectively and with less rework. By using BIM processes and workflows, unnecessary and negative duplications and iterative loops in the process of information flow and rework would be reduced due to the features that the BIM approach provides and thus, this would benefit the project in terms of saving time and through better management of the information flow (Al Hattab & Hamzeh, 2013). This aligns with A1 in declaring that due to the lack of a live 3D model platform, there are challenges in managing the flow of information.

It was explained by A1 that the project team have to wait for other team members to comment on a piece of information (either approve or reject the information) and wait for that comment to come back to the system. This does not always work effectively because sometimes a team member might put the wrong information, or the information is not being issued at the right time, and then the information approval process takes time. Consequently, these issues not only *"increase the waste (such as rework, time, extra processing, waiting, etc.) in the process"* (A5) but would also result in poor management of the flow of information.

Lack of a BIM Collaborative Environment

Similarly, A1 also believed that if the live platform in a collaborative environment was available in this project, then instant information could have been issued and therefore, the project team could comment and make a decision on them immediately instead of waiting for everybody's comments to come back to the system. This would have improved the process of information flow management as information is being created and shared using a 3D model in the BIM environment, and all project members can collaboratively work together to visualise the model and the information within the model.

Therefore, if there are any design changes required or if there are any issues with the information in the model, then project teams can modify the model and adjust the information automatically through the BIM model (Al Hattab & Hamzeh, 2013). BIM is also viewed as a "virtual process" that involves integrating all project members and disciplines to collaborate and share information more effectively and accurately than using traditional processes of sharing information (Azhar, 2011).

Moreover, in the BIM information flow process, once the information is integrated and coordinated, prompt adjustments of the information in the model are enabled. Therefore, the information is always up-to-date, and a continuous flow of information is allowed, which ultimately enhances information flow management (Al Hattab & Hamzeh, 2013). Likewise, through the BIM approach, two-way information exchange between different disciplines in the project is allowed in real-time (Al Hattab & Hamzeh, 2013). Because the real-time information model can indicate the real conditions of the project (Khudhair et al., 2021), the flow of information can be managed easily and more quickly.

Most participants believed that by having such a platform, the process of managing information flow would be faster and more effective. Nevertheless, an interesting statement was made by A5, who indicated that by implementing collaborative processes and approaches like BIM that enable a live information-sharing platform, the information flow would be quicker and more reliable. The information will be checked and validated before it is sent through, makings the information flow more reliableande efficient.

Moreover, it was stated by A4 that if project members do not follow the processes of information flow accurately and in time, even in a project environment where collaboration is enabled, then "people" as 'Socio-Organisational Barriers', can be considered as key contributor factor of poor information flow management. Similarly, all participants believed that if people worked effectively and according to their timelines, the processes of managing the information flow would not have caused many issues. Otherwise, people as a socio-organisational barrier can be the primary root cause of many problems and challenges related to information flow management.

4.5.3 Socio-Organisational Barriers

As a socio-organisational factor, people are always the critical aspects of any project because they are the main contributory factor of any project to work. This has been highlighted many times in the literature (Chatzipanagiotou, 2017; Murthy & Screenvias, 2014; & Hickethier et al., 2013; Phelps, 2012; Robertson, 2005).

Initially, based on the findings from the literature, it was assumed by the researcher that people could be the key positive drivers for the project to work effectively and to achieve its goals towards effective information flow management. However, when asked about the main challenges of information flow management during the interviews, some interesting responses emerged. The first and most influential factor causing challenges within the information flow management which all participants reported, was "people" and considered as a socio-organisational barrier to effective information exchange.

It was interesting to find that people directly or indirectly contribute to poor information flow management because of many aspects influencing people's work and sharing information.

It was highlighted by A5 that *"the technology is there, the process is there, it is just how people use the technology and follow the processes"*. Likewise, both A3 and A1 stated that because the project *"is relying on so many people"* from different backgrounds, then it is essential to ensure that people are in the right direction and following the workflows of the information correctly. The findings from interviewees' responses indicated that there are three main factors associated with the 'Socio-Organisational Barriers' sub-theme, which was found to result in ineffective information flow management. The factors that have emerged under the sub-theme of 'Socio-Organisational Barriers', which will be discussed in this section, include:

- Non-Digital Mindsets and Behaviours
- Non-Collaborative Mindsets and Behaviours
- Lack of Knowledge

4.5.3.1 Non-Digital Mindsets and Behaviours

It was emphasised by some of the participants that one of the main challenges related to people as the socio-organisational barriers to effective information flow management is the fact that many people are not comfortable using an online cloud-based system to share information. A4 stated that getting people to use the system and technology to share information is the main challenge in exchanging information.

The majority of interviewees believed that many of the project team members have limited recognition and knowledge surrounding digital technologies and procedures. Consequently, due to having non-digital mindsets and behaviours, an ineffective exchange of information occurs.

Resistance to Change

It was explained by A4 that it is challenging to get people to work collaboratively and to use the technology in this project to use the online systems (CDE) due to people being used to working in a traditional (2D CAD) design process. Some project members in this project are used to issuing drawings or any other sort of information on paper and manually. Therefore, these people do not like the fact that there is an online cloud-based system (CDE) for information exchange, and this is mainly because *"people do not like new changes"* (A4) and when asked to adopt new technologies, people are usually "resistance to change".

Additionally, A4 claimed that some people in the construction industry *"do not want to sit at a computer and look at all this information in the system, they want to just be out there on-site doing it"*. That is also to do with people's "mindsets" that when they are used to a process or a way of working, then they do not want to change that. Many project participants, including architects, have habitual “resistance to change” because they are satisfied and confident with designing using traditional methods (Yan & Damian, 2008).

Therefore, to overcome challenges within information flow management, it is important to change people’s mindsets (A4, A5). Thus, it can be found that people do not like change. Therefore using a new way of sharing information in an online system is difficult for them. Therefore, people are considered to be the current barrier to the BIM approach because the most critical issue for the management side is the “resistance to change” (Davies et al., 2015). It is, therefore, essential to reduce any potential resistance to change in projects by getting people to realize the potential and benefits of using innovative and technological processes such as BIM and its value over the 2D environment (Xianpeng et al., 2021; Arayisi et al., 2011). This would also be achieved by increasing people’s knowledge and understanding of new technologies and processes through education and training. The importance of knowledge enhancement in terms of effective information flow management will be discussed in more detail later in this section (Section 4.5.3.3)

4.5.3.2 Non-Collaborative Mindsets and Behaviours

In addition to the non-digital mindsets and behaviours, it was revealed that there is a lack of collaborative mindsets and behaviours, which also act as a Socio-Organisational Barrier that results in ineffective information flow management. It was argued by A4 that the main challenge of actual information sharing is getting people to use the system and collaboratively share the information.

According to A5, when people do not issue the data when they are supposed to, which happens a lot, then delays happen, and the flow of information does not occur accurately. This was an issue that A4 also pointed out; although the project team had several days to upload their information, they did not do it on time, and that made other project members have to wait to receive the information in order to be able to comment on them before going for approval.

All these issues that also make the process of managing and sharing information longer are related to people not sharing information on time and/or the correct information. A5 explained that the reason behind this could be that some of the project team may still not understand the processes of sharing information collaboratively and the requirements of it so *“when they do not know what is needed”* then they do not take any actions toward that requirement.

Additionally, it was highlighted by A3 that there were a few experiences of subcontractors working on the wrong revision of drawings because the contractor had given them the old version of the information. This happens when either project teams do not check the updated information on the system or, instead of using the CDE system to share information, they send updated versions of information via emails which makes the information flow management difficult and challenging because there would be confusion in the versions of information available in the systems which leads to delays and reworks (A3).

These issues result from several factors that influence people's way of working, which is not collaborative. Some of these factors have emerged from the interviewee's discussions that will be explored in this section.

Behavioural Barriers

One of the factors that were highlighted by several participants that causes some of the issues regarding information flow management is the fact that there are some human nature "behaviours" based on individuals' different personalities that need to be taken into account when managing the information flow. For example, A4 emphasized that due to human nature behaviours when it comes to doing the required tasks, which may take some time or need adjustments or are not the number of priorities of that person at a time, then some project members think as *"I will do that later"* and what happens is that *"they forget about it"* which cause delays in the process. Similarly, A1 believed that "*people generally cause a problem*" because of their behaviours in terms of not doing their job appropriately based on the job's requirements as sometimes people get busy and "*forget about*" what they have been asked to do with a piece of information or it may be that they make necessary changes to the specific drawing, but they forget to upload in on the system.

Furthermore, sometimes people choose to wait for other project members to notify them or let them know of any change requirements or any work that needs to be done by their side. This is because project members have to go through a lot of information daily due to the requirements of the information flow process, so they cannot consistently dedicate that much time to check for any change requirements.

Therefore, it happens that project teams have to go through hundreds of drawings and some have various changes needed and some with minor changes, but they still need to go through them all, which takes time and therefore, some project members do not wish to spend that much of time going through those drawings and prefer to wait for other members to notify them of any changes that are required (A4). However, this was contended by A2 that people do not wish to go through all the drawings and information in the system because, apart from their natural behaviours, a lot of drawings might not apply to them, and this overloading people with too much information to check is causing issues.

All these issues related to human behaviours demonstrate the importance of understanding this factor and, more importantly, the need to address this factor. The substance of information-sharing behaviour by project teams should be prioritised and driven for improved information flow management and, thus, successful BIM adoption (Ibrahim et al., 2019).

Lack of Collaboration and Communication

As explained previously, behaviour may not seem a prominent issue when considering the challenges of information flow due to the lack of importance given to this factor in practice and in the literature.

Also, this factor is not a standalone issue as people's behaviour could be directly or indirectly related to their work environment. Likewise, as stated by Al Hattab and Hamzeh (2018) concerning BIM adoption, there is a lack of consideration of fundamental challenges in both "communication" and the behaviours of project teams. Therefore, there needs to be a reconsideration of the importance of these two factors to improve information flow management, as "the success of information sharing in the digital environment depends on organisational behaviour supported by the collaborative constructs" (Ibrahim et al., 2019, p. 25).

As discussed under the 'resistance to change' sub-section (Section 4.5.3.1), there were views in relation to people not being interested in using new technologies and systems in terms of sharing information. In contrast to the explained view that people are not willing to use the online system, A1 stated that *"when there is a fully automated live system people would have more willingness to do their piece of work"*. To confirm this, an example was given by A1 that when there was a project meeting scheduled, people were not willing to attend the meeting in person, and they used to find excuses not to attend, but when the same meeting was arranged online or live via Skype almost all of the project members attended that online meeting.

Thus, A1 believed that when everything is being done in a live collaborative platform in which everyone can easily communicate with each other and comment on any information instantly, and from wherever they are, people are more willing to do that rather than attending a meeting in person with having many drawings printed off on the table and people having to go through them manually. Therefore, from this argument, it can be found that some of the information flow management challenges relating to people are due to the lack of a fully automated system that supports "collaboration". This is also in line with the findings that were explored in the 'Technology and Software Adaption' section under the 'Digital Technologies and Tools' sub-theme (Section 4.5.1.2).

Even though this project has adopted a CDE as part of its BIM Level1/Stage 2 requirements, this system does not fully support collaboration in the project, as indicated by several participants. This is because of the nature of this project that is not a fully BIM project, and the level of collaboration and coordination is therefore limited due to having a 2D environment in which the project team "*are not able to do coordination*" (A3) which eventually results in information flow challenges.

Therefore, using BIM as a tool (which is the online-based system - CDE) in this project would not support collaboration throughout the project (Al Hattab & Hamzeh, 2018), which would result in causing information flow management issues. However, it was believed by several participants that if BIM was fully implemented in this project as a collaborative platform, then many factors concerning Socio-Organisational Barriers as information flow management challenges, would have been tackled.

BIM provides a collaborative platform in which a 3D model that comprises all the required information is provided to enable visualisation, clash detection, faster and more effective information flow processes, and better design (Khudhair et al., 2021; Meganathan & Nandhini, 2018; Eastman et al., 2011; Azhar, 2011). Communication between project teams would be facilitated through visualization as part of the BIM collaborative platform, which would also enable a continuous flow of information (Al Hattab & Hamzeh, 2013) and, thus, overcome challenges within the information flow that are related to the lack of communication and collaboration between project teams.

The collaboration feature of BIM would also reduce delays in the project because, as stated by A1, in the BIM collaborative environment, people have access to all information in one live 3D model and any design errors or any required changes can be adjusted quickly and more effectively, which is in contrast to what happens in this project whereby people have to wait for other project members to comment on a drawing or a piece of information so that the information can proceed. Additionally, in a BIM project, the collaboration is enhanced between the project team, which makes people feel "*more involved in the process*" (A1), which in turn, would also encourage people to share information on time because it improves the coordination and collaboration in the information flow management (A2).

Collaboration can also help reduce issues related to people's behaviours and resistance to change because BIM encourages people to both realize and see the benefits that it provides to the projects and to get involved in project meetings to collaborate with other project teams. Therefore, in BIM projects, collaborative meetings where all project participants join to visualise the model and exchange information improve communications between project teams and enable rapid decision-making early in the design process (El Ammari & Hammad, 2019; Azhar, 2011). Therefore, it can be found that collaboration and communication are needed to integrate the experiences of all project members from different backgrounds to help to solve problems and to make design decisions while having a mutual contribution to the project (Durugbo et al., 2011, cited in Al Hattab & Hamzeh, 2018).

Early design collaboration is critical for a mutual understanding of project priorities and specifications. Therefore, collaboration is critical for information sharing and effectiveness, as collaborators can influence organizational behaviour by pooling their experience and knowledge (Durugbo et al., 2011, cited in Al Hattab & Hamzeh, 2018). Through collaboration and communication in the project, people can become a beneficial factor in improving information flow management (Hickethier et al., 2013; Phelps, 2012) instead of being a barrier to it.

4.5.3.3 Lack of Knowledge

Based on the findings from interviewees, another factor that has emerged to act as a socio-organisational barrier to effective information flow management was discovered to be the 'Lack of Knowledge' of people involved in the project. All participants repeatedly highlighted this factor as one of the leading factors of ineffective information flow management.

Most participants pointed out that lack of knowledge comprises the lack of people's skills and their low level of understanding of new technologies and processes and the benefits they would provide. This would also result in a lack of awareness of individuals' capabilities to use and adopt new technological processes and in some cases, underestimate their skills and capabilities to work in a digital-enabled process. Therefore, these factors will be explored in detail in this section.

Sense of Capabilities and Skills

There was a different point of view in terms of people being the main contributing factor to poor information flow management. A2 argued that people might not be the challenge themselves, but other influential factors make the work or the work environment difficult for people, and that, in turn, then leads to poor information flow management. As an example, not realising people's capabilities and overloading people with too much information could cause delays in people's work because they have to go through every piece of information on the system, which takes time (A2).

As part of the system requirements of the information flow, project teams have to go through hundreds of drawings on certain days. Some of these drawings have various changes needed, and some with minor changes, but they still need to go through them all to check whether any changes are required, which eventually takes time. Also, if people are not trained enough to use the system and/or because of their lack of knowledge about the system and, as a result, they would not recognize the skills needed to use the system, then they will face issues along the way, and that causes delays and challenges in information exchange. A2 gave an example that if a project member uploads information in the wrong folder in the system or if somebody does not type the exact drawing's number and coding, then the system could put it up as a different drawing or count it as a wrong piece of information.

Therefore, it is important that project members understand all the information flow requirements and protocols to share information effectively. This point which highlights the importance of people' "knowledge" of using a system and their level of understanding of their capabilities and skills towards using the system,, was pointed out by all participants.

The Need for Education and Training

It highlighted by A4 that it is vital to ensure that people use the system, but it is more crucial to ensure that the system is usable for everybody and that people have the right knowledge and skills to use the system effectively. To ensure that people have a good understanding and knowledge of using the system, it was revealed by A4 and A5 that there were some training sessions for project teams at the beginning of the project to educate people on using the system.

Even though participants held different views on why people were a main contributing factor to the challenges of information flow management, all agreed on one aspect to improve this. "Training" was considered by all of the participants as the key positive important factor which enables people to work efficiently. Thus, instead of people preventing the information flow management system from working effectively, they can help to improve it.

In this project, A5 revealed that some training sessions were provided at the beginning of the project to make people aware of the processes to follow. From a design management point of view, A2 argued that the project team needed to be trained to understand the whole system, whether they were involved in one stage or more stages of the project. A4 also mentioned that the briefing workshops organised at the start of the project were believed to be beneficial in terms of helping people understand how to use the system and the process requirements. Similarly, A1 explained that it would be an excellent opportunity to have briefing workshops where there is a chance to ask questions and understand the processes. However, A1 believed that the best way to learn is to learn it along the way (on the job) because *"if you just learn it and do not practice it then it will be forgotten"*.

Therefore, both training and lessons learned throughout the project are essential. This was in line with A2 in stating that *"the best learning is to physically get involved in a job and do it"*. Moreover, the importance of training was highlighted by A5 by stating that *"technology is easy, processes are straightforward, but the difficulty is with people. So, it is critical to train people to enable them to engage in that process and use the technology"*. Similarly, it was pointed out by A1 that *"people need to be fully trained to be able to make the best use of both technology and the process"*, as the lack of training and education is considered to be one of the barriers to the adoption of digital approaches (Dainty et al., 2017). This was also mentioned by A1 that if there are the best technology and process in place, but people do not have the knowledge to use them, then there are no benefits gained.

Hence, to use any system effectively within the BIM environment, training is needed for the better performance of project teams (Pengfei et al., 2019). Moreover, according to all participants, training can be found as the best and most important way of improving and enhancing other factors, such as non-collaborative and non-digital mindsets and behaviours that influence people in terms of effective information flow management.

The findings indicate that there are different aspects concerning people as a socio-organisational barrier to be the main contributing factor to poor information flow management in this project. These aspects, which were highlighted by the participants at different stages of the interview's discussion, have been highlighted in this section, including their non-digital and non-collaborative mindsets and behaviours and their lack of knowledge and training. These main aspects, with their highlighted and detailed, explained other factors under them related to people, could be found as the root cause of people being the challenge in terms of effective information flow management.

As discussed previously, if people do not have the right mindset to change their way of working, they will not adopt the new online systems and BIM approach, and they may resist sharing and exchanging information within that system. Also, if people's knowledge is not as up to date as the project requirements and there is a lack of understanding of the process of sharing and managing information due to the lack of effective training, then project teams are not fully aware of what needs to be done and how to do it.

Furthermore, people's behaviour would directly impact the project in a way that if they are not willing to share information or they do not share the correct information or not at the right time, then delays and reworks in the project would occur.

Last but not least, in a collaborative environment where communication and coordination are enabled through using technological and innovative processes such as BIM, people can become a beneficial factor in improving information flow management by sharing and exchanging information effectively and collaboratively between project participants (Hickethier et al., 2013; Phelps, 2012) instead of being a barrier to it. Therefore, addressing and understanding these elements is essential when considering people as the main challenge of information flow management.

All the previously mentioned issues causing ineffective information flow management could be linked back together as one factor could act as an influential factor to another. But, most participants believed that to address most of the effective information flow management challenges mentioned above, such as issues concerning digital technologies and tools, processes and workflows, and socio-organisational barriers, the importance should be given to this last point of "lack of knowledge". All participants believed that if people's knowledge improves, the other factors would subsequently improve in terms of sharing and exchanging information effectively and achieving an effective and enhanced level of information flow management.

4.6 Theme 3 – The Role of BIM/Lean in Relation to Effective Information Flow Management

It is widely believed that implementing BIM would provide many benefits to built asset projects (Sacks et al., 2018; Al Hattab & Hamzeh, 2013; McGraw Hill Construction, 2013; Eastman et al., 2011). In the context of this research and specifically in this project, the role of BIM/Lean in enhancing information flow management is explored through the analysis of the findings. However, as this project was a Defined project in which BIM implementation was limited (as explained in 4.2.2 Project's BIM Maturity Level) it was found that there are no noticeable advantages and factors in this context.

Hence, this theme can be considered the shortest theme amongst all themes in this Case Study due to the nature of this project's BIM Maturity Level. So, based on the interviewees' responses and the findings, two sub-themes of 'The Common Data Environment (CDE)' and 'The Absence of BIM/Lean Adaption' merged under this theme to explore how BIM/Lean has/has not affected this project in terms of the information flow management.

4.6.1 The Common Data Environment (CDE)

As can be found from 4.2.2 Project's BIM Maturity Level, this project was identified as a Defined project (BIM Maturity Level 1/Stage 1) due to the client's requirements. Therefore, the level of BIM implementation in this project was very limited and up to the standard level of SFT (2019), which clarifies that *"BIM Level 1 maturity encompasses the management of digital, indexed construction information, including that generated by 2 or 3D CAD systems within a common data environment. Disciplined design and information management policies for collaboration and a specified naming policy shall be used."*.

So, as explained previously, the requirements set out in BS 1192:2007 standards were followed in this project for its BIM implementation, which included a mixture of 3D design for concept work and 2D for drafting and storing statutory approval documentation and Production Information and use of common data environment (CDE) to carry out electronic sharing of information and data.

As stated by all participants, it can be discovered that only one aspect of the BIM approach was adopted in this project which relates to the usage of a Common Data Environment (CDE) to share and exchange information amongst project teams.

So, the primary technological tool as part of the BIM Defined project's requirements that was used to manage the flow of information was the CDE in this project. It was believed by the majority of participants that the CDE provided many benefits to the information flow management because *"the system works very good"* (A1) in this project despite the challenges that it may have (which have been already discussed previously under 4.5 Theme 2 – Challenge of Effective Information Flow Management).

4.6.2 The Absence of BIM/Lean Adaption

In the previous section, one of the most beneficial factors of having a Defined BIM project (BIM Maturity Level 1/Stage 1) from the participant's point of view was highlighted, which was an online-based platform to share, exchange and manage information (CDE). However, even this factor was argued to be challenging at different points throughout the project due to not providing extensive beneficial features such as enabling a collaborative environment, which was explained more previously in 4.5.1.1 The Common Data Environment (CDE) under Section 4.5 Theme 2 – Challenge of Effective Information Flow Management. This is because of 'The Absence of BIM/Lean Adaption' due to the limited level of BIM implementation and not adapting any of the Lean principles in this project.

The project participants mentioned many times that there could have been many benefits provided in this project if BIM had been fully implemented to an advanced maturity level. Also, it was believed by most of the participants that many of the information flow management challenges (which were explored in the previous section) could have been improved if BIM had been fully implemented in this project because of the features that BIM provides. For example, as communication between team members is facilitated through BIM visualisation and collaborative platform features thus, a continuous flow of information would be enabled (Al Hattab & Hamzeh, 2013), which enhances collaborative working and, as a result overcoming challenges related to lack of collaborative environment (A1, A2). This is because the sharing and exchanging of information processes in a BIM collaborative platform is more coordinated as *"a lot of information is fully coordinated"*, and information is not being shared in isolation like in this project (A2).

Moreover, there have been other aspects of the BIM approach which would have improved this project in terms of overcoming the information flow management challenges, which are explored throughout the discussions under the following sections;

- Section 4.4 Theme 1 - Effective Exchange of Information
    - ➢ Section 4.4.1 Adaption of Digital Tools
- Section 4.5 Theme 2 – Challenge of Effective Information Flow Management
    - ➢ Section 4.5.1.1 The Common Data Environment (CDE)Section 4.5.2.2 – Non-BIM Information Flow Management Workflows

Therefore, due to the limited implementation of the BIM approach in this project, there were also limited benefits gained in terms of enabling effective information flow management through the BIM application. As discussed in previous sections, it was pointed out by some of the participants that in this project, the role of BIM concerning effective information flow management was very limited as the number of beneficial BIM features such as advanced 3D modelling, clash detection, visualisation, 4D scheduling, etc., which could have improved the information exchange and the management of information was not implemented in this project.

Furthermore, while discovering the interviewees' responses about the role of BIM/Lean in this project, it was interesting to notice that 'BIM implementation' and its benefits were repetitively acknowledged by all participants, but the 'Lean' approach and its principles and benefits were only mentioned once by A3. Hence, it was discovered that there was no implementation of Lean Construction and its principles in this project as stated by A3 that *"we are not achieving or doing any Lean"* in terms of its standardisation or its principles.

On the other hand, it can be found that the level of understanding of most of the project participants in Lean Construction was very low because when explicitly asked about Lean, there were statements like *"I'm not very familiar with it"* or *"not very knowledgeable about it"* (A1, A2). So, in the context of this research, due to the absence of Lean implementation, there were no benefits gained in enhancing information flow management through Lean application.

4.7 Chapter Summary

This chapter analysed and discussed the findings of Case Study A as a BIM Maturity Level 1/Stage 1 project which comprised interviews carried out with five key people who were involved in this project. Based on the interviewees' responses, three main themes emerged associated with sub-themes that were introduced and explained in this chapter. Each sub-theme was then explored further, along with discussing all factors influencing them that emerged from the findings.

Furthermore, the factors were explored and analysed through the lens of the review of the extant literature and the Case Study project. The findings firstly highlighted the importance of ‘Effective Exchange of Information’ and how this was accomplished in this project by ‘Adaption of Digital Tools’, which is managed through specific ‘Roles and Responsibilities’. Then, the ‘Challenges of Effective Information Flow Management’, which was categorised into three main factors of ‘Digital Technologies and Tools’, ‘Processes and Workflows’, and Socio-Organisational Barriers’, were explored and discussed further. Finally, ‘The Role of BIM/Lean in Relation to Effective Information Flow Management’ was discussed under two sub-themes of ‘The Common Data Environment (CDE)’ and ‘The Absence of BIM/Lean Adaption’.

The findings of this chapter represent the Defined project which is in line with BIM Maturity Level 1/Stage1. To achieve the aim and objectives of this research, it was essential to study projects with a more enhanced level of BIM Maturity Level as well. Therefore, the next chapter introduces Case Study B, which is a Managed project. The next chapter will discuss and analyse the findings of Case Study B.

Chapter 5. Case Study B – Data Analysis and Findings

5.1 Chapter Overview

The previous chapter introduced Case Study A, which demonstrated a Defined project (BIM Maturity Level 1/Stage 1) and explored the findings that have been discovered from the analysis of Case Study A data. This chapter will present Case Study B as a Managed project (BIM Maturity Level 2/Stage 2). The purpose of this chapter is to explore and analyse the findings from a qualitative study based on semi-structured interviews that were conducted for Case Study B.

In order to discuss the results of this case study, specific key themes, as shown in Figure 48, were identified to form the basis of the presentation and analysis of the data. This includes the exploration of identified themes and issues, which have been structured into a number of superordinate themes and associated subordinate themes. The relation to themes explored as part of the interview design will be noted in the sections of the themes where appropriate.

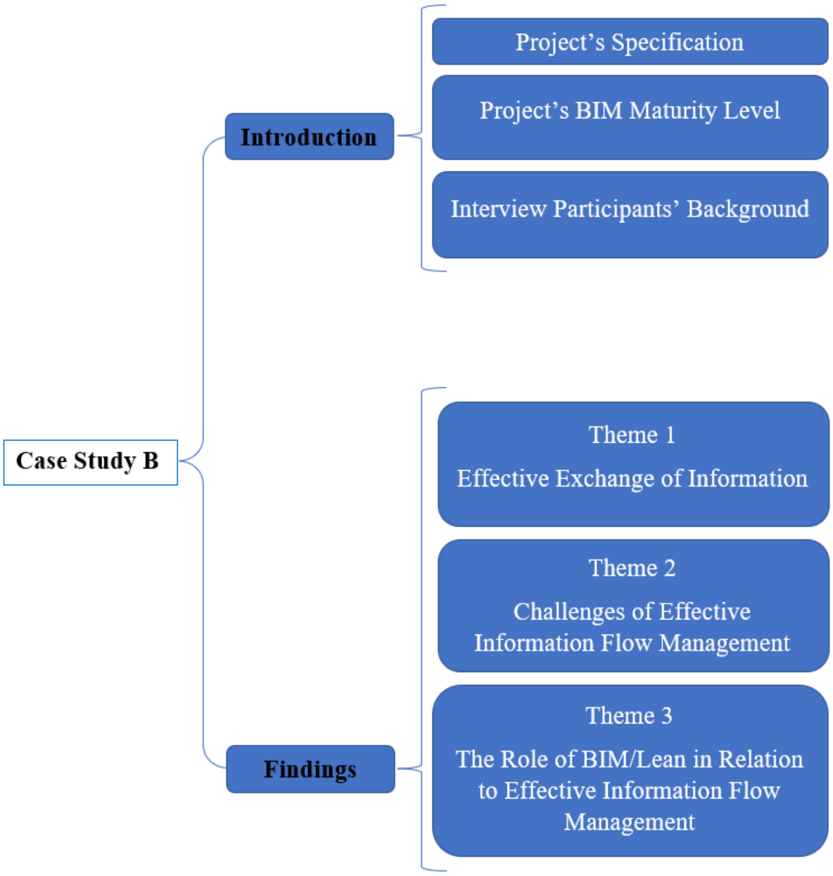

Figure 48 - Chapter 5 Overview

The early part of this chapter gives an introduction to the Case Study B project. The second covers the presentation of the findings which are categorised into three superordinate themes. The structure of this chapter is shown in Figure 48, which depicts that the project is first described in terms of its nature and type of project, size, location, etc. The level of BIM maturity in this project is then discussed, followed by an explanation of the interview participants' backgrounds. This will then be followed by a complete exploration and analysis of the findings through superordinate and associated subordinate themes that emerged from the data/interview verbatim transcript.

The chapter summary is presented at the end (5.7 Chapter Summary).

5.2 Introduction to Case Study B – Defined Project

5.2.1 Project's Specification

Case Study B is the new home for various departments within the Faculty of Arts and Humanities at one of the Universities in Manchester. As well as new teaching spaces, the building was envisaged to encourage strong public engagement through various activities provided at the ground floor level, such as:

- A new Manchester Poetry Library, in collaboration with the University Special Collections
- A public Café/Restaurant/Bar
- A public foyer providing space for public exhibitions curated by the Special Collections team
- A 250-seat studio theatre

The building was supposed to replace the 1970s Mable Tylecote facility on Oxford Road and was expected to form part of an estate-wide investment programme. The new 13,000sqm facility was designed to include a high-specification theatre at its core with state-of-the-art performance, recording and audio spaces.

The cost of the project was £43.5 million, and the duration of this project was set for 86 weeks, with the completion date scheduled for September 2020.

5.2.2 Project’s BIM Maturity Level

As an educational building project, Case Study B was chosen as the second case study for this research because of its level of BIM implementation in the project. Based on the client’s requirements, this case was a Managed project (BIM Maturity Level 2/Stage2).

This project’s BIM implementation requirements are based on the PAS 1192-2:2013 standards, internationally recognised as ISO 19650-1 and 2. The BIM requirements in this project involve developing building information in a fully collaborative 3D environment, with all project information and documentation being electronic and shared electronically between team members through a Common Data Environment (CDE).

The level of BIM implementation in this project is defined as BIM Level 2/Stage 2, which “requires all project and asset information, documentation and data to be electronic, which supports efficient delivery at the design and construction phases of the projects.” (GCS, 2016). Through BIM Level 2/Stage 2, collaborative working is enabled, which requires “an information exchange process that is specific to that project and coordinated between various systems and project participants.” (SFT, 2019).

As indicated by all of the interview participants, this project was a Managed project in which all of the BIM Level 2/Stage 2 requirements had been implemented. As part of these requirements to manage information, data, and models professionally, a Common Data Environment was used, which is an “agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process.” (ISO 19650-1).

The Common Data Environment (CDE) in this project is an “online cloud-based system” which enables information to be available and accessible to those who need it to undertake their task. As revealed by the interview participants, to comply with the projects’ needs and in line with the PAS 1192 and ISO 19650 series, this project comprises the managed 3D environment in which building information is developed in a collaborative 3D environment with all information and data attached to it. All the data and information are created in separate discipline-based models, and then assembled to form a federated model. The models will be shared between project members in a collaborative environment which CDE provides.

All BIM features that would enhance information flow management, such as collaboration and coordination, visualisation, clash detection and 4D scheduling, have been enabled in this project due to the project's BIM requirements.

The process of information management in this project is in line with the BIM Level 2/Stage 2 requirements set out in ISO 1965-1:2018. This process involves information requirements preparation, review of potential appointed parties in information management, establishing a detailed plan for delivery of information, and evaluation of information deliverables against the information requirements before their integration with operational systems. The overview of the concepts and principles of the information management process adopted in this project is shown in Figure 49.

As can be found in Figure 49 and according to the ISO 1965-1:2018, "the number and description of sub-divisions of asset lifecycle (solid rectangles), points of information exchange (solid circles) and decision points for delivery teams, interested parties or appointing party (diamonds)" within the information management process would indicate local practice, involved party and assigning party requirements, and any agreements or conditions precise to project delivery or asset management.

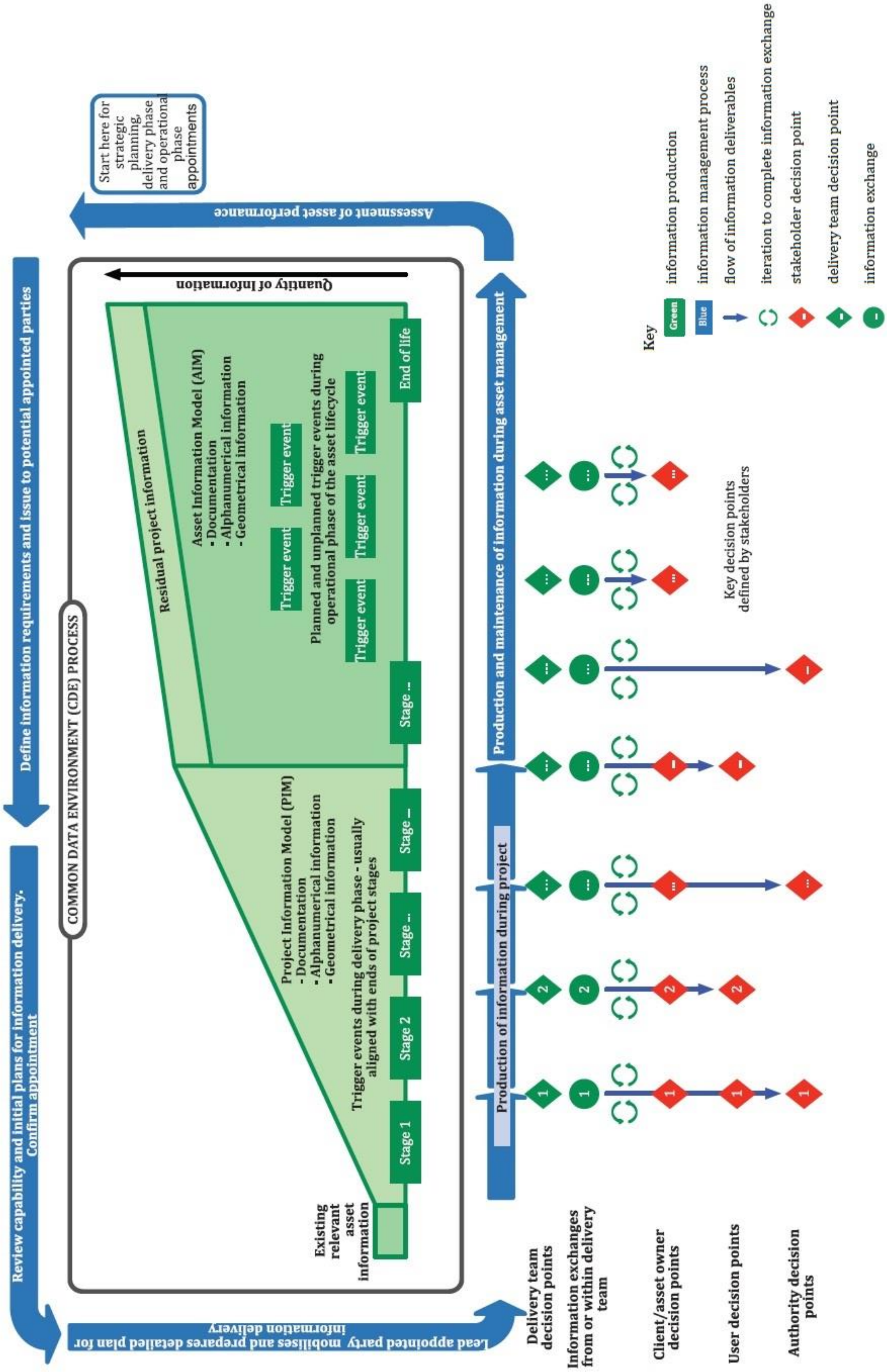

Figure 49 - Overview and illustration of the information management process

5.2.3 Interview Participants' Background

To meet the research aim and objectives, five (5) semi-structured interviews were conducted to obtain an in-depth exploration of Case Study B. The aim of the interviews is to study the factors that affect information flow management in regard to the project's BIM maturity level. To meet this aim, key project participants were identified in relation to their job role and their level of participation in the project because interviews should be designed in a way that people who are directly involved with the case study is targeted to allow the development of in-depth insight into the research aim and objectives (Knight & Ruddock, 2008). Similarly, according to Robson (2002), choosing the participants based on the depth of their knowledge and experience about the research phenomenon under investigation is an essential aspect of qualitative interviews.

Therefore, participants who are knowledgeable about the entire project scope, the project team and resources, the project schedule and the success or failure of any tasks throughout the project have been targeted in this research because they are involved in day to day using information management systems, so they are well informed about the challenges in terms of information flow management in the context of this research. These participants include:

- Project Manager,
- Design Manager,
- Lead Designer,
- Document Control Manager, and
- BIM Implementation Manager

The participants that are mentioned above have sufficient experience and background in the construction industry and in their specific field of expertise, which enables the researcher to first achieve useful insight in terms of how the information flow is managed and what challenges have been encountered in this project in the context of this chapter. The participants' background would also enable the researcher to understand how their experience influence and motivate the process of information flow management in relation to the project's BIM maturity levels which will be discussed further in the discussion chapter later on (Chapter 7. Cross-Case Analysis and Discussions).

Moreover, the interview participants were labelled B1, B2 … B5 in accordance with ethical considerations of the use of anonymous quotes. Table 14 below presents a summary of sampled participants of the semi-structured interviews in Case Study B (CSB), providing details of the interviewee's position, background, years of experience and level of understanding of BIM.

Table 14 - Summary of Interview Participants Information

Case Study B (CSB) Managed Project – BIM Maturity Level 2/Stage 2				
Participant Code	**Position**	**Field of Expertise and Background**	**Years of Experience**	**Level of Understanding of BIM (Low, Medium, High)**
B1	Project Manager	Project Management	23	Medium
B2	Design Manager	Architectural Engineering, Design management	6	Medium
B3	Lead Designer	Architectural Engineering	3	High
B4	Document Control Manager	Administration	20	High
B5	BIM Implementation Manager	Architectural Engineering, BIM Manager	13	High

5.3 Outline and Structure of Findings to be Discussed

5.3.1 Introduction to the Themes

The areas of analysis of CSB will now be outlined. As discussed in Chapter 3. Research Methodology, through thematic analysis, three superordinate themes and associated subordinate themes emerged from the data analysis, which will be discussed in this section. The first section of findings to explore, which refers to the first main theme, is the 'Effective Exchange of Information' (5.4 Theme 1 - Effective Exchange of Information). This section pertains to the importance of managing information flow effectively (Baldwin et al., 1999; Chatzipanagiotou, 2017; Detlor, 2010; Robertson, 2005), which will be discussed under two associated subordinate themes of 'Adaption of Digital Tools' and 'Roles and Responsibilities', as shown in Figure 50.

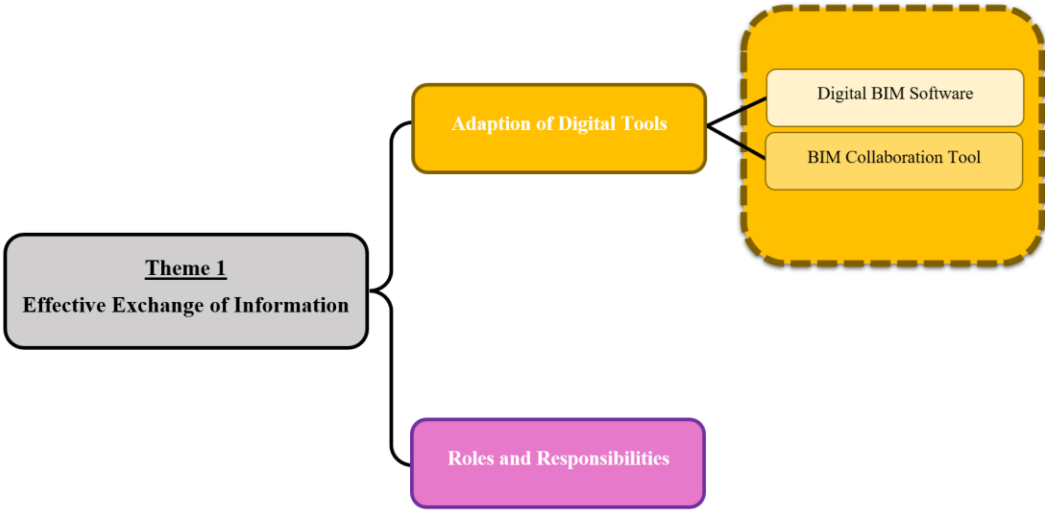

Figure 50 - Case Study B Theme 1 Outline

After discussing effective information flow management and understanding the project's practices to manage information flow, it is then essential to explore the challenges facing the project in terms of managing the flow of information, which creates the research's second superordinate theme. Therefore, the next section of findings to explore, which refers to the second superordinate theme, is the 'Challenges of Effective Information Flow Management' (section 5.5 Theme 2 – Challenge of Effective Information Flow Management).

This section which is the core research analysis of this case study, is divided into three subordinate themes. Under each subordinate theme, a number of factors/issues have emerged from the data related to that subordinate theme which will be explored and discussed accordingly. The overview of this section, which presents theme 2 is outlined in Figure 51. Finally, the role of BIM/Lean in enhancing information flow management will be explored under the third theme of 'The Role of BIM/Lean in Relation to Effective Information Flow Management'. Due to the nature of this project as a Defined project in which BIM implementation was limited (5.2.2 Project's BIM Maturity Level), it was found that there are no noticeable advantages and factors in this context to explore under this theme.

Therefore, this final theme can be considered the shortest theme amongst all themes in this Case Study, which will be discussed under two sub-themes of 'The Common Data Environment (CDE)' and 'The Absence of BIM/Lean Adaption' as shown in Figure 52.

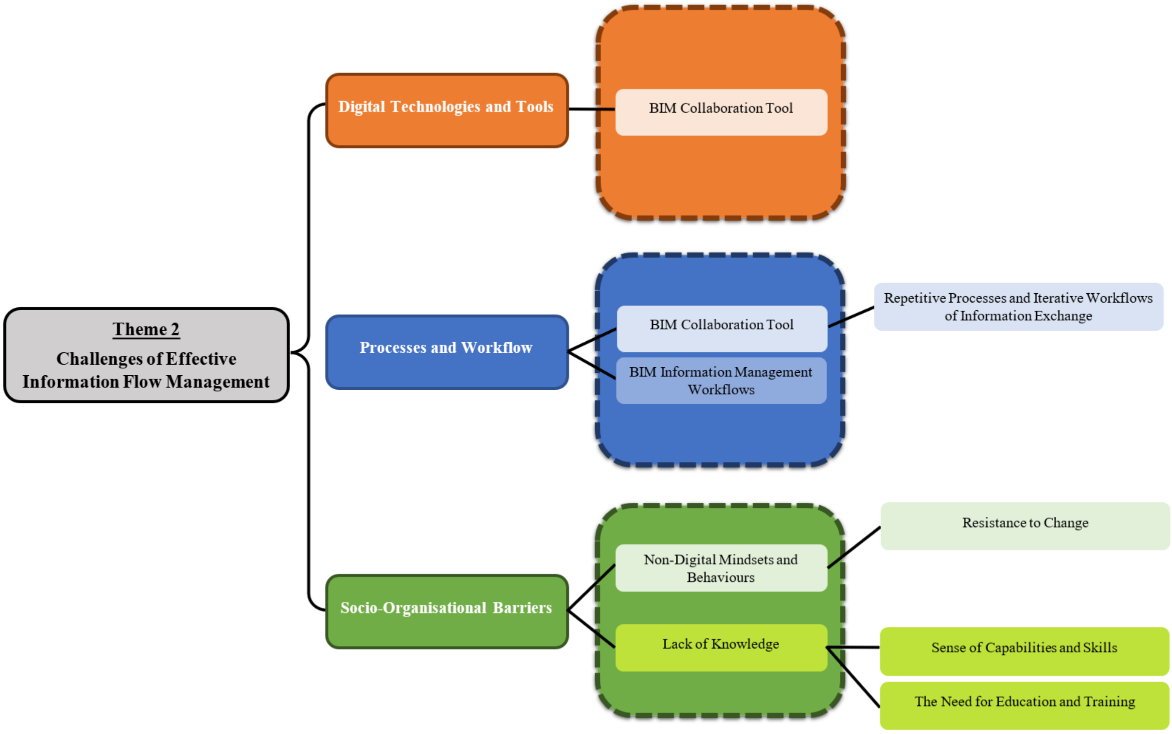

Figure 51 - Case Study B Theme 2 Outline

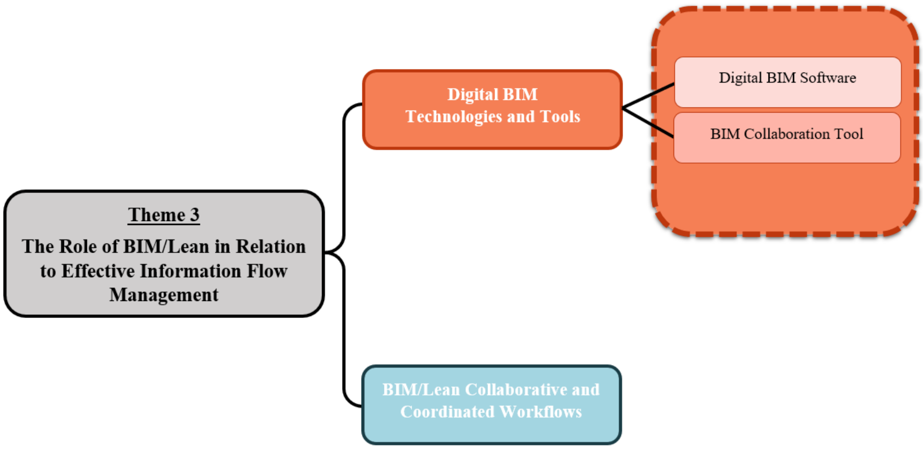

Figure 52 - Case Study B Theme 3 Outline

5.4 Theme 1 - Effective Exchange of Information

Due to the increased level of information sharing and exchange, it is widely believed that effective information flow management is critically important (Baldwin et al., 1999; Chatzipanagiotou, 2017; Detlor, 2010; Kania et al., 2021; Robertson, 2005). All of the interviewees also mentioned that effective information flow management is essential to project's success. Considering that Case Study B was a BIM Level 2/Stage 2 project, the level of information being produced and shared between project members increased massively throughout the project phases due to the required BIM information management process, as justified by the interviewees. Therefore, it can be found that the project relies heavily on information, and the effective management of this information is crucial for project success.

Similarly, it was stated by Kania et al. (2021) that one of the main contributing factors to achieving project goals is effective control of information flow. It was identified from the majority of interviewees' perspectives that the quality of information and the overall project's performance and productivity could be enhanced if information flow is managed effectively through BIM implementation. This is because "BIM provides opportunities to support collaboration" (El Ammari & Hammad, 2019), and collaboration is one of the essential elements of BIM, which provides effective and efficient information management within a digital model, establishing a reliable foundation for decisions during the building lifecycle (Bradley et al., 2016 Cited in Machado et al., 2020).

To produce and exchange high-quality information and consequently improve the overall project performance and productivity, it is essential to manage information flow effectively (Zeng, Lou, & Tam, 2007). Therefore, in the context of this case study project, it is crucial to understand the approaches to managing the information flow to identify the opportunities and challenges of the information flow management in relation to the research aim and objectives.

So, based on the main superordinate themes and the interviewees' responses, two subordinate themes merged under this theme. These subordinate themes aim to explore how and by whom the information flow is effectively managed in this project. Firstly, as this case study is a Managed project in which there are technological solutions implemented to manage and exchange information effectively, it is important to discover the digital tools and technologies that have been used in this project based on the interviewee's justifications. So, this will be explored under the 'Adaption of Digital Tools' subordinate theme. Secondly, according to the project's specifications and interviewees' responses, it was found that there are particular responsibilities under specific roles for the information flow management system and the digital tools that have been implemented in this project which enable effective and efficient information flow management throughout the project. So, in this section, this will be discussed under the second subordinate theme of 'Roles and Responsibilities'.

5.4.1 Adaption of Digital Tools

Based on the interviewees' responses and the nature of this project, the adaption of digital tools in this project is considered under two aspects. First is the Digital BIM Software that was used to create and produce the information consisting of the model information such as 3D models, 4D scheduling, clash detection data, etc. Secondly, the BIM collaboration tool was used to share, exchange and manage the created and existing information. These two aspects in relation to the ‘Adaption of Digital Tools ‘subordinate theme will be discussed in this section.

5.4.1.1 Digital BIM Software

As this project is a managed project, there are various digital software and tools adapted to comply with the BIM level 2/Stage 2 requirements. As stated by Ingram (2020), choosing the right software and tools are crucial to ensure the achievement of BIM benefits. This is because all the project’s information is created and shared using these software and tools.

There are many digital BIM software and systems available, but it is important that all projects’ parties use the same software and systems to ensure that information flow management is facilitated. In this project, as explained by B2, it was assured *“from the start of the project”* that all project stakeholders *“are using the same software and the same version”* of any software and tools that have been chosen.

It was revealed by all of the participants that Autodesk Revit was the main and most utilised BIM software used by different disciplines and stakeholders in this project. This software and its various application and features are design and documentation solutions which support all phases and disciplines involved in a project (Autodesk, 2021). As mentioned by the majority of participants, the digital BIM software was used to create and produce information for different disciplines such as architectural design, MEP, structural engineering and construction, and this information can be viewed in various formats of 2D drawings, 3D models, 4D scheduling, 5D costing, etc. This produced information was shared and exchanged and thus managed using a BIM collaboration tool which enabled easy accessibility of information by all project parties.

5.4.1.2 BIM Collaboration Tool

It was explained by all the interviewees that to manage the information flow, a digital system as a BIM collaboration tool is being used, which enabled the sharing and exchanging information in an effective manner. It was stated by B1 that *“we have a central area called Viewpoint, where all information is uploaded in there”*. As reported by all interviewees, this system was an online cloud-based platform that allowed the flow of information between all project members. As this case study has adapted BIM Level 2/Stage 2, hence it was required by the client that there should be a Common Data Environment (CDE) to share and manage the information.

According to ISO 19650, the Common Data Environment (CDE) and its workflow "is used to support collaborative production, management, sharing and exchange of all information" throughout the project, and it enables the "development of a federated information model", which comprises "information models from different lead appointed parties, delivery teams or task teams". In addition to the information models, CDE can hold information related to all aspects of the project, including documents, contracts, reports, meeting minutes, bids, etc., as revealed by the interview participants.

Therefore, in this project as a Managed project, the CDE plays a critical role in achieving an integrated information management system by providing instant insights into the project performance (Ozkan & Seyis, 2021). So, according to all the interview participants, the mentioned online cloud-based system worked as the CDE in this project, which is considered the BIM Collaboration Tool in this context. As stated by B2 that *"All information is produced on the Common Data Environment"*, which allows information management processes to be done in accordance with the PAS 1192-2:2013 and ISO 19650-1 and 2 standards.

Most interviewees believed that the use of this system as a BIM collaboration tool is straightforward and *"it is easy to track information and find out who has uploaded the information"* (B1) because when information is shared and goes onto the system, *"all parties get notified of information"* (B3). Despite the positive views on the system as a user-friendly BIM collaborative tool, several statements argued that there are some limitations as well. For instance, it was argued by B2 that *"getting the file naming right and not making errors on the system"* is one of the limitations of this BIM collaboration tool. B2 explained that if someone *"names a drawing wrong before it gets to the right person, then it is rejected from the system straightaway..."* and therefore, inconsistency in the document and information would create delays and cause issues.

Similarly, it was stated by B1 that as the project relies on people to upload information, it is essential to ensure that information is being uploaded *"with the correct naming convention"*. Otherwise, systematic issues will arise, which would negatively affect the effective exchange of information. As mentioned by interviewees, it was found that some of these issues are related to both the system and the people who use the system. Therefore, these issues will be discussed in detail in section 5.5 Theme 2 – Challenge of Effective Information Flow Management.

Moreover, since all the information that was used in this project was stored on the CDE (B3), the project benefited from many advantages that the usage of this system provided (B1). As agreed by the majority of participants, CDE provides a BIM collaboration tool in which all information is analysed in a collaborative environment where for example, clash detection was carried out and all relevant project teams could easily have access to the analysed information and could accordingly make any necessary changes and corrections to the information.

Therefore, the number of inaccurate or missing information was eliminated in this project as there have already been *"picked up on the right stage and at the right time"* due to the enabled BIM collaboration tool and the existing digital BIM software (B1). So, the shared and exchanged information within the CDE would result in coordinated information, reducing delays, time, quality losses and cost overruns (Ozkan & Seyis, 2021).

B2 pointed out that this BIM collaboration tool is very accessible to everyone who is already in the project and who may join later on. This is in contrast to using emails as an information exchange platform (like in non-BIM projects) because people may not have access to their old emails, but with this system, people would always have access to it as the information is *"shared on the common platform that everyone can access at any point"* (B2).

Also, working with this system in a BIM environment *"encourages collaboration"* and collaborative working between team members (B1) as the system itself was recognised to be a *"collaboration tool"* (B4). It was argued by B1 that if this project was not a BIM Level 2/Stage 2 project, there would have been fewer benefits to the project in terms of the usage of CDE and the information flow management system. This is because although this system may be used in BIM Level 1/Stage 1 projects as well, it cannot be used effectively due to the lack of collaborative approaches that would support the efficient coordination between participants to enable utilising the system and getting the benefits from it (B1).

It can be found that the project's benefits in terms of the digital tools adaption were because of BIM implementation as it enforces collaboration between all project parties (Ingram, 2020). So, it can be found that effective information flow management can be achieved through the use of CDE as a BIM collaboration tool in this project. Nonetheless, there is a management side to control and maintain the system's information flow process and enable effective exchange of information. As some of the participants mentioned, the management side of this information flow system is a crucial part of the BIM collaboration tool to work effectively. Therefore, the management side with its role and responsibilities will be discussed in the next subordinate theme regarding the effective exchange of information.

5.4.2 Roles and Responsibilities

Based on the interviewees' responses, it was found that to ensure the information is exchanged and managed effectively through the Digital BIM Software and the BIM Collaboration Tool, there were two managements side responsible for controlling and managing the whole process. One was responsible for the information being produced and shared within the digital BIM software, whereas the other management side was only responsible for the information that was being shared and exchanged through the BIM collaboration tool, which was the CDE.

So, to manage the information within the digital BIM software, an Information Manager plays an important role. According to B2, the information manager manages the information and data produced within the model and checks the development of the model. So, the information manager "is in charge of integrating and coordinating information within the information model" (Scheffer, Mattern, & König, 2018, p.248).

Although the design manager is responsible for managing the design as stated by B2, it is important to have a specialist who can evaluate and review the 3D model in terms of the data within the model to *"properly assess whether all the designers are profitably build a model in terms of the information"*. It was explained by B3 that when there is a clash detection process, the information manager *"is responsible for making sure that the respective parties and the members of the design team close that clashes"* so that the shared and exchanged information is reliable and accurate and effective exchange of information within the digital BIM software and the BIM collaboration tool is enabled. So, the Information Manager is responsible for supporting reliable information exchange and maintaining and receiving information in the information model (Scheffer, Mattern, & König, 2018).

Also, it was claimed by B2 that the models and the information built into the models need to be reviewed and checked by the information manager. This is to ensure that all the designers have accurate information and have produced expected levels of information into the model in accordance with the BIM Level 2/Stage 2 requirements.

The information produced and shared within the digital BIM software, such as Revit, is managed by the information manager. But the flow of information to and from the CDE as the BIM collaboration tool is managed by a Document Control Manager. So, according to the interviewees, the document control manager is responsible for ensuring that the BIM collaboration tool works properly and the process of flowing information within the CDE is managed effectively. As stated by B4, the document control manager manages how the information is shared and whether they are in accordance with the CDE BIM Level 2/Stage 2 requirements. As part of the CDE requirements in ISO 19650-2:2018, there should be a status code associated with each information container.

Therefore, to comply with this requirement, a status coding system was adapted so that all the information being shared within the CDE had a specific status and file naming revision codes. For example, there are status codes of S1, S2, S3, etc, where S1 means Suitable for Coordination, S2 means Suitable for Information, etc. (B1, B4). Also, other status filing names indicate the status and work stage of that specific information. As explained by B4, for example, when an information file has a status of AC, it indicates that information is accepted for construction without any comments, and VC is accepted for construction with comments. These file naming and status coding systems *"have come out of PAS 1192"* originally, and the document control manager is responsible for ensuring that everybody in the project is using this system accurately so that *"the right information goes to the right place"* through the managed information workflows (B4). So, it can be found that the roles and responsibilities of both the information manager and the document control manager are crucial to managing the digital BIM software and the BIM collaboration tool, which ultimately results in the effective exchange of information.

5.5 Theme 2 – Challenge of Effective Information Flow Management

There may be some challenges concerning information flow management in any project. As the level of information produced and exchanged and the amount of information is different in projects, the information flow management challenges would be varied as well.

As this project was a Managed project, it was assumed by the researcher that there should not be any challenges with the information flow management. This is because, according to the literature, inadequate information flows between project parties that are due to the jumbled and overlapped flows of information are the leading cause of information flow challenges that occur in traditional projects where BIM is not fully implemented up to Level 2/Stage 2 (Rathnasinghe et al., 2020; Park & Lee, 2017; Zoubeir et al., 2014; Al Hattab & Hamzeh, 2013). Therefore, as this project was a BIM Level 2/Stage 2 project, it was expected that the flow of information would be managed effectively and without any issues. However, when the researcher raised the question and discussion around the information flow management challenges, most participants claimed that there were some issues regarding this matter. Issues are mainly concerning the BIM collaboration tool and how people are using this tool.

The majority of participants held the view that the challenges of managing information flow are mainly related to the BIM collaboration tool and how it was used by the project teams. It was also reported by the interviewees that the workflows and processes required to manage the information flow were time-consuming at some stages, which resulted in reworks and delays in the project.

Moreover, it was believed by all the interviewees that one of the main challenges associated with information flow management is the socio-organisational barrier. Based on the interviewees' responses, many of the issues concerning information flow management are directly or indirectly related to people who are involved in the project. This is because when people do not follow the process and workflows within the project and do not use the required technology, the information flow cannot be managed effectively.

So, the researcher further explored the challenges within information flow management. Based on the research findings and the interviewees' responses, three subordinate themes emerged under the Challenge of Effective Information Flow Management theme in this section. The subordinate themes that emerged from the findings concerning the challenges of effective information flow management include the 'Digital Technologies and Tools', 'Processes and Workflows', and 'Socio-Organisational Barriers'. So, this section presents the findings of 'Theme 2 - Challenge of Effective Information Flow Management' that emerged from the interviews under the following subordinate themes.

5.5.1 Digital Technologies and Tools

In this project, as part of BIM Level 2/Stage 2 requirements, there were various digital technologies and tools used to enable sharing and exchange of information between project teams. Based on the interviewees' responses and the nature of this project as a BIM Level 2/Stage 2 project, the digital technologies and tools implemented in the project consist of

Digital BIM Software and the BIM Collaboration Tool. Digital BIM software such as Revit was used to create and produce information containing model information, such as 3D models. It was found from the interview participants that the project does not face any challenges in terms of information flow management related to the digital BIM software. Even though it was argued by B2 that sometimes the technology is a degree of a challenge because *"managing a big volume of information is a challenge"*, B2 clarified that the design management team provided some solutions at the beginning of the project to resolve this issue.

It was explained by B2 that the development of the 3D models and coordinating the models would cause some issues in terms of information management because as the project evolves the amount of information within the models increase, and the models become larger and harder to operate and manage. However, this issue was tackled by splitting the models into different zones to reduce the file size when sharing and coordinating the models so that the information flow would be managed efficiently (B2).

So, it was found that the project team were not facing any considerable issues in terms of the digital BIM software, and they were able to overcome the minor challenges caused by using the digital BIM software regarding information flow management. However, there were arguments around the BIM Collaboration Tool which were used as a CDE platform to share, exchange and manage the information. Therefore, based on the interviewees' responses, one main factor elicited in regard to the 'Digital Technologies and Tools' subordinate theme, which was found to cause challenges within the information flow management in this project. This factor which is the 'BIM Collaboration Tool' is discussed in this section.

5.5.1.1 BIM Collaboration Tool

In this project, BIM Collaboration Tool as a CDE was used to manage the flow of information between project teams. Participants believed that some of the challenges within the information flow management are due to the factors concerning the BIM collaboration tool. The software that was used to work as the BIM collaboration tool, which was called Viewpoint, was considered to be challenging due to some barriers and limitations that it had.

When the technological aspects of the information flow management challenges are concerned, one of the factors that can impact the effectiveness of exchanging information can be considered to be the software itself. Choosing the right software as the BIM collaboration tool is essential to manage the information flow effectively. The limitations of the software could cause challenges in managing the information flow and cause delays in the whole project's process. Even though the majority of interviewees believed that the software choice in this project was good, and the project team became familiar with the BIM collaboration tool, but there were still some limitations with the software itself. One of the limitations of the BIM collaboration tool software was “the ability to download information” due to the internet connection (B2).

It is widely believed that ‘Internet’ provides many benefits to projects in terms of supporting the exchange and sharing of information, aiding planning information, coordination, visualisation, and communication (Zeng, Lou, & Tam, 2007; Yu, Gao, & Ren, 2016) and enabling the collaborative working and real-time management among the project teams (Zeng & Wang, 2020). However, despite these benefits, it was argued by B2 that the internet could be viewed as a limitation in the context of the information flow because if the internet connection fails, then it would be challenging to download information and access the information. This is because the BIM collaboration tool software relies on an internet connection and project teams also rely on the internet to be able to access the information within the BIM collaboration tool.

So, lack of internet connection would cause unnecessary delays and rework as people have to either wait for the internet to work again or share information using emails. Sharing information via email would cause additional issues because when the internet connection is back, project teams have to upload all the information that was exchanged offline via email back to the software to be able to manage the information flow in the BIM collaboration tool and that cause more delays and reworks. After all, late information exchange would result in extreme delays and issues downstream in the design phase and subsequently in construction (Al Hattab & Hamzeh, 2013).

Therefore, it can be found that the internet as a communication platform that facilitates an effective information flow throughout the project lifecycle (Chen et al., 2018; Zeng, Lou, & Tam, 2007) could also become a barrier to project if it fails to connect and if people cannot have access to it.

Moreover, in addition to the limitation of the software, It was claimed by B1 that *“how the information is stored on viewpoint could be made a lot simpler”* because *“it does take time to find a drawing”* at some points and due to the increased level of information and the enormous amount of drawings produced throughout the project, it can happen that there would be drawings in the system that *“you may never knew they existed”*. B3 agreed that the process of information exchange through the BIM collaboration tool is time-consuming. However, B3 disagreed with B1's previous statement, which argued that the missing information was due to issues with the system itself. It was revealed by B3 that there was some information shared and exchanged offline and not through the BIM collaboration tool. Even though, as part of the BIM Level 2/Stage 2 requirements, all information had to be shared through the BIM collaboration tool, it was interesting to know that there was still some information shared between project teams externally, which caused some challenges in terms of the information flow management.

According to B3, the challenge was that the information was not 100% shared through the formal process via the BIM collaboration tool because *"a lot of offline informal sharing of information"* was taking place in the project. Likewise, B2 held the same view that one of the challenges of information flow management is making sure that people share information on the viewpoint as the BIM collaboration tool and not *"throwing information via email"*. This issue was explored further to understand why despite the project's requirement, some information was still exchanged externally and not through the BIM collaboration tool.

So, it was found that there were two main reasons why this was happening. The first reason was related to the people's behaviours and the fact that it was still preferred to share information via email as it seemed to be faster than going through all the formal BIM collaboration tool processes. It was explained by B3 that there was a certain date by which the designers were required to upload the 3D models onto the BIM collaboration tool for clash detection workshops and review workshops. To meet this deadline, sometimes the models were shared between the project teams via emails which was faster than the formal sharing of information through the BIM collaboration tool. This was because, for example, the designers worked on something in particular that the structural engineers needed to have in order for them to finalise their elements and be able to upload their model on time (B3).

So, to meet specific deadlines and to exchange information faster, project teams preferred to share models and information via emails or outside the BIM collaboration tool. Another reason behind this issue, which also explains the people's preference of not using the BIM collaboration tool at all times, is the set of requirements and restricted workflows of the system. It was argued by B5 that due to these workflows as part of the BIM Level 2 /Stage 2 requirements, *"the technology is just bringing in additional work"* and that is a challenge in terms of information flow management.

Based on the requirements and the regulations set out in PAS 1192 and ISO 19650 in regard to the information management process, the lead designer manages the design, including the development and approvals of all information, and the lead designer is responsible for signing and approving the documentation for detail design coordination, and this has to be done prior to passing the information onto the BIM collaboration tool. In accordance with this requirement, it was mentioned by a number of interviewees that as part of the PAS 1192 and ISO 19650 requirements, all information *"has to go through the lead designer first"* (B4) and *"the lead designer has to check all the information before it comes to the design manager"* (B5). However, this caused some issues regarding the information flow management due to the delays that happened as part of this process.

As explained by B5, although this process was working, and the lead designer team were checking all the information but *"they are doing that in a manual process"*, which means that the team were printing out the drawings and making the comments on the printed drawings. Therefore, the comments and new information on the drawings were not being coordinated through the system. It was argued by B5 that even though the updated information and new comments had to go through the system and the team were required to do this, but there was *"some sort of resistance"* to do this. This caused some issues in the project in terms of managing the flow of information because there were some information and updated comments missing from the system, and the team struggled to communicate in regard to those missing information (B4, B5).

It was clarified that one of the factors causing issues in regard to the information-checking process by the lead designer is the lack of resources. As the lead designer and its team are *"the main people to coordinate the project"*, the information has to be checked by them (B4), but the problem is that there are not enough resources and manpower to aid this (B4, B5). It was argued by B4 that *"we do not have the manpower"* to support this as the number of information and drawings that have to be checked by the lead designer and its team is a lot more than what they usually deal with in a non-BIM project. So, the necessary process of checking information by the lead designer takes time and causes delays in the project because it happens that there would be *"some information being held by the process"* because the lead designer team have not processed the information through the system yet (B5).

Even though it was clarified that the project faces a lack of resources in the lead designer team, and that was one of the reasons why there were some delays in producing and sharing the information, but it seemed that even resolving this issue is a challenge in itself. Because it was revealed by B5 that *"getting the lead designer to allocate the correct amount of resources is a challenge"*. This could be due to the fact that project managers prefer not to employ more people to manage the cost of the project, as also stated by B4 that *"to employ more people who is going to pay for them"* and therefore, the lead designer has to work with the allocated manpower that was already employed.

When these challenges and interviewees' arguments were further explored by the researcher, it was found that the causes of these issues are related to different factors, such as the lack of resources, socio-organisational barriers and factors related to the process and workflows. The first factor is already discussed in this section, but the other two factors will be discussed and explored in detail in the later sections as they are less related to the BIM collaboration Tool factor under the 'Digital Technologies and Tools' subordinate theme. It is essential to understand the other factors affecting the information flow management, i.e. processes and workflows and socio-organisational barriers, because managing the information flow is not only limited to the information itself but also focuses on addressing the digital technologies and tools that are being used, the processes and workflows of sharing the information, and people who exchange the information and use the technology and process (Chatzipanagiotou, 2017; Robertson, 2005).

5.5.2 Processes and Workflows

According to the research findings and based on the previous discussion about the first subordinate theme of 'Digital Technologies and Tools', it was revealed that one of the challenges of effective information flow management is related to 'Process and Workflows' in the project. Therefore, the 'Process and Workflows' in this project were considered to be the second subordinate theme of this case study which will be explored in detail in this section. From the interview participants' opinions, challenges within the processes and workflows of information flow management resulted in delays and rework in the projects. So, based on the responses received from the interviewees, there are two main factors elicited regarding the challenges of effective information flow management that are related to the 'Processes and Workflows' subordinate theme. These factors which will be discussed in this section are as follows:

- BIM Collaboration Tool
- BIM Information Management Workflows

5.5.2.1 BIM Collaboration Tool

Based on the interviewees' responses, it was found that the first contributor factor of ineffective information flow management that is related to the 'Process and Workflows' was the 'BIM Collaboration Tool' used in this project. Even though initially most participants held the view that the process of sharing information is working reasonably well, during the interviews' discussions, some opposite expressions were discovered when this matter was further explored.

Participants believed that the process and workflows of information flow within the BIM collaboration tool had some challenges due to the iterative loops of information exchange that caused delays and reworks in the project. It was claimed by B2 that some of the project members did not believe that the BIM collaboration tool is *"that user friendly"* as *"it is quite intensive in terms of additional time you spent all the time"* to go through the process of information exchange and information approval due to the specific BIM requirement for information flow management process.

Other interviewees had similar opinions regarding the process and workflows within the BIM collaboration tool being complicated and time-consuming due to some repetitive process and iterative workflow of information exchange that project members had to go through most of the time.

Repetitive Processes and Iterative Workflows of Information Exchange

In this project, all project members were required to follow specific processes when sharing information through the BIM collaboration tool. For the process to work effectively, certain regulations and requirements had to be followed by the project teams, which were constructed based on the BIM Level 2/Stage 2 information flow management requirements set out in PAS 1192 and ISO 19650.

So, as stated by all interviewees, there is a protocol for file naming in this project, meaning that all the information that goes onto the BIM collaboration tool must be labelled and coded in accordance with its version, status and the work stage. It was explained by B4 that there are S1, S2, S3, and S4 workflows, and each of these status codes has a different description. For example, S1 describes that information is suitable for coordination, and S4 means that information is suitable for stage approval (B4) (ISO 19650-2, 2018).

Also, there are other naming conventions as well to show whether that specific shared information has been accepted and signed off with comments or without comments and etc. As an example, AC stands for accepted for construction without any comments, and VC is accepted for construction with comments (B4).

Additionally, as *"everything has to be status driven"* in the project (B4), it was believed by B1 that managing the flow of information relies on the process. This is because *"to get a drawing from information status through to the construction status, you are relying on certain approvals being carried out"* to ensure that the correct file naming is used and the information is passed through the correct workflow, which would then allow the information to be passed onto the other project members to be managed (B1).

In terms of the importance of information workflows, it was mentioned by B4 and B5 that there were different workflows in the BIM collaboration tool to share and exchange information. For example, some workflows were for coordination information, some were for construction information and construction records (B5). So, all information cannot go into one workflow because there were separate workflows with specific statuses and filing names related to each workflow (B4, B5). So, it is vital that project members exchange information through the right workflows and with the correct naming convention, as *"only certain personnel allowed to see"* each workflow based on their discipline (B4).

Even though these file naming systems and different workflows for working progress within the BIM collaboration tool may seem to be beneficial to the process of information flow management, but all participants viewed this as one of the main challenging factors of managing the information flow concerning the processes and workflows. As stated by B1 and B2, the file naming system was complicated and was causing delays in the process of information flow management. This is because, as explained by B2, *"if people name a drawing wrong" then it will get "rejected from the system straightaway"* and that causes delays in terms of the information getting shared between the project teams and being processed.

As revealed by the participants, when a piece of information gets rejected in the system, it has to be uploaded again with the corrected naming convention, and this process of reuploading the information is time-consuming and causes delays and reworks. It was argued by B5 that this issue has resulted in value loss throughout the process of information flow management due to the unnecessary repetitive processes and iterative workflows of information exchange that occur as a result of file naming errors in the BIM collaboration tool.

It was clarified by B5 that *"if someone uploads a piece of information and that is named the wrong way then we have to refuse it"* thus, that causes rework because someone needs to re-upload that information. This process of reuploading that information with the corrected naming convention *"may take one or two days, and that will cause delays"* because other project teams are waiting for that information to get through the process, and the information is not accessible and usable for them *"until it hits a point on the workflow that can be visible and usable to everyone"* after it is uploaded correctly (B5).

Additionally, as mentioned by the interviewees, as part of the BIM Level 2/Stage 2 process requirements, all information had to go through the lead designer first to be checked and approved before it could be shared between other project teams. Figure 53 shows the four main phases of the PAS 1192 illustrated CDE (BIM collaboration tool in this project), which demonstrates that all the information has to go to the lead designer first to be checked, reviewed and approved and then it can be shared with other project teams.

This process of checking information by the lead designer team was taking time because sometimes they could get *"200 drawings to check"* despite the fact that *"they don't have the resources for that"*, which resulted in delays in delivering the comments and sharing information (B5). As explained by B5, it happened that other project teams *"needed a piece of drawing to start building on site"*, but that drawing was still not checked and approved by the lead designer to be shared and made available in the BIM collaboration tool. So, *"it means that some information is being held by the process because it's not a direct flow"* (B5), and information had to be checked and approved by the lead designer first, which would ultimately cause delays in the process of sharing information and thus managing information flow.

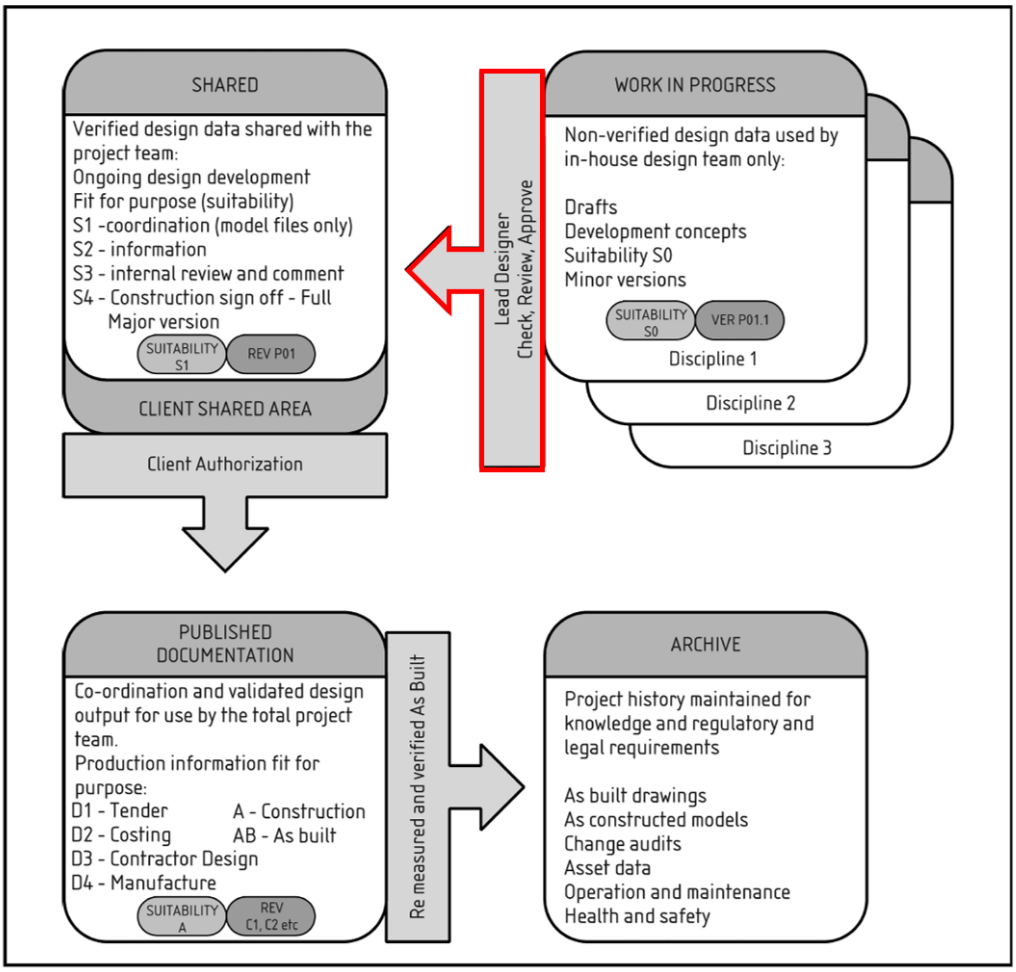

Figure 53 - Outline of the CDE phases

So, it was agreed by all interviewees that the process and workflows within the BIM collaboration tool, specifically concerning the file naming protocols and the required process and workflows of information exchange, caused challenges in terms of information flow management. Some of the participants believed that these challenges are caused as a result of complicated BIM processes and workflows to manage information flow which were required as part of BIM Level 2/Stage 2 project's requirements.

5.5.2.2 BIM Information Management Workflows

According to the interviewees, despite all the benefits that BIM implementation had in this project, restricted processes and workflows of information flow process caused some challenges in terms of managing the information flow. As indicated, a number of times, the BIM Level 2/Stage 2 processes and workflows of information management were complicated and caused delays, errors, and rework in the project.

It was argued by B2 that by using the BIM information management workflows within the BIM collaboration tool to exchange information, *"you lose time on very basic things"* because *"you end up spending time with these errors, you're going over reviewing and rejecting information, having delays, designers spending time re-uploading information correctly, doing things twice…"*. It was believed that the file naming protocols that came from the PAS 1192 (2007) and ISO 19650 (2018) as part of the BIM Level 2/Stage 2 requirements made the project teams do extra unnecessary work, which required *"extra time doing something that is almost administrative"* (B2).

So, B2 argued that this administrative work was bringing additional unnecessary work to the designers, and instead of them being worried about the design-related issues, they had to be concerned and spend extra time on work that was not directly related to their profession. However, since BIM is a complex process, it requires coordinated efforts between all project teams to be successfully completed (Manoj et al., 2021). Similarly, it was argued by B4 and B5 that all project members had to follow these rules and regulations as they were part of the PAS 1192 and project teams *"should have already been using them"*.

In addition, it was argued by B5 that *"we had some sort of resistance"* to follow the BIM required processes and workflows within the BIM collaboration tool because people prefer to use the old system of sharing information without any specific rules and file naming protocols. This could be due to the difficulty of using time-consuming processes and workflows within the BIM collaboration tool discussed before. However, it was believed by almost all interviewees that many of the issues related to the processes and workflows within the BIM collaboration tool were related to people. This is because *"you have to reply on people"* to make the process work and follow the rules (B1).

Similarly, it was argued by B2 that although the BIM collaboration tool has limitations in terms of information flow management but some of the *"limitation of that is getting file naming right and not making errors on the system"*, which means that people are responsible for ensuring that they follow the correct naming convention and not make errors to cause issues. So, it is crucial that people have the right knowledge and the right digital mindset and behaviours to enable the effective exchange of information. Likewise, B5 believed that the issue with the file naming protocols and the BIM collaboration tool processes and workflows is people's understanding of the process and thus following it. Because sometimes, people may not be aware of BIM standards from PAS 1192 and *"they don't have been working towards that* *standard, so they tend to upload information in the wrong way"*, and that causes issues. Moreover, it was argued by B5 that the challenges of information flow management in terms of the processes and workflows within the BIM collaboration tool *"it's not down to the process, it's down to people"* because people need to understand *"what they need to do"*. Furthermore, as agreed by most of the participants, even if you have the technology and process in place, but people do not have the right knowledge and mindsets to use the technology and follow the processes, then challenges would be created.

Therefore, one of the main factors of ineffective information flow management is related to 'Socio-Organisational Barriers' concerning people. So, people as a socio-organisational barrier can be found as the main root cause of many of the information flow management challenges.

5.5.3 Socio-Organisational Barriers

According to the literature, it is widely believed that people as a socio-organisational factor play an important role in terms of the project success (Chatzipanagiotou, 2017; Murthy & Screenvias, 2014; Hickethier et al., 2013; Phelps, 2012; Robertson, 2005). So, based on findings from the literature, the researcher initially believed that people could be one of the beneficial factors in this project to enable effective information flow management. However, in contrast to the researcher's initial assumptions, interesting findings merged during the interviews.

One of the key questions of the interview was 'what are the main challenges of information flow management and the answers were directly or indirectly related to people. So, based on the interviewees' responses, 'people' were considered as one of the most significant factors causing challenges within the information flow management and considered as 'Socio-Organisational Barriers' to effective information exchange.

As mentioned by most of the interviewees, the process and technology are in place in this project, but *"you have to rely on people to do that process"* (B1) and to ensure that people share information at the right time and to the right people using the correct processes and workflows. Because if people make errors or do not share information as required, then there would be a *"backlog of information"* that the project needs to build and *"the right people are not seeing the right information at the right time"* (B1).

In this project, the level of technological approaches and tools used to manage information were advanced and were in accordance with the BIM Level 2/Stage 2 project requirements.

However, there are still challenges in terms of people using these technologies and processes to share information. It can be realised that even if the proper technology and processes are implemented, but people do not use them, then their benefits cannot be achieved because *“technology is always driven by people”* (B4).

Thus, as argued by B4, *“if the technology is not working, it’s something that we’ve done to make it not work”*, so the challenges related to the Digital Technologies and Tools and The Processes and Workflows can also be found to be related to the socio-organisational barrier. It is, therefore, crucial to understand and realize the importance of people’s role in terms of the success or failure of BIM implementation (Phung & Tong, 2021), specifically regarding information flow management.

The responses from the interview participants identified that people were the main contributing factor to ineffective information flow management due to some factors influencing socio-organisational barriers. These factors that emerged from the interviewees' responses under the subordinate theme of ‘Socio-Organisational Barriers’, which will be discussed in this section, include:

- Non-Digital Mindsets and Behaviours
- Lack of Knowledge

5.5.3.1 Non-Digital Mindsets and Behaviours

It was believed by some of the participants that one of the issues concerning people as a socio-organisational barrier is their unwillingness to use the technology and the BIM collaboration tool to exchange information. It was argued by B2 that there would not be any critical issues in terms of information flow management if people shared information onto the BIM collaboration tool and within the required processes. Similarly, B4 believed that some of the project members were not comfortable using the digital BIM software and BIM collaboration tool and preferred to use the traditional way of sharing and exchanging information.

It was agreed by most of the participants that although this is a BIM Level 2/Stage 2 project, but there are still some people with limited understanding of digital technologies and procedures, and this is a result of having non-digital mindsets and behaviours which would ultimately cause some challenges in terms of information flow management.

Resistance to Change

One of the factors causing issues as a result of non-digital mindsets is people not willing to change and use the new required BIM technologies and processes, such as the BIM collaboration tool. It was argued by B2 that one of the challenges regarding the socio-organisational barriers to effective information flow management is making sure that when people share information, they share that onto the BIM collaboration tool and not *"throwing information via email"*.

It was found that there were still some people not sharing information through the BIM collaboration tool, and as stated by B2, *"people sharing information via email is a big problem"*, which would cause many issues related to the information flow management. Because there would be some information missing from the BIM collaboration tool, and other project members who were required to work on a piece of information could not access that information via the system as it has not been shared onto the system. Also, that would create inconsistency in the BIM collaboration tool, which would ultimately cause delays (B2).

Similarly, it was explained by B5 that some of the project teams still do the information-checking process manually. For example, because the lead designer has to check all information before it goes to the other project teams, they do all the checking in the manual process where *"they print out the drawings and make the comments"*. When the reason behind this behaviour was explored, there was a direct answer given by B5, which revealed that there was *"some sort of resistance"* to using the BIM collaboration tool as a technological solution to share information. Similarly, B4 explained that some of the project teams do not agree that BIM has positive impacts in terms of information sharing and thus, they resist using the technologies and processes associated with BIM. The majority of participants believed that the resistance to change comes from the fact that people still do not see the value of BIM due to their non-digital mindsets.

It was stated by B4 that "some people just don't like change, or they like to do things their way without a discussion" because they are not open-minded people, and due to their lack of non-digital mindset, it would be difficult to convince them to adopt the new approaches and processes of working in a BIM collaborative environment. So, resistance to change is one of the main factors causing challenges in terms of effective information flow management because it can be found that one of the core barriers to successful BIM implementation that is related to people is their resistance to change (Davies et al., 2015; Leśniak et al., 2021; Olanrewaju et al., 2021; Siebelink et al., 2021).

It was agreed by most of the participants that there are some resistances to change in this project where people had difficulty in changing their ways of working and following the BIM required procedures of sharing information in the BIM collaboration tool. However, some participants argued that this resistance to change might not be just due to the individuals' behaviours and their unwillingness to change.

It was believed by B2 that *"it might not be so much resistance to change, I think people perceive it to be more work"*, and that is why they prefer to use the traditional way of sharing information. Based on the requirements of the BIM Level 2/Stage 2 project set out in PAS 1192 in terms of the information flow management processes, people had to follow the restricted file naming protocols as part of the processes and workflows of sharing information. As explained in the previous section, there were issues in terms of following those requirements because if people made an error while sharing the information, then the information had to be rejected, and the approval process for the rejected information was quite time-consuming. So, one of the reasons people resisted using the BIM collaboration tool was the lengthy workflows and processes of information exchange.

Therefore, as people had to do more work than they were used to do in a non-BIM project due to the technological aspect of BIM implementation, they had difficulty adapting to these changes. Likewise, it was agreed by B5 that *"the technology is bringing in additional work"* in the project, and that was causing issues, even though the additional work was part of the BIM Level 2/Stage 2 requirements for future benefits. B4 made an argument in relation to the additional technological processes that needed to be adapted in this project which claimed that *"it actually might be that the process is wrong"* and that in result causes people a lot more work. So, the lengthy workflows and processes of information exchange were believed to be one of the causes of people resisting change and the use of the BIM collaboration tool.

Additionally, the lack of understanding of the benefits of BIM adaption and its required workflows by the project teams was one of the other reasons behind their behaviours towards using the BIM collaboration tool. As stated by B4, the challenge is that people do not understand why they have to spend extra time doing extra work especially with the file naming protocols, which was argued by B2 to be administrative work and not related to designers. It was clarified by the majority of participants that despite the long-term benefits of using BIM

Level 2/Stage 2 standards and protocols for sharing information, many people perceive these processes and workflows as extra work in the short term due to their lack of digital mindsets and their knowledge of BIM. So, it can be seen that people tend not to use the BIM workflows and processes as a result of perceived complexity, perceived disadvantages, time pressure, and distrust of technology, leading to the persistent use of traditional approaches (Adriaanse et al., 2010, Cited in Siebelink et al., 2021).

It was believed by all participants that these perceived opinions of people in relation to the BIM workflows and processes, especially in regard to the information flow management, are due to their lack of knowledge of the BIM approach. It was mentioned by most of the interviewees that as BIM is relatively new to all project members, there is a lack of knowledge and understanding of BIM requirements and its benefits.

5.5.3.2 Lack of Knowledge

One of the factors that merged from the interviewees' responses in relation to the socio-organisational barriers to effective information flow management was the 'Lack of Knowledge' of people involved in the project. This factor was mentioned several times by all participants as one of the crucial factors causing many of the challenges concerning the socio-organisational barriers which result in ineffective information flow management.

Some participants believed that many of the other challenges related to the processes and workflows and the digital technologies and tools could also be the result of people's lack of knowledge of using the technologies and adapting the processes. This is because a lack of knowledge is one of the barriers to successful BIM implementation (Leśniak et al., 2021). It was stated by B3, *"it is about having the knowledge"*, which enables people to use the technology and follow the workflows and processes effectively.

Based on the interviewees' responses, the lack of knowledge included the lack of people's skills and their low level of understanding of the new BIM technologies and processes and their ultimate benefits to the project. This would also result in a lack of awareness of individuals' capabilities to use and adopt new technological processes and, in some cases, underestimate their skills and capabilities to work in a digital-enabled process.

Additionally, it was found that one of the factors resulting in a lack of knowledge is the limited training available to people and the need for education. Therefore, these factors will be explored in detail in this section.

Sense of Capabilities and Skills

It was agreed by all participants that people are the main contributing factor to ineffective information flow management. However, some participants held the view that people may not cause the issues themselves, meaning that the challenges generated are due to external factors. For example, overloading people with extra work due to the restricted BIM information flow management processes could cause delays in the project. This includes having to ensure that certain file naming protocols were performed correctly, and if an error was made, then there would be additional work to deal with these errors and go through the rejection and approval process.

So, it was stated by B2 that this was extra work as people *"end up spending time with these errors"* that they are not even design-related issues, whereas designers and project members are professionals who need to devote their time to their disciplines related areas and not on something *"that's almost administrative"*. So, not realising people's capabilities and skills would result in people making errors and ending up spending time and effort to deal with the errors that have been made unintentionally.

Additionally, it was argued by several interviewees that the system and BIM collaboration tool need improvements as the information flow processes, specifically the filing system, are complicated for people, and that is the reason why they make errors and mistakes. This is in line with a statement made by B5 saying that *"the technology is just bringing additional work, and that is an issue"*, which would make people face challenges in terms of using the system.

So, it can be found that if people are not trained enough to use the system and to follow the BIM required workflows because of their lack of knowledge about the BIM implementation and its requirements, they would not recognise and acknowledge the skills needed to use the system. This would ultimately result in people facing issues and causing delays, and make the management of information flow challenging. It was stated by B4 that it is important to ensure that people understand the system and the skills needed to use the system. The importance of people's knowledge of how to use the system based on their understanding of their capabilities and skills was highlighted by participants. All interviewees pointed out that training and education are critical factors in preventing people from making mistakes and to enable them to understand how to use the system and gain benefits.

The Need for Education and Training

It was highlighted several times by all interviewees that training is a crucial factor in terms of effective information flow management. It was believed by all participants that training would enable people to work effectively and towards the projects' requirements. Especially in BIM projects, the lack of trained people prevents the BIM transition (Chien et al., 2014; Eastman et al., 2011; Underwood & Isikdag, 2009, Cited in Siebelink et al., 2021).

As stated previously, participants believed that people as the main socio-organisational barriers could cause issues in terms of information flow management. But participants also agreed that *"the solution to that is training"*, which would ensure that people are clear on what they need to be doing, and their level of understanding of the BIM collaboration tool and the information flow processes and workflows would be improved.

It was found that there were some training sessions organised in this project, but B4 and B5 argued that those were not formal training and there were just some initial explanations of the project's requirements. Thus, people still face some challenges in terms of a lack of knowledge of the processes and workflows required as part of the BIM level 2/Stage 2 requirements. It was believed by B2 that *"making sure people are adequately trained, and the degree of training is hands-on"* would help people understand the project's requirements and, more importantly, prevent some of the challenges they could create due to their lack thereof of knowledge. So, to use the BIM collaboration tool and related features, training is needed for the better performance of the project members (Pengfei et al., 2019).

Moreover, it was highlighted by B2 that although the initial training is an essential element for people's successful performance but *"you can't be an expert in your job until you've done it for so many years"*. So, people have to work on BIM projects and learn while working to better understand and gain knowledge in terms of the processes and workflows that they have to follow. Nevertheless, it was indicated by B3 that an excellent example of training people and improving people's knowledge is through education. An example was given by B3 that *"the younger team members in our project who used Revit throughout the University"* were able to work with BIM collaboration tools and software and towards the BIM requirements.

It was explained by B3 that those project members who had education in BIM and related disciplines *"understood how to model on Revit, the concept of sharing information, the need for plugging in information"* and the required BIM processes and workflows because they learned those in the University and when they joined the project, they already had the knowledge to do what they were required to do.

So, these people with the right knowledge and education were not causing any challenges regarding information flow management. However, the older generations who did not have the knowledge and understanding of BIM were the main contributing factor to poor information flow management because lack of training and education is considered to be one of the barriers to the digital approach's implementation (Dainty et al., 2017).

Also, it is more challenging to train and educate the older generation who are used to working in a traditional way. It was argued by B4 that one of the biggest challenges is educating some of the people, especially the older generation, because *"when you say BIM to them, it means absolutely nothing to them"*, and therefore it is very difficult to train them to understand BIM and implement it correctly. So, training and educating some of the people is a challenge itself because, as agreed by all participants, BIM is new to many of the project members and also industry-wide.

Therefore, the number of BIM experts and people who can teach BIM are very limited. It was argued by B4 that *"there aren't enough people at the moment with the expertise and the background"* because BIM has not been around for a long time, and this causes challenges in terms of training people. It was explained by B5 that the number of BIM experts in the project is very limited, and they have one BIM manager who people would go to if they have any questions or training required, but if that person goes on holiday or not available, then people ask *"who do we go to now"* as the number of BIM experts are limited in projects. So, there is a shortage of qualified people, which makes training people challenging in organisations (Siebelink et al., 2021). The lack of people with expertise in BIM could be seen as another issue associated with this project which makes information flow management challenging.

Nevertheless, it was believed by all participants that training and education can be identified as the best way to improve and enhance other factors causing information flow management challenges, such as non-digital mindsets and behaviours.

The findings indicate that there are different aspects concerning people as a socio-organisational barrier to be the main contributing factor to poor information flow management in this project. These aspects, which were highlighted by the participants at different stages of the interview's discussion, have been highlighted in this section which included their non-digital and non-collaborative mindsets and behaviours and their lack of knowledge and training. These main aspects, with their highlighted and detailed, explained other factors under them related to people, could be found as the root cause of people being the challenge in terms of effective information flow management.

As discussed previously, if people do not have the right mindset to change their way of working, then they will not adopt the new online systems and BIM approach, and they may resist sharing and exchanging information within that system. Also, if people's knowledge is not as up to date as the project requirements and there is a lack of understanding of the process of sharing and managing information due to the lack of effective training, then project teams are not fully aware of what needs to be done and how to do it.

Furthermore, people's behaviour would directly impact the project in a way that if they are not willing to share information or they do not share the correct information or not at the right time, then delays and reworks in the project would occur. Last but not least, in a collaborative environment where communication and coordination are enabled through using technological and innovative processes such as BIM, people can become a beneficial factor in improving information flow management by sharing and exchanging information effectively and collaboratively between project participants (Hickethier et al., 2013; Phelps, 2012) instead of being a barrier to it. Therefore, it is essential to address and understand these elements when considering people as the main challenge of information flow management.

All the previously mentioned issues causing ineffective information flow management could be linked back together as one factor could act as an influential factor to another. But most participants believed that to address most of the above-mentioned challenges of effective information flow management, such as issues concerning digital technologies and tools, processes and workflows, and socio-organisational barriers, the importance should be given to this last point of *"lack of knowledge"*. All participants believed that if people's knowledge improves, then the other factors would subsequently improve in terms of sharing and exchanging information effectively and achieving an effective and enhanced level of information flow management.

5.6 Theme 3 – The Role of BIM/Lean in Relation to Effective Information Flow Management

BIM implementation has been rapidly increasing in the last decade as it provides many benefits to projects (Al Hattab & Hamzeh, 2013; Eastman et al., 2011; Ingram, 2020; McGraw Hill Construction, 2013; NBS Digital Construction Report, 2021; Sacks et al., 2018). This project was a Managed project in which BIM Level 2/Stage 2 was implemented. So, in the context of this research, the role of BIM/Lean in effective information flow management is explored through the analysis of findings.

The findings indicated that there were many beneficial factors influencing information flow management due to the BIM implementation. It was interesting to note that there were some overlaps between the factors identified earlier in the previous section as the challenges of effective information flow management and the factors that will be discussed in this section as the beneficial role of BIM/Lean in terms of effective information flow management. This could be a result of BIM/Lean's short terms and long-term benefits that were mentioned by some of the participants as well.

As stated by B2, some of the challenges associated with the BIM implementation and the use of BIM collaboration tools were perceived to be more work in the short term, but there would be many benefits later to the project; thus, *"people need to appreciate the long terms benefits of making that investment now"*.

The researcher initially believed that as this project is a BIM Level 2/Stage 2 project, the number of benefits in terms of the role of BIM/Lean to enhance information flow would have been much more than the challenges associated with the BIM implementation. However, it was found that the number of challenges faced by the project teams was significant compared to the benefits that interviewees revealed.

So, based on the responses received from the interviewees, two subordinate themes merged under this theme to explore how BIM/Lean has affected this project in terms of effective information flow management. The two subordinate themes which will be discussed in this section include:

- Digital BIM Technologies and Tools
- BIM/Lean Collaborative and Coordinated Workflows

5.6.1 Digital BIM Technologies and Tools

In this project, there were different digital technologies and tools used to aid design managers, project managers, architects, engineers, and all project members in improving the information coordination and control of planning, design, estimating and construction in the entire project process and develop effective communications which aimed to ultimately result in effective information flow management. The technological aspect of BIM is widely believed to bring numerous benefits to the project, specifically in terms of information flow management due to the various features that BIM provides, such as visualisation, clash detection, detailed information asset, etc. (Azhar, 2011; Eastman et al., 2011; Ingram, 2020; NBS National BIM Report, 2019).

As explained previously, based on the interviewees' responses, it was found that the digital technologies and tools implemented in this project as part of the BIM Level 2/Stage 2 requirements consist of Digital BIM Software and the BIM Collaboration Tool. These two technological aspects of the BIM approach will be discussed in this section to explore how BIM/Lean has helped in terms of effective information flow management.

5.6.1.1 Digital BIM Software

Since this project adapted BIM Level 2/Stage 2, various digital software and tools have been used to ensure the achievement of the BIM benefits. All participants reported using Autodesk Revit as the leading utilised BIM software that was used by various disciplines and stakeholders in this project. It was stated by B2 that since the beginning of the project, all project stakeholders were using *"the same software and the same version"* of Autodesk Revit and the other linked software and tools to ensure that the effective exchange of information was enabled.

As explained by most of the participants, the digital BIM software enabled the creation of 2D drawings, 3D models, and 4D scheduling for all various disciplines across the project. Based on the interviewees' responses, it was found that the features of the digital BIM software provided many benefits in terms of the creation of 3D models, detailed information assets, visualisation, clash detection and lifetime information to the end user, and these benefits eventually enabled effective information flow management.

The digital BIM software enabled the creation of 2D and 3D models that contained all the project information from different disciplines, including architectural design, MEP, structural design, construction information etc. As stated by B1, the benefit that the project has achieved in terms of having the model and being able to access the model was significant. Everyone in the project could access the model and view the information within the model, which enabled effective information flow management. All the participants agreed that the BIM model enabled effective working to exchange information in a way that, in the meetings, project teams can show and share the model with other parties to review and manage the information. It was stated by B5 that there were so many benefits regarding the BIM model as people did not have to look at the 2D drawings *"on a piece of paper"* that they *"need to sit down and interpret whether that is a program or drawing or drawing with markups of the coordination"* which would result in delays in the project and issues based on wrong interpretations.

Additionally, it was believed by B3 that *"having shared models with other consultants is amazing"* because all the information that other consultants have plugged in can be easily visible and accessible, which led to a better-enhanced understanding of the design by all project teams. As all the design information, such as 3D views, conventional working drawings, schedules, costing and quantities, can be extracted from the BIM model (Ingram, 2020), effective information flow management would be enabled.

Moreover, the visualisation factor was one of the most beneficial elements enabled through the BIM model. It was highlighted several times that the visualisation aspect of the digital BIM software provided many benefits to the project in terms of information flow management. Because all the information within the BIM model could be visualised early in the design process by all project members, which allowed early decision-making through the process based on the information that was shared in the model. As stated by B2 many of the benefits that the project gained were related to visualisation.

As highlighted by all interviewees, project members were able to visualise their models and everyone else's models, which enabled the effective exchange of information in a collaborative environment where any design errors could be identified easily and thus corrected without causing any delays or rework later in the project. Likewise, it was mentioned by B2 that any changes to the design could be done live in the model while the designers are sharing the model and reviewing it.

An example was given by B2 that if the client wants to check the design of a room, the architect could easily show the entire design of them by rendering an image of the room through the BIM model. Because everything is modelled exactly as it is required, then the realistic 3D image of that design could provide great insight into the design. Thus the rendering image provides an instant visualised picture and visual feedback about the model and the information within the model (Ingram, 2020). The visualisation aspect of the digital BIM software helps massively in terms of enabling project teams to have a better understanding of the detailed information within the model, whereas *"just looking on 2D drawings doesn't give you a true appreciation for all the different levels and all the different locations that (for example) scaffolding is needed"* (B1).

Furthermore, visualisation helped the project teams who were working on site as they could also visualise the BIM model through enabled digital BIM software. It was explained by B1 that there were QR codes placed on the joins in the model so that the site team *"can just use their phones and actually visualise the model to see how it should look like…. before we actually build it"*. So, it was believed that sharing information and managing it through the BIM model helped the project members during the design process and during the construction on site.

It can be found that the visualisation element enabled through the BIM model had many benefits to the project, specifically in terms of enhancing the information flow management because when people can easily visualise the information and have a better understanding of it, then the process of managing information can be done more efficiently. In this regard, additional BIM benefit was identified through the interviewees' responses: the 4D visualisation and 4D scheduling (B1, B2 and B5).

It was explained by B1 that the BIM model could have been incorporated into the construction program, which enabled real-time construction scheduling. So, when the BIM model is linked to the program, *"we click on the program at this time next year, and the model will show how it will ever build, it should look like that at that particular point in the time"* which was believed to be a huge benefit to project. It was also stated by B5 that the 4D scheduling benefits the project in terms of the client's awareness of what stage the project was according to the program and if there were any information needed to be added to the program or any changes required that could have been communicated to the project in advance.

So, the 4D scheduling made the visualisation of the BIM model and the information creation and management easier (B5) as it enabled the designers to identify any missing information, duplicated information, and wrong information and thus take any actions required. Through 4D scheduling and visualisation, the information reliability would be improved alongside enhanced collaboration and communication in the project (Andersen & Findsen, 2019; Brito & Ferreira, 2015; Hartmann et al., 2008; Koo & Fischer, 2000).

Another essential point all interviewees emphasised was the ability to detect any clashes within the model, which was enabled through visualisation. Through clash detection, project teams could visualise all the information within the model to identify any design information errors, missing elements, or clash information. All disciplines upload their models on one of the BIM clash detection software (in this project, Solibri) to identify any clashes between the various models. For example, if there is a wall cutting through another wall, this will be identified through the clash detection software (B3), which would enable the designer to visually identify any design errors and resolve it. So, any clashes can be identified and resolved from all the different disciplines models, whether that is a structural engineering clash, an architectural clash or a mechanical engineering clash (B3).

As stated by B3, "*the BIM clash detection information is really helpful*" because it enables the designers to identify any information issues within the model and resolve it early in the process. This would result in having more reliable information, which would get exchanged between project members and thus improves the information flow management. Similarly, it was claimed by B1 that there were many advantages the project gained through clash detection as a result of BIM Level 2/Stage 2 implementation. It was believed by most participants that the benefits of this BIM feature were not only related to detecting the clashes itself, but the BIM collaboration and coordination meetings and workshops organised as part of the clash detection procedure had provided many benefits to the project members. This will be discussed more in the next section.

Even though it was argued by B3 that *"the clash detection workshops take a long time, and they are quite time consuming"* but all participants believed that the ultimate benefits that these workshops provide are worth the time and effort spent during these workshops. Also, as the BIM model design and construction information inaccuracies and errors can be *"picked up on the right stage and at the right time"*, then the accurate information will be exchanged between project members throughout the entire project lifecycle, which ultimately leads to eliminated rework on the construction site as well (B1).

So, it can be found that there were many benefits gained through clash detection, which resulted in reliable and accurate information exchange between project teams and therefore enabled effective information flow management.

In this project, the digital BIM software and its features, such as 3D models, detailed information assets, visualisation and clash detection, provided many benefits in terms of effective information creation and exchange throughout the project. As explained in the previous section, to share and exchange all the project's information, including the BIM model information, project documents, reports, meeting minutes, etc., a cloud-based system common data environment is used. The common data environment, considered the BIM Collaboration Tool in the context of this project, provided many benefits to effective information flow management and is discussed in this section.

5.6.1.2 BIM Collaboration Tool

As part of the BIM Level 2/Stage 2 requirements, the BIM collaboration tool was adapted in this project to enable effective exchange and management of information flow. As stated by all participants, to comply with the PAS 1192 and ISO 19650 information management process requirements to use a common data environment to support collaborative creation, sharing and managing the information, the BIM collaboration tool was implemented in this project.

The main software used as the BIM collaboration tool in this project was called Viewpoint, which enabled sharing and exchanging of information between project participants. It was interesting to discover that the BIM collaboration tool in this project was both challenging and beneficial. The challenges within the BIM collaboration tool are already discussed in previous sections, and the benefits that it provides in terms of information flow management are explored in this section. According to the interviewees' responses, despite the issues associated with the BIM collaboration tool, it provided benefits as well.

One of the advantages of the BIM collaboration tool was *"the sharing, the retrieve ability and the accessibility of the actual date"* and the point that all information can be shared and exchanged *"in a consistent approach that is easily retrievable by all parties"* (B4). So, if any of the project members needed a piece of information, it is simply and instantly accessible *"without having to search around and spend months flowing through files"*.

It was agreed by almost all participants that understanding, retrieving, and identifying the information that is needed by project teams within the BIM model were easy and straightforward. B3 and B1 revealed that when a piece of information gets uploaded onto the system, project teams will receive an email notifying them of that exact uploaded information. So, the email contains a link which would take the user to all the information that was uploaded, including the properties information such as the person who has uploaded that information, the information revision and etc. (B3 and B1).

Due to file naming protocols that had to be followed in this project as part of the BIM Level 2/Stage 2 requirement, the identification and tracking of information in terms of its status, its revision and its work stage were straightforward. Although the majority of participants held the view that the file naming protocols were time-consuming and resulted in delays and reworks at some points (as explained in previous sections) but there were certain beneficial factors achieved in terms of information flow management.

Due to the file naming protocols, all information consists of certain status and naming conventions which provide many benefits in terms of information consistency, transparency and traceability (B5). B2 stated that managing the information flow and tracking the information was made easier using the file naming convention because all the information stored on the BIM collaboration tool was *"fully referenced"*, which allowed ongoing coordination of the information (B3) as well.

Also, as all information is shared in the BIM collaboration tool, which is an electronic system then, managing information flow has been done more effectively, reliably, and instantly *"because it's all electronically managed"* (B4). So, people did not have to *"wait for a week for a drawing to turn up, or to get a phone call to say, well, it's wrong….and you're going to wait for another week for it to come through again"* as everything is instant through the enabled BIM collaborative and coordinated workflows (B4).

So, successful project management, including information management, can be supported by the BIM collaboration tool through instant insights into the project's information and performance, which ultimately lead to the elimination of non-value-adding activities such as rework (Ozkan & Seyis, 2021). Therefore, it can be found that there were many benefits facilitated through the BIM collaboration tool in this project.

Moreover, the BIM collaboration tool provided a common platform to support collaboration and communication between project members. So, as stated by B2, it was clear that the BIM collaboration tool aided the collaboration as well. Therefore, it can be found that one of the main beneficial factors that were achieved through both the digital BIM software and the BIM collaboration tool was the enabled collaborative and coordinated workflows to share and manage information flow.

5.6.2 BIM/Lean Collaborative and Coordinated Workflows

One of the most important factors as the beneficial role of BIM/Lean in terms of effective information flow management, which is enabled through both digital BIM software and BIM collaboration tool and through the BIM-enabled feature of visualisation, is 'collaboration and coordination'. Communication and collaboration between project members can be facilitated through the BIM model and visualisation, which enables better coordination across all project parties and different disciplines (Andersen & Findsen, 2019).

It was argued by B5 that the digital BIM software and the BIM collaboration tool are there to support the collaboration as the most beneficial role of BIM is the enabled collaboration and coordination between the team members, *"which would not be available in a BIM Level 1/Stage 1"* project. Likewise, B1 stated that one of the valuable roles of BIM/Lean in terms of information flow management is that *"it encourages collaboration"* amongst project parties.

All interviewees emphasized that collaboration which was enabled through BIM Level 2/Stage 2 implementation provided many benefits to the project in terms of the effective exchange of information. When asked about the role of BIM/Lean in information flow management, all interviewees agreed that it helps with collaboration and coordination through BIM digital technologies and tools and BIM workflows. This is in line with what has been found in the literature, which highlights that collaboration enhancement is one of the main BIM advantages to the project (Al Hattab & Hamzeh, 2013; Khudhair et al., 2021).

To comply with the BIM Level 2/Stage 2 requirements, project members worked collaboratively together to facilitate information flow management. During the interviews, it was mentioned several times that every four to six weeks, there were BIM collaboration and coordination meetings and workshops in which all project parties from different disciplines participated to coordinate and share information and to work collaboratively on the current project information.

These meetings and workshops enable project participants to exchange information and to visualise all disciplines models, including architectural models, structural engineering models, and MEP models would improve communication and coordination between project teams and enable instant decision-making early in the design process (Azhar, 2011; El Ammari & Hammad, 2019). During these regular meetings, project members, including all designers, *"get together and look through the models and look for clash detection"* and *"talk about any issues"* that is found within the information model (B1). This encourages collaborative working between project teams as they can sit together in the BIM collaborative meetings where they can visually view the models of all different disciplines so that they can detect any clashes within the models, make any necessary changes to the design and finalise the models together.

So, the integrated and coordinated information through BIM enabled collaborative and coordinated workflows, and meetings and prompt adjustments of the information in the model are enabled. Therefore, the information is always up-to-date, and a continuous flow of information is allowed, which ultimately enhances information flow management (Al Hattab & Hamzeh, 2013).

Moreover, the collaborative and coordinated BIM workflows enable two-way information exchange between various disciplines in the project via real-time BIM collaborative meetings (Al Hattab & Hamzeh, 2013) and as the real-time information model can reveal the real conditions of the project (Khudhair et al., 2021), therefore, the flow of information can be managed quickly and more effectively.

Additionally, one of the factors that B1 and B2 pointed out in terms of the beneficial role of BIM/Lean to effective information flow management was that BIM collaborative and coordinated workflows enabled lean processes and supported lean principles. Although not all the interviewees had advanced levels of understanding of lean and its principles to clearly address the role of lean in this project, but it was found that some of the lean principles were achieved in this project through BIM Level 2/Stage 2 implementation.

Through the BIM collaboration workshops where all project participants visualise information models and can run clash detection, any missing information, wrong information, duplicated information, and any errors or mistakes can be detected and thus resolved. So, any potential issues could be resolved, which *"prevents waste happening on site or rework happening on site"* (B1). This would not only prevent waste creation on site but also, during the design process, delays and reworks could be eliminated, which makes the information flow management more leaner.

It was believed by B1 that through BIM implementation and by practicing BIM features such as collaboration and coordination, *"we are trying to get a leaner project"* and *"build it more leaner"*. Similarly, B2 argued that through BIM implementation, the project *"will become a more lean process"* in which information flow management would be more enhanced. So, based on the interviewees' responses, it can be found that some of the lean principles in terms of waste reduction were achieved in this project through enabled BIM features such as collaboration, coordination, visualisation, clash detection and the required BIM information flow management processes. This shows that the interaction of BIM and lean can provide benefits to the project (Machado et al., 2020; Sacks et al., 2010; Schimanski et al., 2021).

The BIM features enabled lean principles in terms of waste reduction, such as waste of time, waste of processing, rework, and delays in the project through collaborative working in coordinated workshops where all clashes and information errors were detected and resolved by visualisation of the 3D BIM information models. Eventually, this resulted in improving the effective information flow management in the project.

5.7 Chapter Summary

This chapter presented the analysis and findings of Case Study B as a BIM Maturity Level 2/Stage 2, which included interviews conducted with five key people who were directly involved in this project. To address the research, aim and objectives and based on the interviewees' responses, three main themes emerged associated with subordinate themes that were introduced and explored in this chapter. Each subordinate theme was further examined through discussion of all the factors that elicited from the findings which influenced the subordinate theme. Furthermore, all factors were explored through the lens of the review of the extant literature and the case study project.

The findings firstly highlighted the importance of 'Effective Exchange of Information and how this was accomplished in this project by 'Adaption of Digital Tools', which was managed through specific 'Roles and Responsibilities'. Then, the 'Challenges of Effective Information Flow Management', which was categorised into three main factors of 'Digital Technologies and Tools', 'Processes and Workflows', and Socio-Organisational Barriers', were explored and discussed further.

Finally, 'The Role of BIM/Lean in Relation to Effective Information Flow Management' was discussed under two subordinate themes, the 'Digital Technologies and Tools' and 'BIM/Lean Collaborative and Coordinated Workflows'. The findings of this chapter represent the Managed project which is in line with BIM Maturity Level 2/Stage 2. To achieve the aim and objectives of this research, it was essential to study projects with a more enhanced level of BIM Maturity Level as well. Therefore, the next chapter introduces Case Study C, which is an 'Integrated Project'. The next chapter will discuss and analyse the findings of Case Study C.

Chapter 6. Case Study C – Data Analysis and Findings

6.1 Chapter Overview

The previous chapter introduced Case Study B, which demonstrated a Managed project (BIM Maturity Level 2/Stage 2) and explored the findings that have been discovered from the analysis of Case Study B data. This chapter will present Case Study C as an Integrated project (Integrated Project Delivery). This chapter aims to explore and analyse the findings from a qualitative study based on semi-structured interviews conducted for Case Study C.

In order to discuss the results of this case study, certain key themes, as shown in Figure 54, were identified to form the basis of the presentation and analysis of the data. This includes the exploration of identified themes and issues, which have been structured into a number of superordinate themes and associated subordinate themes. The relation to themes explored as part of the interview design will be noted in the sections of the themes where appropriate.

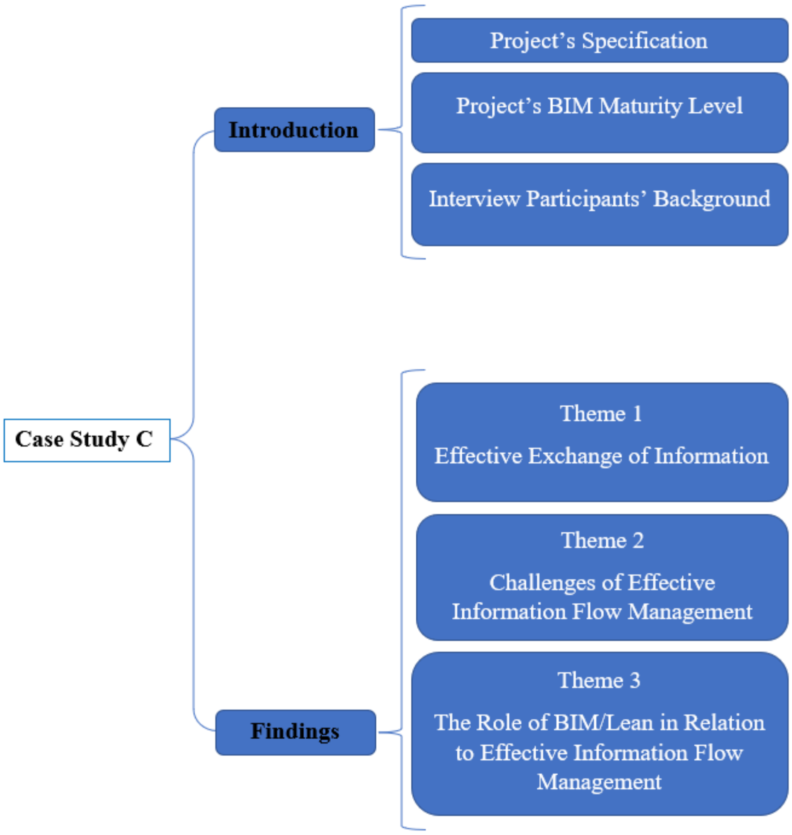

Figure 54 - Chapter 6 Overview

The early part of this chapter gives an introduction to the Case Study C project. The second covers the presentation of the findings which are categorised into three superordinate themes. The structure of this chapter is shown in Figure 54, which depicts that the project is first described in terms of its nature and type of project, size, location, etc. The level of BIM maturity in this project is then discussed, followed by an explanation of the interview participants' backgrounds. This will then be followed by a complete exploration and analysis of the findings through superordinate and associated subordinate themes that emerged from the data/interview verbatim transcript.

The chapter summary is presented at the end (6.7 Chapter Summary).

6.2 Introduction to Case Study B – Defined Project

6.2.1 Project's Specification

The concept for Case Study C was to bring together the Barrie Police Service, Barrie Fire and Emergency Service and Simcoe County Paramedic Services together on a shared campus in a partnership arrangement where each party will benefit. Through shared space and staff amenities, each partner will have access to more efficient and improved facilities as compared to what would be feasible or affordable in separate standalone buildings.

The prime objective was to build a 200,000 sq. ft. fully integrated and multifaceted campus incorporating the following three major components:

- Barrie Police Headquarters – to replace the existing outgrown Barrie Police building
- Barrie Fire and Emergency Service Dispatch Facility
- County of Simcoe Paramedic Service – Paramedic operational hub with ambulance storage, mobile command unit, support areas, and staff/administrative spaces

This facility was planned to meet a 25-year space projection; the layout and design will allow for future growth and expansion beyond that timeline.

The project cost was $87 million, and the project started on December 2017 with the completion date scheduled for February 2020.

6.2.2 Project's BIM Maturity Level

Case Study C was chosen as the third case study for this research due to its BIM implementation level and project delivery methods. Based on the client's requirements, this case was an Integrated Project in which Integrated Project Delivery (IPD) was adopted.

The prime objective of this project was to create a highly efficient emergency services campus that combines police, fire, and paramedic services in one facility. Creating a highly efficient facility requires a highly efficient process. Therefore, IPD was chosen for this project as the best delivery approach to meet the objectives of this project. With the complexities of a multi-stakeholder facility, tight budgets, and a high-profile project in the eyes of the public, an Integrated Project Delivery approach (IPD) to design and construction has been utilised in this case study.

IPD represented an optimal path to best align expectations and outcomes across every possible dimension of the Barrie-Simcoe Emergency Services Campus project. It further offered the opportunity for the City of Barrie to demonstrate leadership not only in the creation of a unique building type (the shared facility) but to the AEC industry in terms of its delivery process.

As this project was outside the UK, therefore the British Standards (PAS 1192, ISO 19650) were not being used. As indicated by C3, BIM was implemented in this project, but the BIM implementation levels/stages were not based on the British Standard but rather referred to as LOD, which is the level of development. Similarly, it was stated by C4 that *"we have different methodology, different standards, and different ways of doing BIM"* compared to the UK BIM requirements and standards. It was argued by C4 that when considering the project's BIM Level in accordance with the British Standards, this project could be viewed as a BIM Level 2/Stage 2 project. In the project, a BIM execution plan was developed, which helped everyone *"to clearly define the role of the various people involved in the project"* (C3).

As stated by all the interviewees, this project implemented an IPD approach in which all project stakeholders, including trade partners, architects, contractors, and owners, get involved early in the project to work together towards shared benefits and risks collaboratively. So, in this project, all parties (contractors, consultants and owners) were active and responsible members throughout the entire progress of the project, from concept development through design, construction and commissioning.

As stated by C1, the main aspect that would make this project an IPD one is *"the way that the contract is set up, it's a poly party contact"*. This is in contrast to typical construction contracts where the owner would enter into a contract with architects. Then the owner would enter into a contract with a general contractor. The architects would have separate subcontractors, and the rest of the consultants would have then had separate contracts between them and their subs, consultants and supplier (C1, C2). So, in this project, all parties *"enter into one poly party agreement"*, and they are all signatories to that agreement (C2) which *"brings everyone together towards a single contract"* (C1), meaning that all project's risks and rewards will be shared between all parties.

According to the AIA (2007), *"Integrated Project Delivery (IPD) is a project delivery approach that integrates people, system, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimise project results, increase value to the owner, reduce waste, and maximise efficiency through all phases of design, fabrication, and construction."*. Therefore, it can be found that IPD would bring many benefits in terms of the information flow management in this project as it is believed that successful IPD implementation facilitates the adequate sharing of information between project teams (AIA, 2007).

Although the BIM implementation in this project was not based on British Standards, but many of the protocols and requirements that were set out and followed through the project's BIM execution plan were very similar to the ISO 19650 BIM requirements. For example, based on the interviewees' responses, it was found that in this project, an online cloud-based system was used to facilitate information exchange between project members, which can be considered as the Common Data Environment (CDE) in the PAS 1192 and ISO 19650.

As explained by all interviewees, there is a collaborative 3D BIM environment in which information models were developed with all information and data attached to them. The model could be shared between project members in a collaborative environment where all parties could access the models and use BIM features such as visualisation, clash detection, and 4D scheduling to exchange and manage the information effectively. So, effective collaboration, visual representation and data management that are enabled through BIM would facilitate efficient information flow (Alreshidi et al., 2017; Maria Christina Georgiadou, 2016, Cited in Bilge & Yaman, 2021). Therefore, as also agreed by the interviewees' BIM, with its beneficial features, was believed to be beneficial in terms of sharing and managing information in this IPD project.

6.2.3 Interview Participants' Background

To obtain an in-depth exploration of Case Study C and to meet the research aim and objectives, four (4) semi-structured interviews were conducted. The aim of the interview was to study and explore the factors influencing effective information flow management in relation to the project's BIM maturity and implementation level. To meet this, key project participants were identified in relation to their job role and their level of participation in the project because interviews should be designed in a way that people who are directly involved with the case study is targeted to allow the development of in-depth insight into the research aim and objectives (Knight & Ruddock, 2008).

Similarly, according to Robson (2002), choosing the participants based on the depth of their knowledge and experience about the research phenomenon under investigation is an essential aspect of qualitative interviews.

Therefore, participants who were knowledgeable about the entire project scope, the project team and resources, the project schedule and the success or failure of any tasks throughout the project have been targeted in this research because they were involved in day to day using an information management system, so they were well-informed about the challenges in terms of information flow management in the context of this research. These participants include:

- Project Manager,
- Design Manager,
- Project BIM Manager, and
- Project BIM Implementation Manager

The participants that are mentioned above had sufficient experience and background in the construction industry and in their specific field of expertise, which enabled the researcher to first achieve useful insight in terms of how the information flow is managed and what challenges have been encountered in this project in the context of this chapter. The participants' backgrounds would also enable the researcher to understand how their experience influence and motivate the process of information flow management concerning the project's BIM maturity levels, which will be discussed later in the discussion chapter (Chapter 7).

Moreover, the interview participants were labelled C1, C2 … C5 in accordance with ethical considerations of using anonymous quotes. Table 15 below presents a summary of sampled participants of the semi-structured interviews in Case Study C (CSC), providing details of the interviewee's position, background, years of experience and level of understanding of BIM.

Table 15 - Summary of Interview Participants Information

Case Study C (CSC) **Integrated Project – IPD**				
Participant Code	**Position**	**Field of Expertise and Background**	**Years of Experience**	**Level of Understanding of BIM** (Low, Medium, High)
C1	Project Manager	Architectural Engineering, Project Management	8	High
C2	Design Manager	Architectural Engineering	20	Medium to High
C3	Project Design BIM Manager	Architectural Technologist	15	High
C4	Project BIM Implementation Manager	Electrical Engineering, BIM Construction	18	High

6.3 Outline and Structure of Findings to be Discussed

6.3.1 Introduction to the Themes

The areas of analysis of CSC will be outlined in this section. As discussed in the previous chapter (Chapter 3. Methodology), through thematic analysis, three superordinate themes and associated subordinate themes emerged from the data analysis, which will be discussed in this section. The first section of findings to explore, which refers to the first main theme, is the 'Effective Exchange of Information' (Section 4.4).

This section pertains to the importance of managing information flow effectively (Baldwin et al., 1999; Chatzipanagiotou, 2017; Detlor, 2010; Robertson, 2005), which will be discussed under two associated subordinate themes of 'Adaption of Digital Tools' and 'Roles and Responsibilities', as shown in Figure 55.

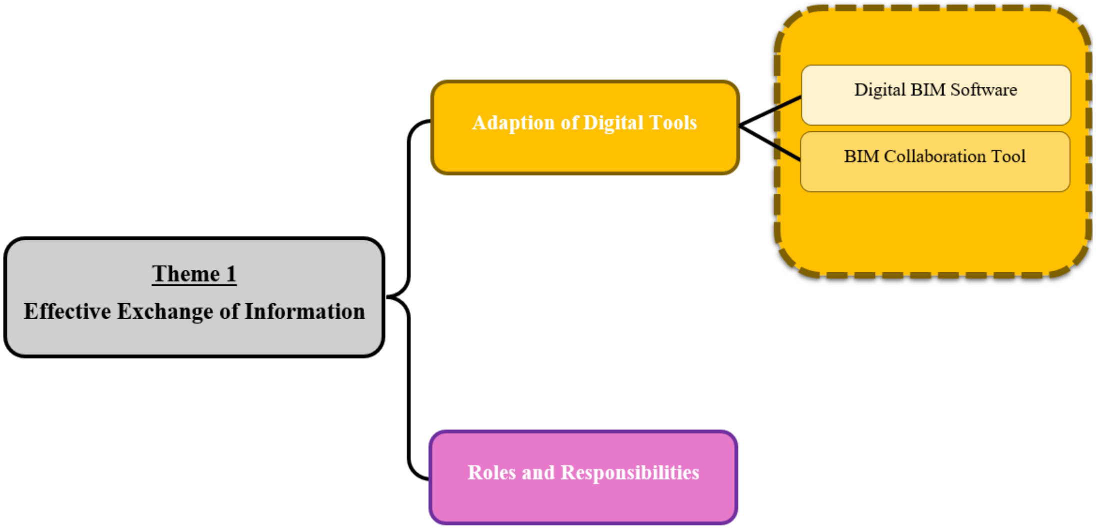

Figure 55 - Case Study C Theme 1 Outline

After discussing effective information flow management and understanding the project's practices to manage information flow, it is then essential to explore the project's challenges in managing the flow of information, which creates the research's second superordinate theme. Therefore, the next section of findings to explore, which refers to the second superordinate theme, is the 'Challenges of Effective Information Flow Management' (6.5 Theme 2 – Challenge of Effective Information Flow Management).

This section is divided into one subordinate theme, and under each subordinate theme, a number of factors/issues have emerged from the data related to that subordinate theme which will be explored and discussed accordingly. The overview of this section, which presents theme 2 is outlined in Figure 56. Finally, the role of BIM/Lean in enhancing information flow management will be explored under the third theme of 'The Role of BIM/Lean in Relation to Effective Information Flow Management'. Due to the nature of this project as an IPD project in which BIM implementation advanced (as explained in Section 6.2.2 Project's BIM Maturity Level), it was found that there are many advantages and factors in this context to explore under this theme.

Therefore, the final theme of this Case Study will be discussed under two subordinate themes of 'Digital BIM Collaborative environment' and 'Enabled Lean Processes' as shown in Figure 57.

Figure 56 - Case Study C Theme 2 Outline

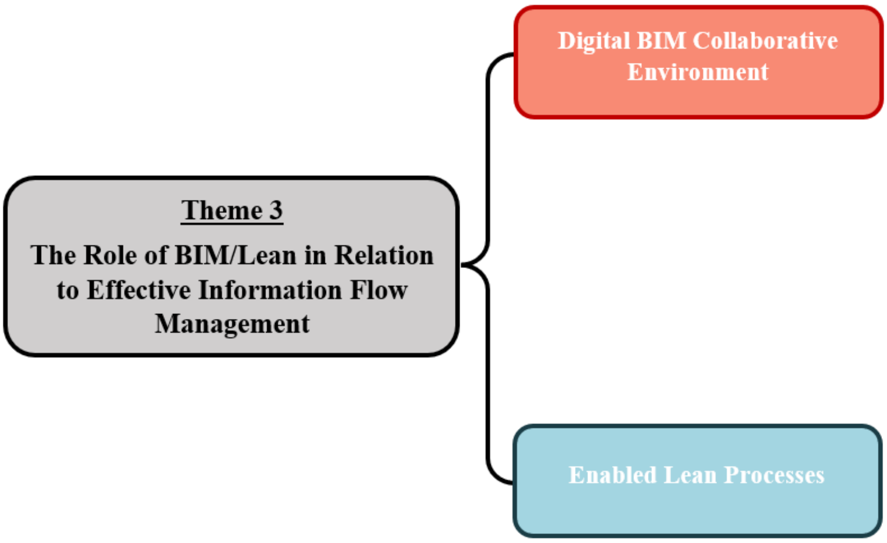

Figure 57 - Case Study C Theme 3 Outline

6.4 Theme 1 - Effective Exchange of Information

It is widely believed that effective information flow management is crucial for project success due to the increased level of information exchange (Baldwin et al., 1999; Chatzipanagiotou, 2017; Detlor, 2010; Kania et al., 2021; Robertson, 2005). Similarly, all interviewees believed that managing information flow effectively is essential to the project's success.

Due to the nature of this project as an IPD project in which BIM was fully implemented, the project relied heavily on information and effective exchanging of information between project teams was crucial. Also, with the increased level of information, the project also becomes more complex and thus effective exchange of information *"is crucial to the outcome of the project"* (C2). So, effective control of information flow can be found to be one of the main contributing factors to achieving project goals (Kania et al., 2021). Based on the interviewees' responses, the quality of information and the management side of it could be enhanced through BIM implementation. This is because there are many benefits achieved through BIM features that enable effective information flow management. For example, BIM provides opportunities to support collaboration" (El Ammari & Hammad, 2019) collaboration was believed by all participants as an important factor in enabling the flow of information between project teams and *"maintain records and data"* (C2).

Similarly, BIM-enabled collaboration provides effective and efficient information management within a digital model, establishing a reliable foundation for decisions during the building lifecycle (Bradley et al., 2016, Cited in Machado et al., 2020). So, effective information flow management is critically important to enable the production and exchange of high-quality information and thus improve overall project performance (Kania et al., 2021; Zeng, Lou, & Tam, 2007). Hence, it is important to understand how effective information flow has been achieved in this project to identify challenges and opportunities of effective information flow management in relation to the research aim and objectives.

Therefore, based on the main identified superordinate themes and the interviewees' responses, two subordinate themes merged under this theme. These subordinate themes aim to explore how and by whom the information flow is effectively managed in this project.

Firstly, as this case study is an Integrated project in which there are technological solutions implemented to manage and exchange information effectively, it is important to discover the digital tools and technologies that have been used in this project based on the interviewee's justifications. So, this will be explored under the 'Adaption of Digital Tools' subordinate theme.

Secondly, according to the project's specifications and interviewees' responses, it was found that there are particular responsibilities under specific roles for the information flow management system and the digital tools that have been implemented in this project which enable effective and efficient information flow management throughout the project. So, in this section, this will be discussed under the second subordinate theme of 'Roles and Responsibilities'.

6.4.1 Adaption of Digital Tools

Based on the findings, the interviewees' responses, and the nature of this project, the adaption of digital tools in this project is considered under two aspects. First is the Digital BIM Software that was used to create and produce the information consisting of the model information such as 3D models, 4D scheduling, clash detection data, etc. Secondly, the BIM collaboration tool was used to share, exchange and manage the created and existing information. These two aspects in relation to the 'Adaption of Digital Tools' subordinate theme will be discussed in this section.

6.4.1.1 Digital BIM Software

This project, as an integrated project, used various digital software and tools to create and manage information. This project, as an IPD project, implemented technological approaches such as BIM, and therefore it was important to choose the right software and tools to ensure receiving the full benefits of BIM adaption (Ingram, 2020). In this project, there were different digital BIM software used, such as Autodesk Revit, which was believed to be one of the most utilised BIM software available.

All different disciplines, such as architects, MEP, structural engineers, and construction engineers, used the digital BIM software to create and produce information in different formats of 2D drawings, 3D models, 4D scheduling and 5D cost estimating. To enable collaboration and coordination of the models and all the information produced by the digital BIM software, a BIM Collaboration Tool was used in this project which supported easy accessibility and coordination of the information by all project parties.

6.4.1.2 BIM Collaboration Tool

It was explained by all the interviewees a cloud-based system as a BIM collaboration tool was utilised in this project to enable effective sharing, exchanging, and managing the information flow. According to C2, *"BIM 360"* was used in this project as *"a cloud-based management tool"* which enabled sharing and managing of information between project teams. It was stated by C3 that BIM 360 *"is basically a platform that allows us to collaborate everything on the cloud"* without needing to upload and download models all the time.

So, this BIM collaboration tool enabled sharing and managing of all the information related to the design and construction models. It can be found that the benefits that the project achieved in terms of the BIM collaboration tool and the digital tools adaption, in general, were because of BIM implementation as it enforces collaboration between all project parties (Ingram, 2020).

In addition to the BIM 360 tool, there was another software used to gather all project data. So, any information unrelated to the model, such as meeting minutes and project specifications, was stored on SharePoint. It was agreed by most interviewees that the use of these BIM collaboration tools was straightforward. It was stated by C1 that the system is *"very accessible"* and if there is any information needed, project teams can easily identify and access that information. So, the shared and exchanged information within the BIM collaboration tool would result in coordinated information, and it will subsequently reduce delays, time, quality losses and cost overruns (Ozkan & Seyis, 2021).

So, it can be found that effective information flow management can be achieved through the use of BIM collaboration tools in this project. Nonetheless, there is a management side to control and maintain the system's information flow process and enable effective exchange of information. As some of the participants mentioned, the management side of this information flow system is a crucial part of the BIM collaboration tool to work effectively. Therefore, the management side with its role and responsibilities will be discussed in the next subordinate theme regarding the effective exchange of information.

6.4.2 Roles and Responsibilities

Based on the findings from interviewees' responses, it was found that there are different managements side responsible for controlling and managing the processes to ensure that information was exchanged and managed effectively through the Digital BIM Software and the BIM Collaboration Tools.

It was discovered from the interviewees' responses that there are not one or two people as a specific document control manager or information manager in this project to manage the flow of information. So, the flow of information was managed more in a discipline-based manner. It was argued by C3 that *"we don't really have an information manager"*, but the BIM managers from all different disciplines manage the information on their side and so the information flow would be managed throughout the various fields.

As this project was a massive project in terms of its size and the number of people and stakeholders involved, and according to C2, *"With a team of a few hundred people working on the job"*, one person cannot be responsible for managing the whole information flow process. In this project, there were different BIM Managers with different responsibilities based on their disciplines. So, all the project's contractors and parties had a BIM lead for each discipline who was responsible for managing the flow of information between their team and within the main digital BIM software and the BIM collaboration tool (C3 & C4). It was pointed out by C3 that *"there are some overlapping there"* in terms of the information flow management, but that would not cause issues as project managers, and BIM managers worked collaborative together so that when an issue was raised, the managers would get notified and together, they would resolve the problem instantly.

BIM managers were responsible for all clash detection detections and ensuring that the level of fit and finish within the models was met (C2). Also, based on the interview participants, the BIM managers were responsible for making sure that project members were following the information flow process and using the BIM collaboration tool and digital BIM software accurately and effectively to enable the effective flow of information.

6.5 Theme 2 – Challenge of Effective Information Flow Management

Due to the increased level of the project's complexities, the information being shared in the project could also become complex. Thus, information flow management may face some challenges. The challenges within the information flow vary from project to project as it depends on the project's specific requirements, the technological tools used, the processes and workflows, the project's teams' knowledge of the process and the level of information exchanged throughout the project.

This project, as an integrated project, adapted IPD and BIM implementation, which is believed to enhance many aspects of the project in terms of efficiency and productivity. According to the interviewees, the IPD approach with BIM features and the application of lean principles enabled the exchange of information more effectively as the synergy between these approaches provided many benefits in terms of the communication level and the team collaboration throughout the project which therefore improve the design and construction project due to the reduction of conflicts and reworks (Machado et al., 2020). Therefore, this leads to a reduction of a number of challenges within the information flow management as the information flow management is significantly affected by the level of collaboration and coordination between project members.

So, in this project, the number of challenges related to the effective flow of information was limited. All interviewee participants argued that the main challenges faced in this project were related to the Socio-Organisational Barriers. Based on the interviewees' responses, many issues concerning information flow management were directly or indirectly related to the people involved in the project.

As stated by C1, the effective exchange of information depends on people because *"you can have the best process, the best implementation plan, but if is not well communicated by people…"* then the benefits would not be achieved. So, as agreed by all interviewees, people as the Socio-Organisational Barriers are considered to be the main contributing factor to ineffective information flow management in this project. So, under the theme of Challenges of Effective Information Flow Management, one main subordinate theme of 'Socio-Organisational Barriers' emerged based on the interviewees' responses.

6.5.1 Socio-Organisational Barriers

The majority of participants emphasised the importance of people in making the processes work effectively. Especially in more complex projects like this one, where the number of people involved in the project increases, the need for collaboration and coordination and accordingly the need for information flow management increases as well (Hickethier et al., 2013). So, people play as a socio-organisational factor play an important role in terms of the project's success (Chatzipanagiotou, 2017; Murthy & Screenvias, 2014; Hickethier et al., 2013; Phelps, 2012; Robertson, 2005). Therefore, it can be found that people would make the project effective or ineffective depending on the nature of the project, their understanding of the project's requirements and the level of information they share and exchange.

Based on the interviewees' responses, it was found that the main challenges concerning effective information flow management were related to people. It was argued by C2 even in the very advanced processes, and there would be some socio-organisational barriers because *"as long as there is human involved, there is going to be loss of information"*. So, people were believed by all interview participants to be the socio-organisational barrier to effective information exchange.

In this project, the level of technological and efficient approaches used to manage information were advanced due to the implementation of IPD and BIM/Lean in this project. However, there were still some challenges in terms of information flow management as a result of people not using the implemented processes and tools and not understanding them appropriately. As argued by C2, people are the main contributing factor to poor information flow because *"people need to understand how the processes and the technology work";* otherwise, the information will be lost, and information flow management challenges will occur.

It is, therefore, crucial to understand and realise the importance of people's role in the success or failure of BIM implementation (Phung & Tong, 2021), specifically regarding information flow management.

The responses from the interview participants identified that people were the main contributing factor to ineffective information flow management due to some factors influencing socio-organisational barriers. These factors that emerged from the interviewees' responses under the subordinate theme of 'Socio-Organisational Barriers', which will be discussed in this section, include:

- Non-Digital Mindsets and Behaviours
- Lack of Knowledge

6.5.1.1 Non-Digital Mindsets and Behaviours

It was found that the project was quite successful, and the number of challenges in terms of information flow management was very limited, but those existing challenges were related directly or indirectly to people. As believed by the majority of participants, one of the socio-organisational barriers concerning effective information flow management was people's lack of digital mindsets and behaviours that led to an unwillingness to change to the new methods of exchanging and managing information through BIM and IPD.

Although this project was an integrated project in which there were IPD and BIM adaptions, there were still some people with limited understanding of the technological and innovative processes, and this was a result of having non-digital mindsets and behaviours which would ultimately cause some challenges in terms of information flow management.

It was claimed by C3 that *"one thing that is very critical to IPD projects is having the right person in the room"* and "*it doesn't necessarily mean that you are the best" but it means that it is important to have the necessary background to the job and "you are also interested in collaboration"*. So having the right knowledge and mindset to work in a digital collaborative environment is the key to effective exchange of information and thus achieving the project targets.

It was argued by C3 that even if somebody is the best engineer or the best architect in the world, but the person does not have *"that personal skill to work with a team and collaborate, then it's not going to be a very easy process to do IPD"* because IPD is all about the collaboration and *"the integration"* and thus people need to be integrated into the project. All the participants agreed that if people had the right mindsets in adapting to the new processes, then there would not have been any significant challenges in the project, especially in terms of information flow management. It was argued by C4 that some of the *"old people who spent most of their life in the old processes and not willing to change"* were the causes of some of the challenges in the project because then the BIM lead teams had to spend time and had to make an effort to convince those people to do the required processes. This was because people *"are panicked from using the new technology,"* and when required to do so, *"they don't react very well out of their comfort zone"* (C4).

It was highlighted by many of the interviewees that there was some resistance to change in this project as people had difficulties changing their traditional work methods to the new technological approaches and processes of sharing information more collaboratively. So, resistance to change was one of the factors causing challenges in terms of effective information flow management because one of the core barriers to successful innovative approaches, such as BIM implementation that is related to people, is their resistance to change (Davies et al., 2015; Leśniak et al., 2021; Olanrewaju et al., 2021; Siebelink et al., 2021).

When the researcher further explored the factors concerning people's resistance to change, it was found that the majority of interviewees argued a fundamental reason affecting these issues. So, the interviewees believed that some project members did not have the right understanding and knowledge of the BIM and IPD processes. Therefore they had some challenges adapting to these processes and workflows and sharing information by using these workflows.

6.5.1.2 Lack of Knowledge

Another important point made by many interviewees was that the issue with the resistance to change was not only because of the individual's behaviours and unwillingness to change. It was argued by C1 that the problem underlying this issue was the lack of knowledge and training. The biggest problem was identified by C1 to be the lack of knowledge about the BIM processes which resulted in the absence of communication between project members.

Similarly, it was indicated by C2 that if people do not work towards the required process, it is because *"they don't know how to do it"*, and that causes issues within the project. So, *"everybody needs to be on the same level of understanding using the software and the processes"* to enable effective exchange and management of the information flow (C2). Although many of the project teams, especially the lead people like the BIM managers, were very knowledgeable about BIM and IPD approach and helped the project in terms of information flow management, there were still some people with a low understanding of BIM. Some participants believed that many challenges in the project could also be the result of people's lack of knowledge of using the technologies and adapting the processes. This is because a lack of knowledge is one of the barriers to successful BIM implementation (Leśniak et al., 2021).

Moreover, it was argued by C1 that the lack of people's knowledge could be because *"we did not allocate enough time to properly educate people"*, and that caused issues later in the project. All interview participants believed that it is critically important to ensure that people have the right knowledge about the processes that they will be adapting to enable collaborative working and thus avoid any issues. In this regard, C2 stated that *"it is important to take the time up front to establish all the processes and make sure that everybody understands them and then get on the projects"*.

So, the importance of training people on the new innovative processes and BIM were highlighted by all interviewees as the training would enable people to work effectively in terms of information flow management, and the lack of trained people prevents the BIM transition (Chien et al., 2014; Eastman et al., 2011; Underwood & Isikdag, 2009, Cited in Siebelink et al., 2021). It was mentioned by C2 that there had been some training during the project, for example, training to use the BIM collaboration tools effectively. But it was argued by C4 that it is essential to train people *"before you implement a new technology or method"* and/or to bring people who already have the same level of understanding of the new technologies and processes to enable the exchange of information effectively. This is because to use the BIM and its collaboration tools, and training is needed for the better performance of the project members (Pengfei et al., 2019).

So, it was believed by some of the participants that the training and presenting of the new processes should be done very early stages of the project, and it needs to be taken more seriously in terms of the time allocated to training.

Furthermore, it was mentioned by some of the participants that although the training prior to and during the project is important, but training that is gained through education would be more beneficial. If people were educated in terms of using the new innovative and technological approaches and processes during young age, then there would not have been any challenges during the projects. It was argued by C3 that another difficulty in the project in terms of lack of knowledge is that *"senior people tend to not have technology background than the younger people do"*. This is because many of the young people who joined the projects already had the BIM or the required technical background learned at the university or college.

Also, younger people are *"more open to change"* and to adapt new processes compared to the old generation (C1); thus, having *"fresh graduates"* who are ready to adapt new technologies and methods of doing the work would prevent the issues concerning the socio-organisational barriers (C4). So, those project teams with the right knowledge and education were not contributing factors to poor information flow management. But those who did not have the right knowledge, mindsets, and understanding of new technological processes were the main contributor factor of poor information flow management because lack of training and education is considered to be one of the barriers to the digital approach's implementation (Dainty et al., 2017).

The findings from the interviewees' responses indicate that if people in the project do not have the right mindsets, then they would not be able to work collaboratively in an IPD and BIM environment, and they may resist change to the new ways of working in which they have to share and manage information within the required collaborative BIM tools. Also, if people do not have the right knowledge of the IPD and BIM processes and technologies in terms of sharing and exchanging information, then they would not be able to understand the processes and the required collaborative information sharing.

Therefore, it is important to understand and address the need for more training and education in terms of using new technologies and processes, such as BIM and the IPD approach to improve the effective exchange of information. It was believed by all participants that training and education can be identified as the best way to improve and enhance other factors causing information flow management challenges, such as non-digital mindsets and behaviours.

6.6 Theme 3 – The Role of BIM/Lean in Relation to Effective Information Flow Management

There has been an increased level of BIM implementation in the last decade due to the many beneficial factors that BIM provide to projects (Al Hattab & Hamzeh, 2013; Eastman et al., 2011; Ingram, 2020; McGraw Hill Construction, 2013; NBS Digital Construction Report, 2021; Sacks et al., 2018). However, there have not been many BIM/Lean implementations by the use of the IPD approach, especially in the UK. This project as an integrated project in which

IPD was implemented along with BIM/Lean. So, in the context of this research, the role of BIM/Lean in effective information flow management has explored the analysis of findings

Based on the interviewees' responses, two subordinate themes merged under this theme to explore how BIM/Lean has affected this project in terms of effective information flow management. The two subordinate themes which will be discussed in this section include:

- Digital BIM Collaborative Environment
- Enabled Lean Processes

6.6.1 Digital BIM Collaborative Environment

In this project, a collaborative environment was provided through various digital BIM technologies and software that enabled all the project parties to improve the information coordination and control of planning, design, estimating and construction in the entire project process and develop effective communications which aimed to ultimately result in effective information flow management.

The technological features of BIM, such as visualisation, clash detection, detailed information asset, etc., which enable working in a collaborative environment, is widely believed to bring numerous benefits to the project, specifically in terms of the information flow management (Azhar, 2011; Eastman et al., 2011; Ingram, 2020; NBS National BIM Report, 2019).

It was mentioned by all interviewee participants that there was various digital BIM software used in this project to create 2D drawings, 3D models, 4D scheduling, and 5D cost estimating across all different disciplines. The digital BIM software and tools used in this project provided many benefits in terms of enabling the project team to work in a collaborative environment where they are capable of managing the information flow effectively through the creation and use of 3D models, detailed information assets, visualisation, and clash detection enabled in the project. So, there were many benefits gained through the enabled digital BIM collaborative environment in this IPD project.

It was stated by C4 that *"BIM as a tool is always beneficial"* and *"it makes every project more lean and more efficient"*. This is because BIM provides a collaborative environment in which people can use the digital BIM software and tools to actively create, share and manage the information models by visualising and analysing the models. As argued by C4, BIM is both a tool and a method for information flow management. Because the tool itself requires right usage and utilisation to be beneficial. So, BIM processes are essential to enable achieving the maximum value of the tools (C4) to enable the effective exchange of information. All interviewees agreed that by using BIM enabled collaborative platform, up-to-date information was provided, which would give immediate insight into the issues as they arise in all project stages. According to C3, *"BIM provides a point for information"*, and it is *"designed to be a collaborative tool"* in which there is a model that contains all project information.

So, based on the interviewees' responses, the BIM model was used to be the central source of information in this project as all the detailed design to construction information was built into the model, and people could visually review the model and instantly make any changes required. So, in this regard, it was believed that many benefits were provided through the visualisation of the BIM model and identifying any clashes and conflicts. As all the design information, such as 3D views, conventional working drawings, schedules, costing and quantities, can be extracted from the BIM model (Ingram, 2020), effective information flow management would be enabled.

Thus, another element of the BIM feature which was enabled through the IPD project was cost efficiency. C3 gave an example to explain better how BIM visualisation and clash detection features enabled the project teams to share information instantly and work towards cost reduction.

"We had some steel columns put in, and the steel was thicker than we originally intended to be. And it was conflicting with the way our design was working. So what we did, instead of just picking in deciding what we thought would be the best solution, we brought all members in, and we were able to look at the existing conditions that were on site and how to redesign the area to work, but also how to make it the most cost-effective. Because now I have access to the pricing information from the person that does concrete pricing information. I have pricing information from a team that does the concrete block work. So, we are able to come up with a design that works something that is efficient but also is cost-saving for the owner. And what that will do is drive down our current cost, and then that money can be realised for other things within the project".

So, through the visualisation of the 3D models, project teams could detect the clashes and conflicts in the design and therefore work collaboratively to not only resolve the clashes but also make the design more cost-effective. Thus, the example demonstrates the beneficial role of BIM in managing information flow effectively.

Moreover, it was believed by the majority of participants that in traditional projects, there are challenges in terms of information exchange. As explained by C4, in non-IPD projects, there is usually a lack of information or duplicated information, or *"the process of obtaining the information is quite difficult"* because "*nobody wants to take responsibility on any mistake in the design"*. Therefore, there are many repetitive processes and iterative workflows of information exchange until it gets approved for sharing between other project members. This is in contrast to what was happening in this project.

So, in the IPD environment, always *"everyone has access to all the information at the same time because it's shared responsibility"*, and project teams did not have to go through a repetitive process of getting approval for sharing or not sharing certain information (C4). This is due to the nature of the IPD project and the way that it has been set as a shared risks and rewards type of contractual process. So, as argued by C4, *"it's not only about the system and technology*", but it is about the contract. Because all the project parties and stakeholders were *"under the same contract"*, so, the responsibilities were shared. So, for example, *"I spend money from my pocket, I'm spending from your pocket at the same time and vice versa"* (C4). Subsequently, in the IPD project, *"someone's mistake is everyone's mistake"*, as it was mentioned by all participants that the project is about sharing risks as well as the rewards.

Therefore, it was believed by the majority of participants that IPD as a *"collaborative environment"* which was enabled through BIM/Lean implementation was believed to be an open environment where information can be effectively shared along with sharing responsibilities between all project stakeholders from the owner to the designer who would all *"focus only on one thing, on how to build better, how to bring the best value"* in the project (C3 & C4).

It can be found that one of the important benefits of having IPD in the project, along with the BIM/Lean approach, was *"more focusing on creativity and solving problems rather than focusing on who is responsible"* for mistakes or issues in the project. So, *"focusing about innovation environment rather than protect myself environment"* was achieved through IPD contractual approach because IPD is a "delivery system that seeks to align interests, objectives and practices, even in a single business, through a team-based approach" (LCI,2013).

Furthermore, it was strongly argued by C3 that *"the IPD contract really changes the mindset of people to put the project first"*. By working collaboratively, people would better understand each other's work and make effective and respectful relationships with different people, which leads to the project's success (C3). Similarly, it was stated by C2 that due to the advanced level of collaboration in the IPD project, people's behaviour towards each other had been significantly improved.

So, *"IPD contract allows that collaborative nature so that people can understand what everybody else is doing in order to put the project first"*. This shows the importance of implementing IPD along with the BIM/Lean approaches to better achieve the benefits, especially in terms of effective information flow management.

6.6.2 Enabled Lean Processes

It was highlighted by the majority of participants that one of the success factors of this project in terms of effective information flow management was the enabled lean processes through both the BIM and IPD approach. It was believed by C4 that the role of BIM and Lean in relation to the effective exchange of information is essential and it is *"mastering every project"*. Especially in the IPD project, *"BIM and Lean processes make the work really easy for everyone and create kind of homogeneous environment that everyone on the project benefit from"*, which would ultimately enhance the information flow management as well. It was stated by C1 that BIM and Lean processes allow people to work together effectively towards more innovative ways of working and sharing information. Thus, in the design process, lean processes helped to bring critical design considerations to the forefront (C2).

Moreover, it was mentioned by some of the interviewees that this project adapted lean processes and principles in terms of working towards reducing waste, rework, and delays, especially throughout the exchange of information. It was argued by C3 that *"we are constantly talking about ways of being lean in order to reduce our rework and provide what needs to be provided"*. An interesting example was given by C3, demonstrating how this project worked towards becoming more leaner and achieving lean principles.

"So, we have a big room in our on our site, it's a big trailer where everybody works. And that particular trailer had a ramp going into the, into the trailer. But the ramp started at the very far side of the building. And so, every day, all the people that come into the building, they need to come sign in. So, you could have 100 or 200 people come into the trailer in one day. And I calculated how much time it took to walk around the building to get to the ramp go inside. And it was about 20 seconds. And so, me, and I think a couple of people that are involved in this project, we knew we crunch some numbers and determine that if 100 people every day had to come in and sign in that this much time that we're losing. And if you take the average cost of

every person doing that work for the lifetime of the project being pretty substantial cost about $50,000 Canadian. So, what we said is, look, we can spend, you know, $1,000 and install a staircase that's in the same path of travel from the building so that when you go from A to B, it's the shortest path. And so, we presented that to the team and everybody, so it's a great idea. And so, it's, it's seemingly such a small thing, you know, spending 30 seconds to walk around the globe ramp. But by putting that staircase, they're actually made the project a lot more efficient, and it was value for the project. So, these types of things are the leading initiatives that we're constantly looking at trying to improve."

The example shows the importance of giving value to the project and working towards enabling as many BIM/Lean principles as possible to make the project more effective and efficient. Also, another aspect of the lean implementation in this project was the adaption of the pull planning system, which was believed to be helpful in terms of managing the flow of information in a way that the level of information needed to be shared at a specific time of the projects schedule was identified. The pull planning system had many benefits in the BIM collaborative environment where people could plan ahead and work towards that plan effectively.

So, it can be found that IPD, with the use of a BIM collaborative environment, improves the project tremendously because of that cultural aspect of it, and the IPD processes are fairly streamlined that are based on Lean and Agile thinking certainly helps the project specifically in terms of effective information flow management. Also, from a technology standpoint, IPD leverages BIM to its fullest in terms of producing and managing information.

6.7 Chapter Summary

This chapter presented the analysis and findings of Case Study C as an IPD project which included interviews conducted with four key people who were directly involved in this project. To address the research aim and objectives and based on the interviewees' responses, three main themes emerged associated with subordinate themes that were introduced and explored in this chapter. Each subordinate theme was further examined through discussion of all the factors elicited from the findings that influenced the subordinate theme.

Furthermore, all factors were explored through the lens of the review of the extant literature and the case study project.

The findings firstly highlighted the importance of 'Effective Exchange of Information' and how this was accomplished in this project by 'Adaption of Digital Tools', which was managed through specific ‘Roles and Responsibilities’. Then, the ‘Challenges of Effective Information Flow Management’, which was explored under one main factor of ‘Socio-Organisational Barriers’, were explored and discussed further. Finally, ‘The Role of BIM/Lean in Relation to Effective Information Flow Management’ was discussed under two subordinate themes of the ‘Digital BIM Collaborative Environment’ and ‘Enabled Lean Processes’. The findings of this chapter represent the Integrated project which is in line IPD approach.

Chapter 7. Cross-Case Analysis and Discussions

7.1 Chapter Overview

Having analysed each case study individually in the previous chapters, this chapter relies on cross-case analysis to discuss the final findings from all cases in relation to the literature review. The discussions are structured and categorised consistently regarding the main case studies themes that emerged from the basis of the literature and the aim and objectives of this research which are shown in Figure 58. Then, having discussed the findings from all cases, the chapter will be concluded through a set of recommendations for effective information flow management based on the discussed findings.

The first section of this chapter includes the findings and discussions related to the first theme of "Effective Exchange of Information". The second covers the presentation of the analysis and findings of the second theme, "Challenges of Effective Information Flow Management", which provides discussions about the details of factors concerning the theme. Then, "The Role of BIM/Lean in Relation to Effective Information Flow Management" will be discussed in the last section. Finally, based on the discussed finding in previous sections, a set of recommendations for improving the information flow will be presented to conclude this chapter.

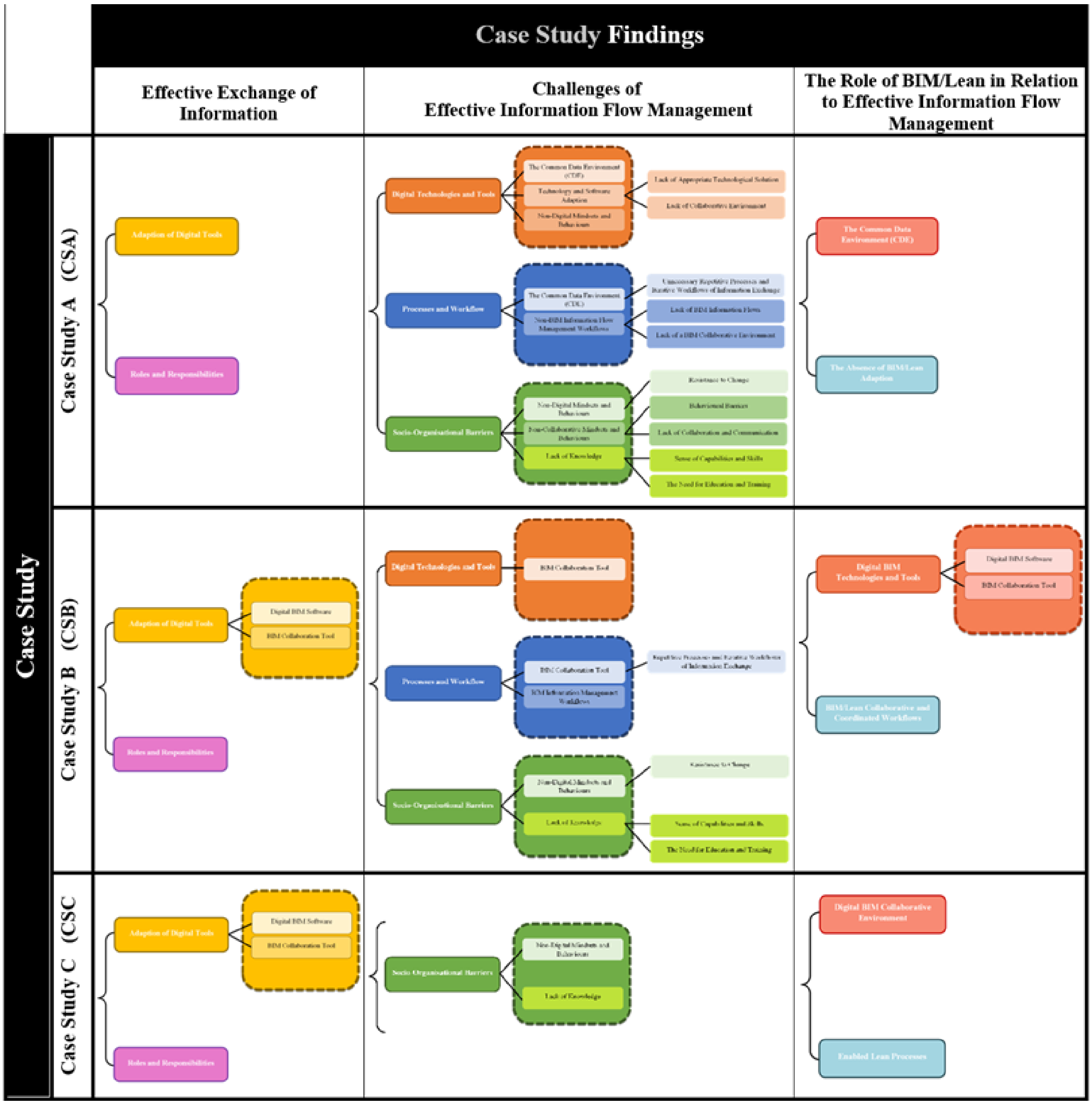

Figure 58 - Chapter 7 Overview

7.2 Effective Exchange of Information

It is widely believed that effective information flow management is critically important to project success (Baldwin et al., 1999; Chatzipanagiotou, 2017; Detlor, 2010; Kania et al., 2021; Robertson, 2005). Due to the increased level of information in the projects, the effective exchange and management of information flow are crucial to achieving project goals (Kania et al., 2021).

The importance of exchanging information effectively was well understood by all the interview participants in all three case studies. In order to exchange information effectively, there is a need for a collaborative platform in which project teams can share and manage information efficiently. To support this information exchange, there is a need for the management side as well. According to the PAS 1192 and ISO 19650, it is required that all projects adopt a Common Data Environment (CDE), which is a "single source of information for any given project, used to collect, manage and disseminate all relevant approved project document for multi-disciplinary teams in a managed process".

So, all case studies adopted a cloud-based system to share and exchange information between project members. So, there was an adaption of digital tools in all case studies. However, due to the various levels of BIM adaption in the case studies and the project's requirements, the level, and the type of this cloud-based system were different.

As can be seen in Figure 59. Case Study A (CSA) adapted the Common Data Environment (CDE) in accordance with the BIM Level 1/Stage 1 requirements set out in PAS 1192. Case Study B (CSB) adopted the same Common Data Environment (CDE) in accordance with the PAS 1192 and ISO 19650, which was referred to as the BIM Collaboration Tool by the interviewees. However, the level of detail and standards that were required to adapt the BIM collaboration tool in comparison with the CDE in Case Study A (CSA) was very substantial and advanced.

So, people had to follow the restricted file naming protocols and approval processes to share and exchange information within the BIM collaboration tool in CSB. Whereas in CSA, there were no such restrictions on file naming conventions to be followed. Similar to what CSB adopted, *"a cloud-based management tool"* (C2) was used in Case Study C (CSC) to enable the effective exchange of information between project teams.

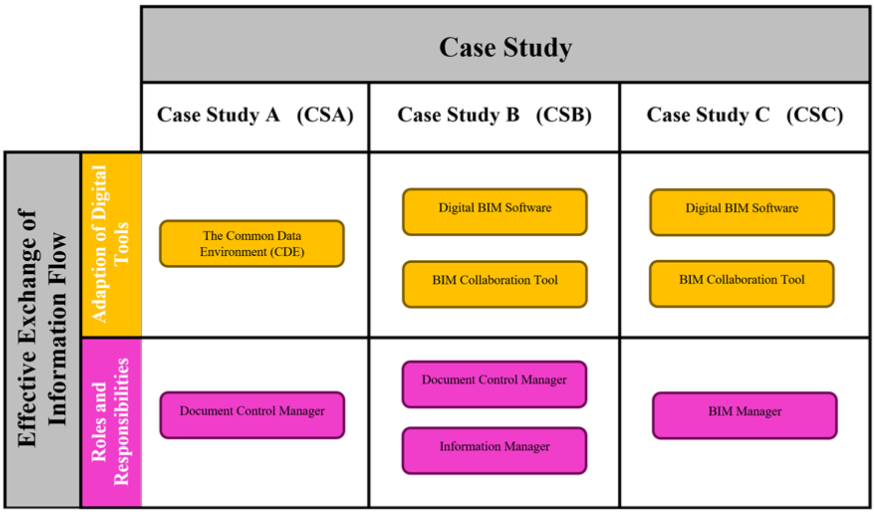

Figure 59 - Effective Exchange of Information Flow Discussion Overview

In all three case studies, participants believed that the cloud-based system that was used to manage information was working effectively with minor issues concerning the required processes and workflows of information exchange which will be discussed in the next section. So, all their case studies reported sharing information using this system because the shared and exchanged information within the CDE would result in coordinated information, and it will subsequently reduce delays, time, quality losses and cost overruns (Ozkan & Seyis, 2021).

It was found that the BIM collaboration tool used in all three case studies was very similar regarding its usage and the benefits provided to the project. However, to better exchange and share information between project members and to create different types of information, CSB and CSC were using additional platforms. As both CSB and CSC had implemented BIM to advanced levels, there were other requirements set out in the project in terms of information creation and management. So, these two case studies used various Digital BIM software to enable the project teams to create model information and exchange them effectively.

So, it can be found that although CSB as a Managed project with BIM Level 2/Stage 2 requirements and CSC as an Integrated project with an IPD approach had additional platforms to create and exchange information models due to their nature of the project as BIM projects, but the overall processes of information exchange seemed not to be significantly different. Especially comparing CSA with CSB in terms of the effectiveness of the information flow exchange, the CDB appeared to be working very similarly, with the only difference being the BIM Level 2/Stage 2 file naming protocols and required approval processes that CSB had to carry out as extra activities to CSA. These additional protocols and workflows were believed to cause some challenges in CSB concerning the effective exchange of information flow management. So, it can be argued that although the cloud-based systems used in both CSA and CAB were very similar but the one in CSB caused challenges in the project. In contrast, the CDE in CSA was believed to be working effectively considering the requirements and the project's needs. So, in all three case studies, there were digital tools adapted to ensure the effective exchange of information.

Moreover, to ensure that the information is exchanged and managed effectively, some management sides were responsible for controlling and managing the whole process. So, both CSA and CSB reported having a Document Control Manager responsible for managing the CDE in the CSA and the BIM collaboration tool in CSB. So, the document control manager had the same responsibilities in both CSA and CSB to ensure that the cloud-based system works properly and the process of flowing information within the CDE is managed effectively. As CSB was a BIM Level 2/Stage 2 project, there was another management side to control the information within the BIM software. So, in addition to the Document Control Manager, CSB had an Information Manager who was "in charge of integrating and coordinating information within the information model" (Scheffer et al. l., 2018).

It was found that if the information manager had to check the model to ensure that the information within the model was accurate and if there were any clashes, the information manager *"is responsible to making sure that the respective parties and the members of the design team close that clash"* (B3). So, the information manager was responsible for supporting reliable information exchange and maintaining and receiving information in the information model (Scheffer et al., 2018). It can be found that as the level of BIM implementation in CSA was up to Level 1/Stage 1 in which, there would not be any advanced levels of 3D modelling and model information did not exist, and then there was not any information manager in that project.

Moreover, it was found that in CSC, there were different management sides responsible for controlling and managing the processes through both digital BIM software and the BIM collaboration tool. It was revealed by the interviewees that as CSC was an IPD project in which all parties had mutually signed contracts, so there was not a specific person responsible for the information exchange throughout the whole project. Yet, the flow of information was managed more discipline-based, meaning that each project's stakeholders and parties had BIM managers for each discipline who were responsible for managing the flow of information between their team and the digital BIM software and BIM collaboration tool.

So, it can be seen that in terms of the management side of the CDE, both CSA and CSB had the same responsible roles. But to effectively manage the information model within the BIM digital software, both CSB and CSC had additional roles. So, it can be found as the level of information increases, the importance of managing the information increases, which as well would require an effective exchange of information (Kania et al., 2021; Zeng, Lou, & Tam, 2007). Therefore, by shifting towards more advanced BIM implementation, additional roles and responsibilities would be needed to manage the information throughout the project because there would be more information with different types produced (3D information model, 2D drawings, documentation information, meeting minutes, etc.).

7.3 Challenges of effective information flow management

The challenges within information flow management vary from one project to another as the level of information shared and exchanged throughout the project differs. So, in the context of this research, it was interesting to identify that although the level of BIM implementation is different in each case study, some of the challenges still exist in all case studies. An overview of all the factors identified in all three case studies can be found in Figure 60.

The challenges of effective information flow management were divided into subordinate themes that emerged from the literature findings and the aim and objectives of this research and the factors associated with them, elicited from interviewees' responses in each case study.

In terms of the challenges of effective information flow management, CSA was found to have more challenges in comparison with the other two case studies due to the level of BIM implementation in this project which was Level 1/Stage 1. So, many of the challenges associated with CSA were due to the lack of full BIM implementation and the issues that caused because of that.

In traditional projects where BIM is not fully implemented up to Level 2/Stage 2 then an inadequate flow of information between project teams is the main cause of major information flow challenges due to the jumbled and overlapped flows of information (Al Hattab & Hamzeh, 2013; Park & Lee, 2017; Rathnasinghe et al., 2020; Zoubeir et al., 2014;). As can be illustrated from Figure 60, in CSA, the number of factors affecting the ‘Digital Technology and Tools’ and ‘Processes and Workflows’ and the ‘Socio-Organisational Barriers’ were more than CSB and CSC.

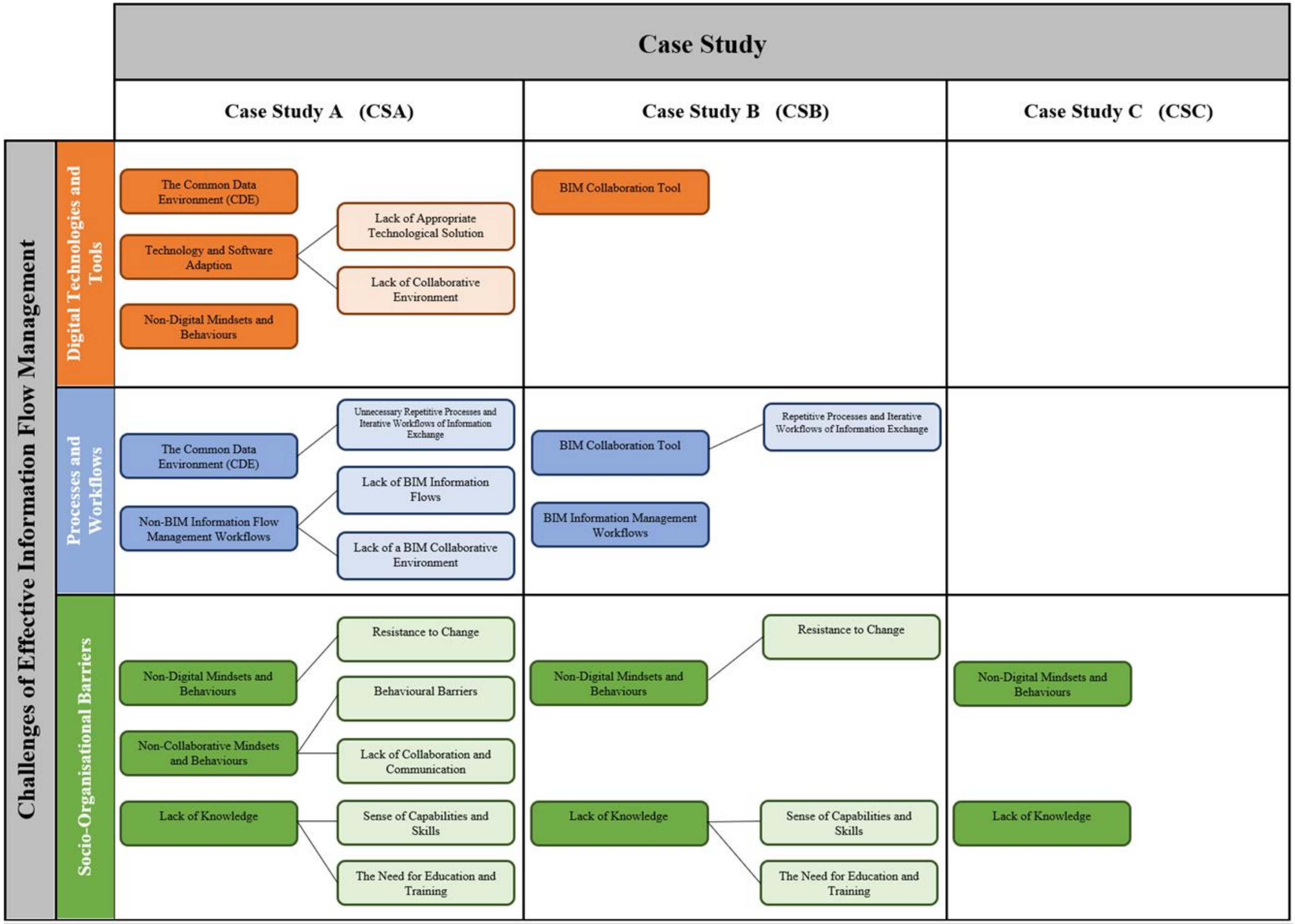

Figure 60 - Challenges of Effective Information Flow Management Discussion Overview

7.3.1 Digital Technologies and Tools

When CSA is to be compared with CSB, it can be found that the number of challenging factors concerning the 'Digital Technologies and Tools' were more in CSA, and as the projects moved towards more BIM implementation and adapted BIM Level 2/Stage 2 then those factors reduced.

So, it can be found that by the adaption of digital BIM software, many of the issues concerning the 'Lack of Collaborative environment' and 'Lack of appropriate Technological Solution' could be tackled. This is because communication between project teams would be facilitated through visualisation as part of BIM software and tools, enabling a continuous flow of information (Al Hattab & Hamzeh, 2013) and, thus, overcoming challenges within information flow. This is evident when the number of challenging factors in CSB is analysed.

In regard to the 'Digital Technologies and Tool', the only factor that remained as a challenge in CSB was the BIM collaboration tool, the CDE. This was due to some limitations and complexities of the software used in the project. Some of these limitations that were revealed include:

- Internet Connection concern: It is widely believed that 'The Internet' provides many benefits to projects in terms of supporting the exchange and sharing of information, aiding planning information, coordination, visualisation and communication (Yu, Gao, & Ren, 2016; Zeng, Lou, & Tam, 2007), which enables collaborative working and real-time management between project teams (Zeng & Wang, 2020). Despite the benefits of the Internet as a technological communication platform which facilitates an effective information flow throughout the project lifecycle (Chen et al., 2018; Zeng, Lou, & Tam, 2007), there were several arguments both in CSA and CSB stressing that internet can be viewed as a limitation in terms of the information flow.

  According to the interviewees' arguments, if the internet connection fails, then downloading and accessing the information would be extremely challenging. This is because the BIM collaboration tools rely on the internet connection to be accessible by the project teams. So, lack of internet would cause unnecessary delays and rework as people have to wait for the internet to reconnect or share information using emails which would cause additional issues. Late information exchange would result in extreme delays and problems downstream in the design phase and subsequently in construction (Al Hattab & Hamzeh, 2013). Therefore, it can be found that in the internet as a communication platform that facilitates an effective information flow throughout the project lifecycle (Chen et al., 2018; Zeng, Lou, & Tam, 2007) could also become a barrier to project if it fails to connect and if people cannot have access to it as argued in CSA and CSB.

However, it is argued that the application of BIM and its tools have been developed to the point where there is no single BIM technology that can meet the construction projects' needs due to the increased amount of information and the complexity of the information management, so internet is found as the mainstream way for construction projects to manage the information effectively (Jiang et al., 2021). Therefore, it is vital to ensure that internet access is enabled throughout the project so that the project teams can use it as an enabled platform and not a barrier.

- Time-Consuming Information Flow: One of the limitations of the BIM collaboration Tool's software was the time-consuming workflows required to exchange information. It was argued that some software limitations did not allow the exchange of information smoothly because if there were a minor issue with the information file naming, the system would automatically reject that information regardless of what that piece of information is. So, if a piece of information was rejected due to the software protocols, then that information must go back to the person who first issued that information to upload it back again using the correct naming convention. That was believed to be a time-consuming process of information exchange which would result in unnecessary delays and rework in both CSA and CSB as these two case studies used similar types of BIM collaboration tools.

  In addition, the time-consuming information flow had resulted in some offline exchange of information, meaning that some information was being exchanged and shared externally and not through the BIM collaboration tool because people preferred to share and receive information as soon as possible, so they emailed the information to each other. This issue was happening in both CSA and CSB because of the limitations that the BIM collaboration tool had in these two case studies.

7.3.2 Processes and Workflows

One of the main contributing factors of ineffective information flow management which was found in both CSA and CSB, was the ‘Processes and Workflows’ within the information exchange. It was found that both CSA and CSB had some challenges in regard to the unnecessary repetitive processes and iterative workflows of information exchange that were associated with the CDE in CSA and the BIM collaboration tool in CSB. Another issue was also found in regard to the BIM and non-BIM information flow management workflows.

The issues concerning the CDE in CSA and the BIM collaboration tool in CSB were both related to information-sharing workflows and information approval processes. The process of information flow between project teams includes several iterative loops that result in idle time, rework, and delays in the project until the architects and owners approve the design (Al Hattab & Hamzeh, 2013).

Interview participants of CSA believed that this issue occurs in CSA because of the lack of BIM application, and if BIM had been fully implemented in this project, then the processes and workflows of information would have been smoother and more efficient. This is in contrast to what was found in CSB. This issue was also found in CSB and pointed out several times by the interview participants in CSB as of challenging factor.

Although the issues seemed to be similar, but the causes of the issue were found to be different in CSB. The lengthy and iterative workflows of information exchange in CSB were due to the BIM Level 2/Stage 2 requirements set out in PAS 1192 and ISO 19650, requiring several restricted information management processes. So, it can be found that by having BIM Level 2/Stage 2 adaption, the issues of the processes and workflows within the BIM collaboration tool would still exist and become even more challenging.

Moreover, it was interesting to notice that the lack of one element was identified to be a challenge in CSA, while the existence of that element was also a challenge in CSB. So, there was an overlapping between the existence and non-existence of one element, being both challenging in CSA and CSB. It was found that in CSA, some of the challenges concerning the processes and workflows were due to a lack of BIM information flow management workflows.

So, the lack of BIM information flows and a BIM collaborative environment were found to cause challenges in effective information flow management. Although the number of challenging factors resulted from non-BIM information flow management workflows was a lot more than the number of challenging aspects as a result of BIM information management workflows, it was noticeable that BIM implementation could be challenging as well. Although BIM provides numerous benefits, as it is a complex process, it requires coordinated efforts between all project teams to be successfully completed (Manoj et al., 2021).

Therefore, some of the BIM Level 2/Stage 2 information management workflows could be challenging due to the BIM requirements, so effective exchange of information could be enabled. The improvement of the effective information flow management through BIM Level 2/Stage 2 in CSB can be realised when compared to the CSA as the number of challenging factors related to the information flow management were reduced in CSB, which is a result of BIM implementation.

Furthermore, when comparing CSA and CSB to CSC, it is interesting to notice that there is a significant change in terms of the challenges concerning both 'Digital Technologies and Tools' and the 'Processes and Workflows'. It can be illustrated from Figure 60 that many of the challenges that existed in both CSA and CSB related to the technology and processes did not exist in CSC, which reveals the significant difference between a Defined and Managed project to an Integrated IPD project. So, because of the advanced level of the project in the CSC as an IPD project, many of the challenges did not exist, or there were minor challenges that the project resolved throughout the process, and they did not cause any significant issues. So, it can be seen that many of the challenges could be resolved by applying the IPD project. Whereas in CSA and CSB, there were not very significant changes even though BIM was implemented in CSB.

As already discussed, when analysing the findings from all three case studies, it was found that the challenges associated with the 'Digital Technology and Tools' and the 'Processes and Workflows lasted in both CSA and CSA, though the number of the challenging factors reduced by the BIM implementation in CSB. Although, these challenges were not found in CSC as the Integrated IPD project. However, the' Socio-Organisational Barriers' was the only challenging factor in terms of effective information flow management faced by all three case studies.

7.3.3 Socio-Organisational Barriers

The most interesting factor that did remain the same in all these three case studies as the challenge of effective information flow management is the 'Socio-Organisational Barriers'.

This factor was the most challenging factor affecting information flow management regardless of its BIM implementation.

As a socio-organisational factor, people are always the critical aspects of any project because they are the main contributory factor of any project to work. This has been highlighted many times in the literature (Robertson, 2005; Phelps, 2012; Hickethier et al., 2013; Murthy & Screenvias, 2014; Chatzipanagiotou, 2017). So, in the context of this research, it can be found that many of the challenges associated with the projects that resulted in poor information flow management were related to socio-organisational barriers. Therefore, many factors, such as non-digital mindsets and behaviours, non-collaborative mindsets and behaviours and lack of knowledge, are the root causes of many issues concerning people. Regardless of the projects' BIM Maturity levels, the two factors of 'Non-Digital Mindsets and Behaviours' and the 'Lack of Knowledge' identified in all three case studies indicate the importance of these two factors in relation to effective information flow management.

There were many factors identified in all three case studies contributing to the socio-organisational barriers, which include:

- Resistance to Change: One factor causing issues due to non-digital mindsets and behaviours was that people were unwilling to change and use innovative and technological tools and processes. It was pointed out in CSA that despite the existence of the CDE for information exchange, some project members still used emails to share information because *"people do not like new changes"* (A4), and even in CSB *"some sort of resistance"* to use the BIM collaboration tool was discovered (B5). This issue also affected the CSC, as stated by C4 that *"old people who spent most of their life in the old processes and not willing to change"*. So, resistance to change was one of the factors causing challenges in terms of effective information flow management because one of the core barriers to successful innovative approaches, such as BIM implementation that is related to people, is their resistance to change (Davies et al., 2015; Leśniak et al., 2021; Olanrewaju et al., 2021; Siebelink et al., 2021). As can be noticed from Figure 60 issue remains in all three case studies from a defined BIM project to a Managed and Integrated project which confirms that people can be considered to be the current barrier of the BIM approach because the most important issues for the management side is the 'resistance to change' (Davies et al., 2015).

- Lack of knowledge: another important factor which was repeatedly highlighted in all interviews of the three case studies as the leading factor of ineffective information flow management was discovered to be the 'lack of knowledge' of people involved in the projects. In all three case studies, interview participants believed that many of the challenges concerning the socio-organisational barriers were related to the lack of understanding of the processes and the benefits of BIM implementation because lack of knowledge is one of the barriers to successful BIM implementation (Leśniak et al., 2021). As highlighted by several participants, "technology is easy, processes are straightforward, but the difficulty is with people. So, it is crucial to train people to enable them to engage in that process and use the technology" (A5).

  It can be found that lack of training and education is one of the barriers to the adaption of digital approaches (Dainty et al., 2017) because training would enable people to work effectively in terms of information flow management, and the lack of trained people prevents the BIM transition (Chien et al., 2014; Eastman et al., 2011; Underwood & Isikdag, 2009, Cited in Siebelink et al., 2021). Although the level of BIM implementation in both CSB and CSC was advanced but there were still some people in the projects who had a limited understanding of the BIM requirements, its tools, and its benefits. Thus that would cause issues in the project because if people do not have the right mindsets and the right knowledge, then they would not be able to work collaboratively in any BIM projects and follow the required processes. So, to the best use of BIM and its collaboration tools, training is needed for better performance of the project members (Pengfei et al., 2019).

  It is interesting to see that many of these factors remained the same in all three case studies indicating that whether the project has limited BIM implementation or adopts advanced approaches such as IPD, people would still be the main root causes of the challenges in information flow management. Therefore, the importance of this factor which all the interview participants highlighted, demonstrates that despite the BIM adaption level, people need to be trained and educated to be able to work in a collaborative environment where they can share and exchange information effectively.

7.4 Effective Role of BIM/Lean in relation to Information Flow Management

It is widely believed that implementing BIM would provide many benefits to built asset projects (Al Hattab & Hamzeh, 2013; Eastman et al., 2011; McGraw Hill Construction, 2013; NBS Digital Construction Report, 2021; Sacks et al., 2018). Additionally, implementing BIM, Lean, and IPD together would provide many benefits to the project's performance, and productivity as the synergies between these three approaches have many benefits to the project's entire lifecycle (Machado et al., 2020; Nguyen & Akhavian, 2019). Therefore, the benefits of these approaches in terms of information flow management are explored in all three case studies.

Table 16 - No. Challenges of Effective Information Flow Management

Number of Challenges of Effective Information Flow Management			
	CSA	**CSB**	**CSC**
Number of Main Factors	**3**	**3**	**1**
Number of Sub-Factors Associated with all the Main Factors	8	5	2
Number of Factors Associated with all the Sub-Factors	10	4	
Number of Overall Sub-Factors	**18**	**9**	**2**

Based on the discussions in the previous section and Table 16, it can be found that the number of factors affecting the information flow management challenges would be slightly reduced as the projects move towards more integrated projects like IPD. So, the role of BIM/Lean in relation to effective information flow management can be identified when comparing the defined, managed and integrated projects.

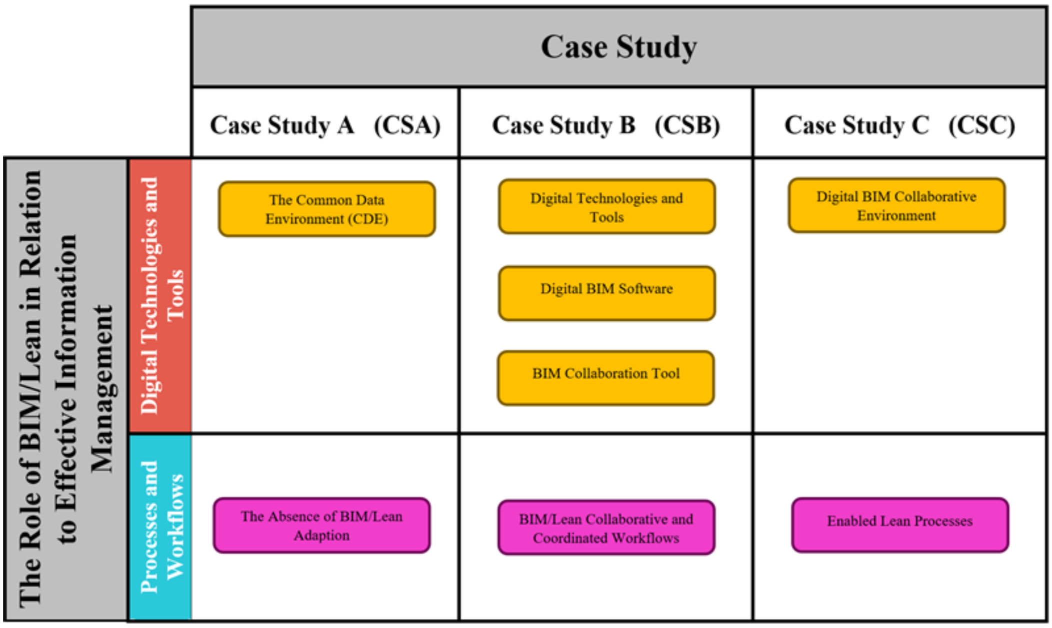

Figure 61 - The Role of BIM/Lean in Relation to Effective Information Management Discussion Overview

As can be seen in Figure 58, it was realised that although the CSA adopted BIM Level 1/Stage 1 but as the BIM implementation was very limited, there were no considerable benefits, and there were no noticeable advantages and factors in this context. As only one aspect of the BIM approach was adopted in CSA, which related to the usage of a CDE to share and exchange information, the only benefits that the project gained were because of this CDE despite its challenges.

The interview participants in CSA believed that there could have been many benefits provided in this project if BIM was fully implemented to an advanced maturity level. Also, it was believed by most of the participants in CSA that many of the information flow management challenges could have been improved if BIM had been fully implemented in this project because of the features that BIM provides. The participants' assumptions were true, as CSB and CSC are the proof for their arguments. However, the CSB still faced many challenges in terms of ineffective information flow management, which shows that the BIM implementation to an advanced level is not the only factor to enable BIM benefits, and there are other factors influencing this as well.

Some beneficial factors have been identified as the role of BIM/Lean in rems of effective information flow management in CSB and CSC where BIM was implemented. These factors were related to the ‘Digital BIM Technologies and Tools’, ‘BIM/Lean Collaborative and

Coordinated Workflows', 'Digital BIM Collaborative Environment', and 'Enabled Lean Processes' shown in Figure 61 are discussed in this section.

- BIM Collaboration and Communication Environment: As stated by Ibrahim et al. (2019), "the success of information sharing in the digital environment depends on organisational behaviours supported by the collaborative constructs," which BIM supports as it provides a collaborative environment to enable efficient and effective information flow management (Machado et al., 2020). So, it can be found that one of the most critical factors in the beneficial role of BIM/Lean in terms of effective information flow management, which is enabled through both digital BIM software and BIM collaboration tool and through the BIM-enabled feature of visualisation, is 'collaboration and coordination'.

  Communication and collaboration between project members can be facilitated through the BIM model and visualisation, which enables better coordination across all project parties and different disciplines (Andersen & Findsen, 2019). So, it can be seen that as BIM implementation in projects becomes more advanced, then the digital BIM software and the BIM collaboration tool could support the collaboration and communication between project members more effectively. So, it can be found from the findings of CSC that the most beneficial role of BIM is the enabled collaboration and coordination between the team members, *"which would not be available in a BIM Level 1/Stage 1"* project (B1).

  Likewise, B1 stated that one of the valuable roles of BIM/Lean in terms of information flow management is that *"it encourages collaboration"* amongst project parties. It was found in CSB and CSC that collaboration which was enabled through BIM Level 2/Stage 2 implementation and the IPD project, provided many benefits to the project in terms of the effective exchange of information. When asked about the role of BIM/Lean and IPD in information flow management, all interviewees from CSB and CSC agreed that it helps with collaboration and coordination through BIM digital technologies and tools and BIM workflows. This is in line with what has been found in the literature, which highlights that collaboration enhancement is one of the main BIM advantages of the project (Al Hattab & Hamzeh, 2013; Khudhair et al., 2021; Machado et al., 2020). In CSB and CSC, project teams worked collaboratively to facilitate effective information flow management.

- Visualisation: one of the most beneficial elements enabled through the BIM implementation and the BIM model was the visualisation factor. Communication between project teams would be facilitated through visualisation as part of the BIM collaborative platform, which would also enable a continuous flow of information (Al Hattab & Hamzeh, 2013) and thus, improving the information flow management.

  In both CSB and CSC project teams benefited from this BIM feature which enabled them to work in a collaborative environment where all project participants could join collaboration meetings to visualise the 3D model and exchange information to ultimately improve communications between project teams and enable rapid decision-making early in the design process (El Ammari & Hammad, 2019; Azhar, 2011). It was highlighted several times by participants in CSB and CSC that the visualisation aspect of the digital BIM software provided many benefits to the project in terms of information flow management. Because all the information within the BIM model could be visualised early in the design process by all project members, which allowed early decision-making through the process based on the information that was shared in the model. In both CSB and CSC projects, members were able to visualise their models and everyone else's models, which enabled the effective exchange of information in a collaborative environment where any design errors could be identified easily and thus corrected without causing any delays or reworks later in the project.

  Therefore, it can be clarified that through visualisation, the information reliability would be improved alongside the enhanced collaboration and communication in the project (Andersen & Findsen, 2019; Brito & Ferreira, 2015; Hartmann et al., 2008; Koo & Fischer, 2000).

- Clash Detection: another essential point that was identified in both CSB and CSC was the ability to detect any conflicts and clashes within the BIM model, which was enabled through visualisation. So, through the visualisation of the 3D models, project teams could detect any design errors, clashes, and conflicts in the design and therefore work collaboratively to not only resolve the clashes, but also to make the design more effective and efficient.

  Therefore, identifying any information issues within the model and resolving it early in the design process would result in having more reliable information and thus improving the information flow management.

- Lean Processes: Additionally, one of the factors that were pointed out many times in CSB and CSC in terms of the beneficial role of BIM/Lean to effective information flow management was that BIM collaborative and coordinated workflows enabled lean processes and supported lean principles. Although not all participants in CSB had advanced levels of understanding of lean and its principles to clearly address the role of lean in this project, but it was found that some of the lean principles were achieved in CSB through BIM Level 2/Stage 2 implementation.

  Through the BIM collaboration workshops where all project participants visualise information models and can run clash detection, any missing information, wrong information, duplicated information, and any errors or mistakes can be detected and thus resolved. So, any potential issues could be resolved, which *"prevents waste happening on site or rework happening on site"* (B1). This would not only prevent waste creation on site but also delays and reworks could be eliminated during the design process, making the information flow management leaner.

  It was believed by B1 that through BIM implementation and by practising BIM features such as collaboration and coordination, *"we are trying to get a leaner project"* and *"build it more leaner"*. Similarly, B2 argued that the project "will become a lean process" in which information flow management would be more enhanced through BIM implementation. So, based on the interviewees' responses, it can be found that some of the lean principles in terms of waste reduction were achieved in CSB and CSC through enabled BIM features such as collaboration, coordination, visualisation, clash detection and the required BIM information flow management processes. This shows that the interaction of BIM and lean can provide benefits to the project (Machado et al., 2020; Sacks et al., 2010; Schimanski et al., 2021).

  The BIM features enabled lean principles in terms of waste reduction, such as waste of time, waste of processing, rework, and delays in the project through collaborative working in coordinated workshops where all clashes and information errors were detected and resolved by visualisation of the 3D BIM information models. Eventually, this resulted in improving the effective information flow management in the project.

  Moreover, in CSC, It was highlighted by the majority of participants that one of the success factors of this project in terms of effective information flow management was the enabled lean processes through both BIM and IPD approaches. C4 believed that the role of BIM and Lean in relation to the effective exchange of information is essential and it is *"mastering every project"*. Especially in the IPD project, *"BIM and Lean processes make the work really easy for everyone and create kind of homogeneous environment that everyone on the project benefit from"* which would ultimately enhance the information flow management as well. It was stated by C1 that BIM and Lean processes allow people to work together effectively towards more innovative ways of working and sharing information.

Thus, in the design process, lean processes helped to bring critical design considerations to the forefront (C2). So, there are many benefits in terms of the integration of IPD with BIM/Lean approaches, specifically in terms of effective information flow management (Machado et al., 2020; Nguyen & Akhavian, 2019).

- <u>IPD approach</u>: there were many benefits gained in CSC that were primarily due to the adaption of IPD. As illustrated in Figure 60 many challenges that occurred in CSA and CSB did not exist in CSC, and this was because of the IPD implementation. It was believed by the majority of participants that there are challenges in terms of information exchange in traditional projects.

  As explained by C4, in non-IPD projects, there is usually a lack of information or duplicated information, or *"the process of obtaining the information is quite difficult"* because "*nobody wants to take responsibility on any mistake in the design"*. Therefore, there are many repetitive processes and iterative workflows of information exchange until it gets approved for sharing between other project members. This is in contrast to what was happening in the CSC project. So, in the IPD environment, always *"everyone has access to all the information at the same time because its shared responsibility"* and project teams did not have to go through the repetitive process of getting approval for sharing or not sharing specific information (C4). This is due to the nature of the IPD project and the way that it has been set as a shared risks and rewards type of contractual process. In the IPD project *"someone's mistake is everyone's mistake"* as it was mentioned by all participants that the project is about sharing risks as well as the rewards.

  Therefore, it was believed by the majority of participants that IPD as a *"collaborative environment"* which was enabled through BIM/Lean implementation was believed to be an open environment where information can be effectively shared along with sharing responsibilities between all project stakeholders from the owner to the designer who would all *"focus only on one thing, on how to build better, how to bring the best value"* in the project (C3 & C4). It can be found that one of the important benefits of having IPD in the project, along with the BIM/Lean approach, was *"more focusing on creativity and solving problems rather than focusing on who is responsible"* for mistakes or issues in the project. So, *"focusing about innovation environment rather than protect myself environment"* was achieved through IPD contractual approach because IPD is a "delivery system that seeks to align interests, objectives and practices, even in a single business, through a team-based approach" (LCI,2013).

Furthermore, it was strongly argued by C3 that *"the IPD contract really changes the mindset of people to put the project first"*. By working together, people would better understand each other's work and make effective and respectful relationships with different people, which leads to the project's success (C3). Similarly stated by C2 that due to the advanced level of collaboration in the IPD project, people's behaviour towards each other has been significantly improved. So, *"IPD contract allows that collaborative nature so that people can understand what everybody else is doing in order to put the project first"*. This shows the importance of implementing IPD along with the BIM/Lean approaches to better achieve the benefits, especially in terms of effective information flow management.

Moreover, it was mentioned by some of the interviewees that CSC adopted lean processes and principles in terms of working towards reducing waste, rework, and delays, especially throughout the exchange of information. It was argued by C3 that *"we are constantly talking about ways of being lean in order to reduce our rework and provide what needs to be provided"*.

So, by comparing all three case studies, it can be found that IPD with the use of a BIM collaborative environment improves projects tremendously because of that cultural aspect of it, and the IPD processes are fairly streamlined are based on Lean and Agile thinking that certainly helps the project specifically in terms of effective information flow management. Also, from a technology standpoint, IPD leverages BIM to its fullest in terms of producing and managing information. Therefore, the great benefits of BIM/Lean in relation to effective information flow management can be achieved through an IPD project.

7.5 Recommendations for Effective Information Flow Management

As can be found from the discussions in previous sections based on the interviewee's responses and evidence from the literature review, having a successful project relies deeply on having effective information flow management (Baldwin et al., 1999; Robertson, 2005; Detlor, 2010; Chatzipanagiotou, 2017; Kania et al., 2021).

In previous sections, the main three themes were discussed critically across the three case studies. Based on these discussions and findings, a set of recommendations are presented in this section which would help industry practitioners and academia realise the importance of effective information flow management and take recommended actions to better manage the information flow in practice.

7.5.1 Digital Technologies and Tools

In order to manage information flow effectively, it is essential to use digital technologies and tools. Especially as projects move from defined to IPD projects, the requirements of using technological and innovative approaches and tools increase which aims to enhance the exchange of information. Based on the findings of this research, there are two main elements associated with this context: The Common Data Environment (CDE) and Digital BIM Software. Some recommendations will be made in relation to adapting these two elements to enhance information flow management through digital technologies and tools.

7.5.1.1 The Common Data Environment (CDE)

To exchange information effectively, a collaborative platform accessible by all project parties at all times and from different locations is required. This is in accordance with PAS 1192 and ISO 19650 that if a project is adapting BIM, then there needs to be a Common Data Environment (CDE) as a "single source of information for any given project, used to collect, manage and disseminate all relevant approved project document for multi-disciplinary teams in a managed process".

However, based on the findings of this research, it can be recommended that this platform requires to be user-friendly meaning that it needs to be easy to learn, use, understand or deal with. This would enable all project participants with different digital skills to be able to effectively exchange information and follow the required processes within this platform. Especially with the project adapting BIM Level 2/Stage 2 it is required that project teams follow the restricted file naming protocols and approval processes through the CDE platform to share and exchange information. Therefore, having a user-friendly platform would allow people to understand and follow the protocols more efficiently.

Also, it can be recommended that it is essential for this platform to provide offline capabilities to avoid issues associated with unreliable internet access and loss of internet connection. It is suggested that industry practitioners consider adapting the user-friendly collaborative platforms that could provide offline access, as it is essential in projects that project participants can access the information and exchange it effectively and at any time required.

Moreover, another essential factor in terms of using the CDE and the other digital tools is that there needs to be a management and control side to these platforms. Because one of the main contributor factors of achieving project goals is effective control of information flow (Kania et al., 2021). So, to produce and exchange high-quality information and consequently improve the overall project performance and productivity, it is essential to manage information flow effectively (Zeng, Lou, & Tam, 2007).

It was found that there are some roles and responsibilities introduced in projects based on their level of BIM adaption. So, It can be recommended that a document control manager role should also be present in BIM Level 2/Stage 2 projects to be responsible for the management of the CDE in terms of the information exchange and flows and the protocol practices. So, together with the BIM manager who is responsible for the BIM tools and practices, a document control manager needs to be involved in enabling an effective exchange of information within the cloud-based system.

A good practice was found in CSC, where the flow of information was managed in a discipline-based manner, meaning that each project's stakeholders and parties had BIM managers for each discipline who were responsible for managing the flow of information between their team and the digital BIM software and BIM collaboration tool.

In order to have effective information flow management it is recommended that all stakeholders involved in the project have both document control managers and BIM managers, which work in line with the project's protocols and BIM requirements.

7.5.1.2 Digital BIM Software

It can be recommended that; digital BIM software needs to be adapted and fully integrated within the project and used by all different disciplines throughout the project lifecycle in any project that adapts BIM regardless of its BIM maturity level.

Based on the discussions in the previous chapter, it can be found that the benefits of BIM implementation would be highly achieved if the digital BIM software is used at its full capacity, meaning that not only the 2D and 3D aspects of BIM tools used but also those 2D and 3D models need to contain information and data which could be then exchanged and shared in a collaborative environment enabled by BIM features.

So, it would be recommended that all digital BIM software with its enabled features need to be fully implemented in all BIM projects to allow effective information flow management. This would also result in tackling the challenges concerning information flow management due to the lack of a collaborative environment and the lack of an appropriate technological solution that was found in this study in previous sections. This is because BIM implementation enforces collaboration between all project parties (Ingram, 2020) and therefore enables effective exchange of information.

Many digital BIM software features, such as visualisation, enable collaboration and communication between project members, which would accordingly allow a continuous flow of information (Al Hattab & Hamzeh, 2013). Therefore, it is recommended that all BIM features need to be implemented in any BIM project and used by all project parties to achieve its benefits.

7.5.2 Processes and Workflow

One of the factors contributing to the effective flow of information is related to the processes and workflows within the exchange of information. Therefore, it can be recommended that the unnecessary repetitive processes and iterative workflows of information exchange that were found in CSA and CSB should be changed and replaced by more effective processes and workflows where the processes are not being repeated unnecessarily. This could be done by revisiting the current processes and workflows of information exchange in projects, redesigning the protocols, and restructuring the processes to avoid any iterative and repetitive processes and information workflows.

Based on the findings of this research, industry practitioners could understand the importance of restructuring their current workflows and identify repetitive processes that make the information flow process problematic. Realising the importance of sharing information between project teams could benefit the project in many ways. An effective information flow process that includes several iterative loops would ultimately result in idle time, rework, and delays in the project (Al Hattab & Hamzeh, 2013).

Also, some of the issues concerning the processes and workflows were related to the BIM Level 2/Stage 2 requirements for information exchange, which are set out in PAS 1192 and ISO 19650, which state several requirements restricted information management processes. Therefore, it can be recommended that academic professionals and industry practitioners need to work collaboratively together to study the practical outcomes and practices of the requirements set out in PAS 1192 and ISO 19650 in more detail.

Therefore, more case studies need to be studied to understand the practical measures that need to take place to follow the BIM workflows in relation to the management process of information flow. This is because BIM is a complex process and it requires coordinated efforts between all project teams to be successfully completed (Manoj et al., 2021). Therefore, synchronised efforts need to be taken in place not only within the projects but also as an external factor when producing measures and regulations.

Based on the findings of this research, there is an apparent necessity for revising the protocols concerning the processes and workflows of information flow management in BIM projects to make them more practical and more effective when applied in projects.

7.5.3 Socio-Organisational Factors

One of the interesting findings of this research is related to the socio-organisational aspect, which was found to be the most challenging factor as socio-organisational barriers affects the information flow management regardless of the project's BIM implementation.

Built on the research findings from both reviewing the literature and analysing the interviews, it is evidenced that people as a socio-organisational factor are always the key aspects of any project because they are the main contributory factor of any project to work (Robertson, 2005; Phelps, 2012; Hickethier et al., 2013; Murthy & Screenvias, 2014; Chatzipanagiotou, 2017).

Many factors, such as non-digital mindsets and behaviours, non-collaborative mindsets and behaviours and lack of knowledge, are the root causes of many issues concerning people. So, based on the findings of this research and the cross-case data analysis, some recommendations could be made to both industry practitioners and academic professionals to tackle the root causes of the mentioned issues, which would ultimately result in improving the information flow management in projects.

7.5.3.1 Non-digital Mindsets and Behaviours

The findings of the study indicated that one of the socio-organisational barriers concerning effective information flow management was people's lack of digital mindsets and behaviours that led to an unwillingness to change to the new methods of exchanging and managing information through BIM and IPD. Therefore, it is recommended that higher education needs to fully embrace digital competencies as a core, fundamental literacy which addresses both technical mastery and a digital citizenship mindset (Martzoukou et el., 2020).

When talking about digital competence, this does not only involve technology mastery, such as the abilities, competencies, capabilities, and skills required for using digital technology, media and tools, but also a digital mindset. A digital mindset consists of attitudes and behaviours necessary to develop as a critical, reflective, and lifelong twenty-first-century learner (Martzoukou et el., 2020).

So, it can be recommended that digital competencies need to be embedded within the education system and the companies' core learning practice. The main digital competence is grouped into five areas by Carretero et al. (2017), which signify both technical and behavioural/attitudinal aspects. These areas include:

- Information and data literacy
- Communication and Collaboration
- Digital content creation
- Safety
- Problem-solving

Critical thinking, reflection, lifelong learning, and innovation are part of practising these competencies. It is highly recommended that these competencies shown in Figure 62 be practiced and trained by industry practitioners and academia at various levels.

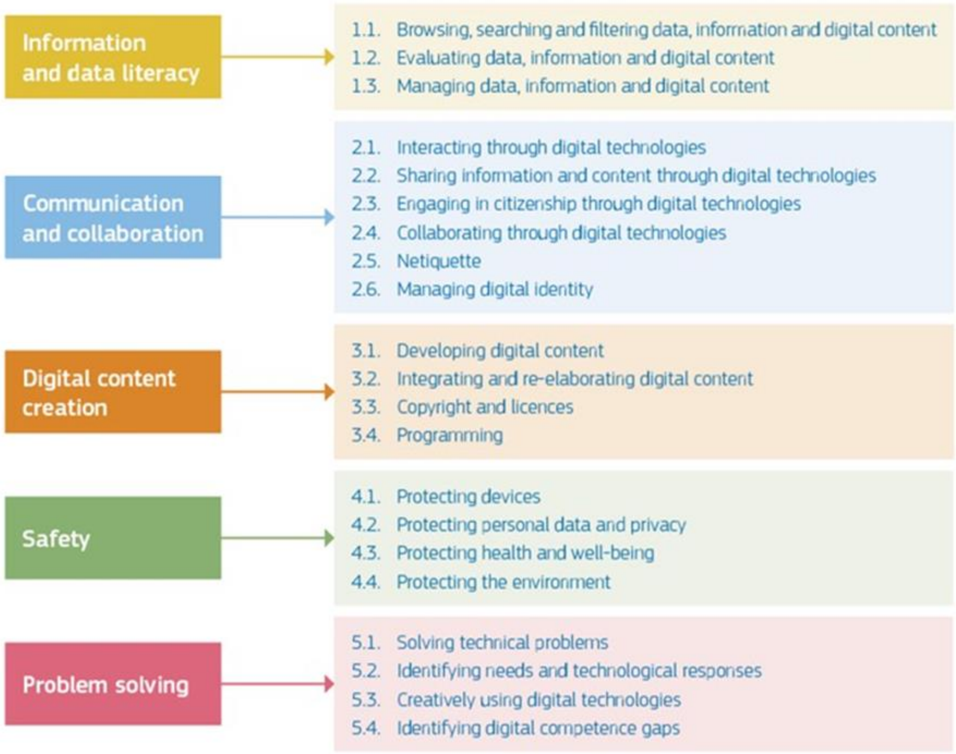

Figure 62 - High-Level Overview of Digital Competence (Carretero et al., 2017)

Education of students, employees, and leaders are recommended to tackle the lack of understanding of the practical application of digital technologies and the lack of leadership support and exemplary pro-environmental behaviour by leaders that would help motivate employees to be more aware and act in a more effective way thereafter (Mendoza, Gallego-Schmid, & Azapagic, 2019). As highlighted in previous sections, as projects move towards IPD where BIM is fully implemented, and more importantly, project participants tend to have enhanced digital mindsets, the challenges of information flow management would be reduced.

It was found in this research that non-digital mindsets and behaviours are the main issue concerning information flow management and thus resulting in poor project performance. But socio-organisational barriers could become socio-organisational enablers if those issues associated with this factor are tackled and addressed appropriately. This means that digital mindsets and behaviours that include intentions, citizens' digital competencies, attitudes, and willingness to adapt technology could act as essential enablers of the development of new rules to regulate interactions and exchanges and turn crises into opportunities for innovation and social change are crucial enablers. (Kashef, Visvizi, & Troisi, 2021).

In this research, one of the factors causing challenges in terms of effective information flow management was found to be resistance to change. Because one of the core barriers to successful innovative approaches, such as BIM implementation that is related to people is their resistance to change (Davies et al., 2015; Leśniak et al., 2021; Olanrewaju et al., 2021; Siebelink et al., 2021). The development of individual digital competencies would result in the reduction of people's resistance to change and to the use of new technologies. This is because learning and practising the critical components of digital competence, as shown in Figure 62, early in the education system or in the career path would reduce the technological fear and privacy concerns about the exploitation of personal information.

This will eventually result in the reduction of fear and uncertainty "that lead actors to activate resistance to technological changes" because people have already developed skills towards adopting a positive attitude towards new technologies. (Kashef, Visvizi, & Troisi, 2021). So, based on the findings of this research, it can be recommended that the digital culture be enriched at an individual level by enhancing people's digital competencies and perceived value and usefulness of new technologies. This can be achieved through training and education of the digital competence elements in both higher education systems and in industry organisations.

7.5.3.2 Lack of Knowledge

According to the research findings, the underlying issue of resistance to change is not only because of the individual's behaviours and unwillingness to change but also the lack of knowledge and training. As lack of knowledge is one of the barriers to successful BIM implementation (Leśniak et al., 2021), some recommendations could be made to tackle this issue and thus improve information flow management.

It is highly recommended that people need to be trained and educated before and during their involvement in any BIM project. BIM concepts, processes and principles need to be educated at higher education levels building both digital competencies capacity with industry-relevance skills and collaborative skills. So, academic professionals need to consider embedding BIM-enabled skills and competencies elements into the education curriculum from undergraduate levels and in various disciplines. This could be done through true proactive collaboration and partnership with industry and academia to promote innovation and growth in technology and the use of new innovative and technological approaches such as BIM and Lean construction. The industry-academia collaboration would drive impact from research and solve real-world problems, which would result in improvements in project performance and in the context of this research, improvement of information flow management.

Although the importance of collaboration between industry and universities has been highlighted in the literature (Collinson, & Quinn, 2002; Vick, & Robertson, 2018; Rybnicek, & Königsgruber, 2019) but based on the findings of this research, it can be found that there is still a gap between the practical works in the industry and the elements taught at universities. It was highlighted that if people do not have the right knowledge of the IPD, Lean construction and BIM processes and technologies in terms of sharing and exchanging information, then they would not be able to understand the processes and the required collaborative information sharing. Therefore, it can be recommended that universities need to work collaboratively with industry practitioners to fill the knowledge gap and identify the fundamental need to train and educate individuals in terms of using new technologies and processes, such as BIM and the IPD approach to improving the effective exchange of information eventually.

Moreover, as mentioned previously, developing an individual's digital competencies would also lead to tackling many issues concerning the information flow management challenges, such as non-digital mindsets and behaviours. So, as recommended improving the individual's knowledge through training and education would improve information flow management.

Chapter 8. Conclusion

8.1 Introduction

This chapter summarises and concludes this research. The key findings of the research are summarised based on the research objectives that were established for the research. The findings are derived from a review of the literature and three qualitative case studies. The first section of this chapter presents a review of the research aim and objectives that is followed by the contribution to knowledge, limitations of the research and recommendations for future studies in the subsequent sections.

8.2 Summary and Conclusion

The overall success of the research in achieving the aim and objectives of this research is reviewed in this section.

The aim of this research was to explore how the information flow in the design process could be improved by the usage of BIM/Lean and in relation to the BIM maturity levels. Therefore, through reviewing literature and qualitative data analysis, the role of BIM/Lean in relation to effective information flow management based on BIM maturity levels was explored. Thereby achieving the aim. Therefore, the following research objectives were formulated to achieve the research aim of this research.

Objective 1: To establish the key challenges in information flow considering three aspects of technology, process, and people in the design process of construction

This objective was achieved with a review of the literature on the challenges in information flow in regard to the aspects of technology, process and people and through the qualitative case study analysis. The initial step of the research process comprised a review of the literature to unearth the issues that were significant to the field of this research.

A literature review in Chapter 2 examined that key information flow challenges in the design process can be categorised into three aspects: people, process, and technology. As the projects rely heavily on information, information flow management is crucial to project success. However, there are various challenges facing projects regarding effective information flow management.

To establish the key challenges in information flow with the consideration of process, people, and technology, an in-depth study of the information management challenges in the design process was carried out through three different case studies of projects with various levels of BIM implementations. The core findings were the identification of significant information flow challenges concerning ‘Digital Technologies and Tools’, ‘Processes and Workflows’, and ‘Socio-Organisational Barriers’. It was discovered that the number of challenging factors associated with these key information flow management challenges were different in the case studies based on each case study BIM implementation.

This research indicates that the information flow management challenges in the design process can be reduced as projects implement more innovative and technological approaches such as BIM and Lean. Although BIM implementation has many benefits to the project, but it was found that there are still some issues within the BIM projects that are mainly due to one factor. Socio-Organisational barriers were found in this research as the most contributing factor to ineffective information flow management.

This research shows that it is very critical for construction projects to educate and train their teams in order to be able to achieve the benefits that BIM provides, primarily in terms of effective information flow management. It is revealed in this study that effective information flow management with minimum challenges would be achieved through the IPD project. This is because of the nature of the IPD contract that project teams are all signed into one contract, which allows them to work in a collaborative environment where they have built mutual trust and they share risks and rewards as part of the IPD contract.

Objective 2: To critically analyse the role of BIM and Lean construction to enhance information flow in the design process in relation to BIM maturity levels

From the literature review, the dimensions and options of BIM/Lean adaption for improving information management in the design process were elucidated. The literature was reviewed on the capabilities of BIM and Lean and the interaction of these two approaches. To analyse the role of BIM/Lean to enhance information flow in the design process in relation to BIM maturity levels, qualitative case studies were carried out in this research to collect perceptions of key project members, including project managers, design managers, BIM implementation managers, BIM managers about the challenges of information flow management and the role of BIM/Lean to enhance those identified challenges in the design process. Many of the BIM-enabled features, such as visualisations, and clash detection was highlighted in the literature along with Lean application advantages.

The qualitative case study asked experts involved in three projects to describe the challenges of information flow management and the benefits that the implementation of BIM/Lean provided to the projects. The case studies had different BIM maturity levels, including BIM Level 1/Stage 1 maturity as a defined project, BIM Level 2/Stage 2 maturity as a managed project, and IPD as an integrated project.

The challenges of effective information flow management were discovered to be different in all three case studies due to their level of BIM and innovative approaches adaption. However, there was one main challenging factor identified to be causing issues in all three case studies.

It was found that there was a basic platform to share information in all three case studies regardless of its BIM/Lean adaption. Although the defined project had a limited level of BIM adaption, but project participants believed that the project was working well in regard to the information flow management as the level of information produced and used was not very significant.

In the managed project where the BIM adaption was up to level 2/Stage 2, the level of advanced technologies and tools improved, which was both beneficial and challenging in terms of information flow management. Some of the challenges were revealed to be related to the standards and protocols set out in PAS 1192, and ISO 19650, and project members had difficulties adopting them. It was interesting to notice that although the defined project and managed project had a significant difference in the BIM maturity levels, the number of challenges that both projects faced in terms of information flow management were not significantly different.

It was noticeable that in the managed project, the level of BIM-enabled technologies and processes played important roles in terms of enhancing the information flow. Also, BIM collaborative processes and workflows enabled lean principles as well, which resulted in the reduction of waste in different aspects of the project in relation to information flow management. Many of the BIM features, such as visualisation, collaboration, 4D scheduling, clash detection, and coordinated workflows, enabled the project to avoid any delays, rework, waste of time, and waste of processing which allowed the design process to become more leaner.

So, it was found that as BIM matured in projects, the number of challenges reduced, which ultimately led to effective information flow management. The significant difference in terms of achieving BIM/Lean benefits in relation to the BIM maturity levels was discovered in the integrated project.

It was found that the ultimate benefits can be achieved when projects implement IPD especially in terms of effective information flow management. Although the managed project was found to benefit from many of the BIM features compared to the defined project, many challenges still remained the same in both projects. This shows that BIM/Lean would play better roles in enhancing the information flow in the design process when implemented in an IPD project.

So, the role of BIM/Lean to enhance information flow in the design process in relation to the BIM maturity levels was discovered in this study which demonstrated that the ultimate benefits of these two approaches could be better achieved in an IPD project which the BIM maturity level is up to Level 2/Stage 2, but at the same time, there are other factors influencing the project in terms of the effective information flow management.

Objective 3: To evaluate the potential benefits of BIM and Lean approaches in terms of information flow management

The third and final objective of this research was 'to evaluate the potential benefits of BIM and Lean approaches in terms of information flow management'. This objective entailed the investigation and exploration of the key aspects of BIM and Lean approaches to effective information flow management.

So, qualitative data analysis was found suitable to meet this objective and hence was used to address these approaches and evaluate their impact on information flow management. A deep investigation was carried out in the qualitative case studies to explore the beneficial factors of BIM/Lean approaches that resulted in effective information flow management.

This final objective is addressed through case studies and the identification of key themes derived from the participants' perceptions. The key critical beneficial factors of BIM/Lean approaches were discovered by cross-case analysis and discussions of three case studies in Chapter 7.

It was revealed in this research that in terms of each project's BIM implementation level, the benefits that BIM/Lean can provide would be different. The findings indicated that the most beneficial aspects of BIM/Lean approaches in terms of information flow management could be achieved in an IPD project. This was explored and discussed in the previous chapter.

8.2 Contribution to Knowledge

This study intended to make both academic and practical contributions. This research contributes to raising awareness regarding the challenges associated with information flow management in relation to projects' BIM maturity level. Therefore, the findings of this research would help academic professionals to rethink the importance of research in information flow management by the BIM/Lean and IPD application with its relation to the BIM maturity level.

Also, this study would benefit the construction industry practitioners to understand the key information flow management challenges better. The beneficial role of BIM/Lean and IPD to enhance information flow would be better realised by industry professionals. This would assist them in taking logical and necessary actions to enable the practical application of BIM/Lean and IPD, thus achieving better-enhanced information flow management.

The effectiveness of information flow management can be better understood and linked to the underlying social and collaborative interactions of the involved parties in projects with different BIM maturity levels. This can enable project members, decision-makers, and managers to take the right actions before and during the project to enhance information flows by targeting the root causes of the challenging factors. While these root causes of information flow management challenges, such as resistance to change, levels of collaboration, lack of knowledge, and lack of technological and innovative approaches, were previously concealed, this study paves the way to address these underlying factors through the adaption of innovative and technological solutions and through adaption IPD approach.

The integrated perspective thus provides deeper insights so that problems and challenges of information flow management in the design process can be tackled and addressed through implementing BIM/Lean and the IPD approach.

In the present study, the contents of information flow management challenges in the design process of projects in relation to different BIM maturity levels are studied, and it is revealed that there are many underlying factors affecting the information flow management associated with 'Digital Technologies and Tools', 'Processes and Workflows', and 'Socio-Organisational Barriers'. This argument has been tested and evaluated by conducting case studies among key people involved in three case studies with various BIM maturity levels.

In spite of the abundance of literature on the in-depth studies on BIM and the Lean approach as methods to manage information flow in the design process, certain lacunae exist in our knowledge. BIM has been determined as a combination of sets of interacting technological, process workflows and organisational culture to maintain and manage information in the design process.

However, there is a lack of literature on classifying the key contributions of BIM and Lean to the quality of the information in regard to different BIM maturity levels. This research fills this gap by investigating and exploring critical factors in technology, process and workflows, and socio-organisational barriers and enablers of BIM and Lean methods to contribute to the information quality and information flow management enhancement in the design process of construction projects. This study's results highlight the need for tackling the socio-organisational barriers to BIM/Lean adaption, which was found to be the most challenging factor contributing to ineffective information flow management.

Based on the findings of this research and the main three themes discussed critically across the three case studies, a set of recommendations was provided to contribute to knowledge in a way that would help both industry practitioners and academia to realise the importance of effective information flow management and to take recommended actions to better manage the information flow in practice. The key recommended factors which have been identified in this research are presented below to highlight the contribution to the knowledge.

Mutual Academia-Industry contribution

The contribution made by the research to the industry and academia is presented by introducing the application of the findings and recommendations to both industry and academia and how these two could collaboratively work together to promote best practices.

- Understanding the processes and workflows within the exchange of information revealed a need for redesigning the protocols and restructuring the processes to avoid any iterative and repetitive processes and information workflows. Therefore, it is recommended that academic professionals and industry practitioners need to work collaboratively together to study the practical outcomes and practices of the requirements set out in PAS 1192 and ISO 19650 in more detail.
- One of the main contributions of this research was discovering the most influential factor for ineffective information flow management, which was the socio-organisational barriers. To tackle this issue, it is recommended that the industry and academia work together to empower digital mindsets and behaviours and improve the

level of individual knowledge through education and training. This could be achieved through true proactive collaboration and partnership of industry and academia to promote innovation and growth in technology and use new innovative and technological approaches such as BIM and Lean construction. The industry-academia collaboration would drive impact from research and solve real-world problems, resulting in improvements in project performance and improvement of information flow management in the context of this research.

- The key benefit of BIM implementation is the opportunity to generate and manage information and its digitally enabled features. So, it can be recommended that the digital culture and digital proficiencies need to be enriched at the individual level by enhancing people's digital competencies and their perceived value and usefulness of new technologies. This can be achieved through training and education of the digital competence elements in higher education systems and industry organisations. So, academic professionals need to consider embedding BIM-enabled skills and digital competencies elements into the education curriculum from undergraduate levels and in various disciplines.

The findings and approach of this study can contribute to research and practice by paying the way for enhanced information flow management through the application of BIM/Lean and IPD approach where root causes of poor information flow management become clear, and the necessary steps to counteract them can be planned and implemented early in the design process to enable achieving benefits of BIM use to improve information flow; making the design process more leaner.

8.3 Research Limitations

There is no limit to knowledge, and research attempts to understand and gain insight into a specific area. Although the main aim of this research is met and the objectives fulfilled, there would still be scope for improvements; some limitations would always be present. In this study,

The lack of previous research linking information flow with BIM and Lean adaption in relation to the BIM maturity levels and IPD approach forced the researcher to mainly focus on the data collected from the interviews to supplement the information gathered from the literature review.

Another limitation was the lack of IPD projects in the UK construction industry at the time that the research was conducted. As this research aimed to explore effective information flow management based on different BIM implementation levels and the IPD approach was found to be the most advanced approach in terms of BIM/Lean adaption, it was essential to explore and analyse an IPD project.

Therefore, as there were no existing IPD projects in the UK, the research had to collect data from an IPD project based in Canada. Finally, time and cost limitations restricted this research to information flow management in the design process. The aim of this research, due to the restricted time and cost of PhD education, is limited to developing an exploratory study to enhance information flow management only in the design process.

8.4 Recommendations for Future Research

This section proposes related areas of research where additional inquiries could further enhance the course of the value of this research. Several ideas relating to potentially interesting and relevant research issues were encountered throughout this research, but constraints arising from a lack of time and resources prevented further perusal. Therefore, these inspired several recommendations for future work, which are as follows:

- Future research can be carried out in pursuance of this research with a larger sample size for the case studies in relation to their BIM implementation level, which might strengthen the results.

- This study can be replicated with additional qualitative data related to information flow management in the construction phase, and comparing the results with the present study would validate this research's findings.

- As the number of BIM projects has increased in recent years, it would be beneficial to investigate again in the UK industry to identify any projects that have implemented IPD recently.

- Investing further impacts of the socio-organisational factors that encourage the adaption of new innovative and technological approaches.

- Future research should replicate the methodology used in this study to identify additional information flow management challenges in the context of different or other studies.

- Finally, as this research is an exploratory study in which information flow management challenges were explored and identified, further research would be beneficial to expand on this research and develop a framework to enhance information flow management by the application of the BIM/Lean and IPD approach.

8.5 Chapter Summary

This chapter presented the conclusion, highlighted the purpose of the research, and reviewed the research objectives. Then, research contribution to knowledge and research limitations were covered. Lastly, recommendations were offered for future research.

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Underwood, J., Shelbourn, M., Carlton, D., Zhao, G., Simpson, M., Aksenova, G., & Mollasalehi, S. (2021). Transforming the Productivity of People in the Built Environment: Emergence of a Digital Competency Management Ecosystem. In Handbook of Research on Driving Transformational Change in the Digital Built Environment (pp. 430-466). IGI Global.

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Appendixes

A- Ethical Approval

University of Salford
MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

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Sajedeh Mollasalehi

6 October 2017

Dear Sajedeh,

RE: ETHICS APPLICATION STR1617-97: Benefits of BIM use to improve information flow; making the design process more Leaner

Based on the information you provided, I am pleased to inform you that your application STR1617-97 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

APHigham.

Dr Anthony Higham
Chair of the Science & Technology Research Ethics Panel

B- Interview Consent Form

University of Salford MANCHESTER

School of the Built Enviornment

Research Participant Consent Form

Title of Project: Benefits of BIM use to improve information flow; making the design process more Leaner.

Ref No:
Name of Researcher: Sajedeh Mollasalehi

(Delete as appropriate)

➢ I confirm that I have read and understood the information sheet for the above study and what my contribution will be.	Yes	No	
➢ I have been given the opportunity to ask questions	Yes	No	
➢ I agree to take part in the interview	Yes	No	NA
➢ I agree to the interview being digitally recorded	Yes	No	NA
➢ I agree to digital images being taken during the research exercises	Yes	No	NA
➢ I understand that my participation is voluntary and that I can withdraw from the research at any time **without giving any reason**	Yes	No	
➢ I understand that the raw data, including the original audio recording of the interview, will be password protected during the study and destroyed at a later date following the student's successful completion of the thesis	Yes	No	
➢ **I agree to take part in the above study**	Yes	No	

Name of participant:
Signature

Date:
Name of researcher taking consent:
Sajedeh Mollasalehi

Researcher's e-mail address:
s.mollasalehi1@edu.salford.ac.uk

If you have any concerns about this research that have not been addressed by the researcher, please contact the researcher's supervisor via the contact details below:

Supervisor's name

Jason Underwood, Andrew Fleming

Supervisor's email address:
j.underwood@salford.ac.uk ,
a.j.fleming@salford.ac.uk

ParticipantConsentFormNov2013v1.0 Page 1

C- Interview Invitation Letter

University of Salford MANCHESTER

School of the Built Environment

Research Participant Invitation Letter

Dear …,

My name is Sajedeh Mollasalehi, and I am a PhD student at the University of Salford, Manchester, UK. I am conducting a study titled "benefits of BIM use to improve information flow; making the design process more Leaner" which aims to explore how the information flow in the design process could be improved in terms of adding value and reducing non-value-adding activities/information that contribute to waste using BIM and Lean approaches.
I would like to invite you to take part in this research study. You are a key person due to having the relevant experience in the construction industry and working with projects that involve BIM implementation. So, I believe you will add a lot to this research by providing your experience and perspectives.
I was wondering if I could take around 60 minutes of your busy schedule to interview you. Each interview is scheduled around 60 minutes, where 50 minutes will be the actual interview and 10 minutes for the additional exchange of information. Your participation is valuable and I would appreciate it if you would agree to participate in my research by accepting my interview invitation.
The interview will start with a set of questions in relation to the participant's background information. Interview questions are divided into 3 main categories and the interview will be concluded by final open-ended questions.

I will take all the required ethical concerns into consideration. You may decide to stop being a part of the research study at any time without explanation. In addition, the data that will be collected will not contain any personal information. Also, all the collected data and information will be kept in a secure and safe password protected computer folder. The raw data, including the original audio recording of the interview, will be password protected during the study and destroyed at a later date following the student's successful completion of the thesis. No one will link the data that you provided to the identifying information you supplied. When your participation in this research is complete, your data will be anonymised. From that time, there will be no record that links the data collected from you with any personal data from which you could be identified (e.g., your name, address, email, etc.). Any other ethical issues related to the research philosophy are considered by the researcher and the University of Salford. Your name will not be attached to the interview responses and I will ensure that your participation remains confidential.

By participating in this study, you are unlikely to be upset or made uncomfortable by the questions asked.

If you have any questions or concerns, please feel free to contact me at
s.mollasalehi1@edu.salford.ac.uk, or my supervisors;
Prof Jason Underwood; J.Underwood@salford.ac.uk
Mr Andrew Fleming; A.J.Fleming@salford.ac.uk

(Note that, if you do participate, you will receive a separate sheet of paper with me and my supervisors' contact information on it to take away with you.)
Thank you.

Kind Regards,
Sajedeh Mollasalehi

D- Interview Guidelines

Interview guidelines

Introduction

The aim of this interview is to understand the interviewee's perspective about the key information flow challenges and the role of BIM and Lean to improve information flow in the design process. The data obtained from this interview will help the researcher to achieve the aim and objectives of this research which would accordingly help to develop the theoretical framework as the final research objective.

Participants' rights

Interviewee has all the right to withdraw from the study at any time during the interview or after and in such case their data and information will be destroyed and not included in the study. Interviewee has the right to ask any questions during the interview procedure or after. The interviewee's information will be kept strictly confidential and his/her name will not be used at all.

Questions

<u>Part 1 – Background Information</u>

1) What is your field of expertise?
2) How many projects have you been involved that BIM was used in their processes?
3) Have you been involved in any projects implementing Lean?
4) Have you been involved in any projects implementing both BIM and Lean?

<u>Part 2 – Main Questions</u>

Section A – Information flow

1) Creation and exchange of information in the design process
2) Activities and processes involved in the flow of information
3) Value and non-value added information
4) Information flow challenges and benefits

Section B – BIM and Lean

1) The role of BIM and Lean in the design process
2) The role of BIM and Lean in information flow
3) Benefits and challenges of BIM and Lean within information flow
4) BIM and Lean benefits to enhance information flow

E- Interview Questions

Interview questions

General Part

- What is your background?
- How many years of experience do you have in your field?
- How many projects that you are currently involved in are using BIM and Lean approaches?
- How would you differentiate a BIM project with a non-BIM project?

About This Project

- Why is this a non-BIM project?
- What makes this project non-BIM?
- How do you asses it in terms of being BIM or non-BIM?
- Do you consider BIM maturity levels to evaluate this?

Main Part

- What are the design process stages/phases in your company? In general
- Do you have any systems or framework within the design process to manage information flow? If yes,
  - what is it?
  - How does it work?
  - Who is responsible for it?

- Do you find it easy to understand and retrieve and identify the information that you need? e.g. is it easy to find a drawing that someone else has been working on?

- Do you know exactly where to find a specific information?
  If yes,
  - How long does it take you to find it? Or to identify the person responsible for it?

  If no,
  - What do you do? Who to ask?

- Where do you store your work?
  - Is it accessible for others if they need it?
  - Do you use any cloud-based systems in this non-BIM project?
- How do you share information? Between individuals and systems
- What types of information do you share?
  - Do you have different ways of sharing specific types of information?

- What are the main challenges when you share information? Considering aspects of;
  - Technology
  - People
  - process
- do you have any information flow management process?
- What are the challenges of information flow management? Considering aspects of;
  - Technology

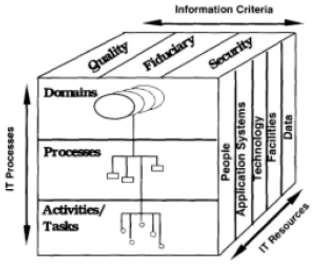
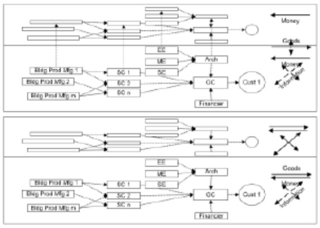
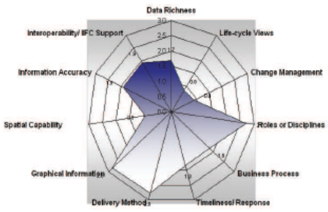
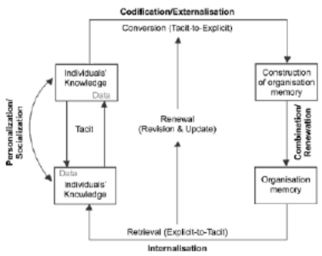
    - People
    - Process
- Which one of the people, technology, and process is the main contributor factor of poor information flow? Why?
- Considering the challenges of information flow;
    - Do you see any value-loss throughout the design process due to these challenges?
    - What are the activities that lead to waste and value-loss?
    - Which one of the people, technology, and process is the main contributor factor of value-loss in projects?
- In your opinion, what could have been done to improve information flow?
    - Technology
    - People
    - Process
- Do you think that implementing technological and innovative approaches could improve information flow management? Or it would make it more complicated?
- Specifically, in this project, what are the challenges in information flow that are due to lack implementing approaches such as BIM and Lean?
- What could have been improved if BIM was fully implemented in this project?
- What are the extra activities in terms of information flow took place in this project due to lack BIM implementation?
- Any value-loss due to lack of BIM implementation?
- Any benefits you gained by not implementing BIM?

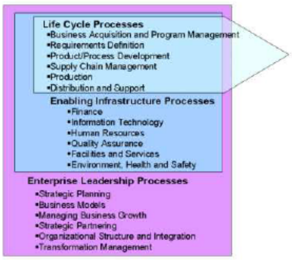
In general;

- In your opinion, what is the role of BIM and Lean in information flow?
- what are the benefits of BIM and Lean in terms of improving information flow?
- What are the challenges of BIM and Lean in information flow management?

F- Maturity Models

Maturity Models influencing the BIM Maturity Index

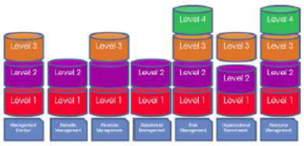
Sample Representation	**Abbreviation, Name –** ***Organisation*** **Description and Number of maturity levels**
 Image from (Lainhart IV, 2000)	**COBIT, Control Objects for Information and related Technology** – *Information Systems Audit and Control Association (ISACA) and the IT Governance Institute (ITGI)* The main objective of COBIT is to "enable the development of clear policy and good practice for IT control throughout organizations" (Lainhart IV, 2000). The COBIT Maturity Model is "an IT governance tool used to measure how well developed the management processes are with respect to internal controls. The maturity model allows an organization to grade itself from nonexistent (0) to optimized (5)" (Pederiva, 2003). COBIT includes 6 Maturity Levels (Non-existent, Initial/ad hoc, Repeatable but Intuitive, Defined Process, Managed and Measurable and Optimised), 4 *Domains* and 34 *Control Objectives*. Note: There is some alignment between ITIL (OGC, 2009) and COBIT with respect to IT governance within organisations (Sahibudin, Sharifi, & Ayat, 2008) of value to BIM implementation efforts.
 Image Source: NASA, Software Engineering Process Group http://bit.ly/CMMI-NASA	**CMMI, Capability Maturity Model Integration** - *Software Engineering Institute / Carnegie Mellon* "Capability Maturity Model® Integration (CMMI) is a process improvement approach that (...) helps integrate traditionally separate organizational functions, set process improvement goals and priorities, provide guidance for quality processes, and provide a point of reference for appraising current processes" (SEI, 2006a) (SEI, 2006b) (SEI, 2008a) (SEI, 2008b) (SEI, 2008c). CMMI has 5 *Maturity Levels* (for Staged Representation, 6 Capability Levels for Continuous Representation), 16 core *Process Areas* (22 for CMMI-DEV and 24 for CMMI-SVC), 1 to 4 *Goals* for each Process Area, each goal is comprised of *Practices*... The 5 Maturity Levels are: Initial, Managed, Defined, Quantitatively Managed and Optimising.
 (Vaidyanathan & Howell, 2007)	**CSCMM, Construction Supply Chain Maturity Model** "Construction supply chain management (CSCM) refers to the management of information, flow, and money in the development of a construction project" as mentioned in (Vaidyanathan & Howell, 2007). CSCMM has 4 Maturity Stages: Ad-hoc, Defined, Managed and Controlled.
 (Suermann, Issa, & McCuen, 2008)	**I-CMM, Interactive Capability Maturity Model** - *National Institute for Building Sciences (NIBS) Facility Information Council (FIC)* This I-CMM is closely coupled with the NBIMS effort (Version1, Part 1) and establishes "a tool to determine the level of maturity of an individual BIM as measured against a set of weighted criteria agreed to be desirable in a Building Information Model" (Suermann et al., 2008) (NIST, 2007) (NIBS, 2007). A more detailed discussion of this maturity model is offered in Section 4. The ICMM has 11 'Areas of Interest' measured against 10 Maturity Levels.
 (Arif, Egbu, Alom, & Khalfan, 2009)	**Knowledge Retention Maturity Levels** Arif, Egbu, Alom and Khalfan (2009) introduced 4 levels of knowledge retention maturity. Knowledge management is an integral part of BIM capability and subsequent maturity. The Matrix thus incorporates these levels: (1) knowledge is shared between employees, (2) shared knowledge is documented (transferred from tacit to explicit), (3) documented knowledge is stored and (4) stored knowledge is accessible and easily retrievable (Arif et al., 2009).



(Nightingale & Mize, 2002)

LESAT, Lean Enterprise Self-Assessment Tool - *Lean Aerospace Initiative (LAI) at the Massachusetts Institute of Technology (MIT)*

LESAT is focused on "assessing the degree of maturity of an enterprise in its use of 'lean' principles and practices to achieve the best value for the enterprise and its stakeholders" (Nightingale & Mize, 2002).
LESAT has 54 Lean Practices organised within three Assessment Sections: Lean Transformation/ Leadership, Life Cycle Processes and Enabling Infrastructure *and* 5 Maturity Levels: Some Awareness/Sporadic, General Awareness/Informal, Systemic Approach, Ongoing Refinement and Exceptional/Innovative.



(OGC, 2008)

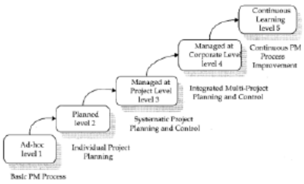
P3M3, Portfolio, Programme and Project Management Maturity Model - *Office of Government Commerce*

The P3M3 provides "a framework with which organizations can assess their current performance and put in place improvement plans with measurable outcomes based on industry best practice" (OGC, 2008).
The P3M3 has 5 Maturity Levels: Awareness, Repeatable, Defined, Managed and Optimised.

(SEI, 2008g)

P-CMM®, People Capability Maturity Model v2 – *Software Engineering Institute / Carnegie Mellon*

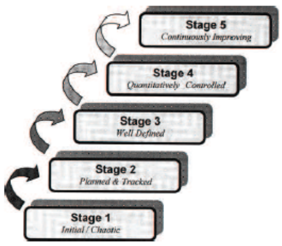
P-CMM is an "organizational change model" and a "roadmap for implementing workforce practices that continuously improve the capability of an organization's workforce" (SEI, 2008g).
P-CMM has 5 Maturity Levels: Initial, Managed, Defined, Predictable and Optimising.



(Kwak & Ibbs, 2002)

(PM)², Project Management Process Maturity Model

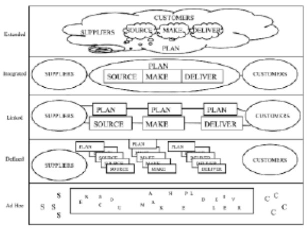
The project management process maturity (PM)² model "determines and positions an organization's relative project management level with other organizations". It also aims to integrate PM "practices, processes, and maturity models to improve PM effectiveness in the organization" (Kwak & Ibbs, 2002).
(PM)² has 5 Maturity Levels: Initial, Planned, Managed at Project Level, Managed at Corporate Level and Continuous Learning.



(Hutchinson & Finnemore, 1999)

SPICE, Standardised Process Improvement for Construction Enterprises - *Research Centre for the Built and Human Environment, The University of Salford*

SPICE is a project which developed a framework for continuous process improvement for the construction industry. SPICE is an "evolutionary step-wise model utilizing experience from other sectors, such as manufacturing and IT" (Hutchinson & Finnemore, 1999), (Sarshar et al., 2000).
SPICE has 5 Stages: Initial/Chaotic, Planned & Tracked, Well Defined, Quantitatively Controlled, and Continuously Improving.



(Lockamy III & McCormack, 2004)

Supply Chain Management Process Maturity Model *and* Business **Process Orientation** (BPO) **Maturity Model**

The model conceptualizes the relation between process maturity and supply chain operations as based on the Supply-chain Operations Reference Model4 (Stephens, 2001). The model's maturity describes the "progression of activities toward effective SCM and process maturity. Each level contains characteristics associated with process maturity such as predictability, capability, control, effectiveness and efficiency" (Lockamy III & McCormack, 2004) (K. McCormack, 2001).
The 5 Maturity Levels are: Ad-hoc, Defined, Linked, Integrated and Extended.

Other maturity models – or variation on listed maturity models - include those on **Software Process Improvement** (Hardgrave & Armstrong, 2005), IS/ICT Management Capability (Jaco, 2004), Project Management (Crawford, 2006), Competency (Gillies & Howard, 2003) and Financial Management (Doss, Chen, & Holland, 2008).

G- BIM Maturity Matrix

Building Information Modelling Maturity Matrix – Static tabular guide at sample granularity.

BIM MATURITY MATRIX

BIM COMPETENCY SETS		BIM Competency Areas at Granularity level 1	a INITIAL	b DEFINED	c MANAGED	d INTEGRATED	e OPTIMISED
	TECHNOLOGY	**Software:** applications, deliverables and data	Usage of software applications is unmonitored and unregulated. 3D Models are relied on to mainly generate accurate 2D representations/ deliverables. Data usage, storage and exchanges are not defined within organisations or project teams. Exchanges suffer from a severe lack of interoperability.	Software usage/ introduction is unified within an organisation or project teams (multiple organisations). 3D Models are relied upon to generate 2D as well as 3D deliverables. Data usage, storage and exchange are well defined within organisations and project teams. Interoperable data exchanges are defined and prioritised.	Software selection and usage is controlled and managed according to defined deliverables. Models are the basis for 3D views, 2D representations, quantification, specification and analytical studies. Data usage, storage and exchanges are monitored and controlled. Data flow is documented and well-managed. Interoperable data exchanges are mandated and closely monitored.	Software selection and deployment follows strategic objectives, not just operational requirements. Modelling deliverables are well synchronised across projects and tightly integrated with business processes. Interoperable data usage, storage and exchange are regulated and performed as part of an overall organisational or project-team strategy.	Selection/use of software tools is continuously revisited to enhance productivity and align with strategic objectives. Modelling deliverables are cyclically being revised/ optimised to benefit from new software functionalities and available extensions. All matters related to interoperable data usage storage and exchange are documented, controlled, reflected upon and proactively enhanced.
		Hardware: equipment, deliverables and location/ mobility	BIM equipment is inadequate; specifications are too low or inconsistent across the organisation. Equipment replacement or upgrades are treated as cost items and performed only when unavoidable.	Equipment specifications – suitable for the delivery of BIM products and services - are defined, budgeted-for and standardised across the organisation. Hardware replacements and upgrades are well-defined cost items.	A strategy is in place to transparently document, manage and maintain BIM equipment. Investment in hardware is well-targeted to enhance staff mobility (where needed) and extend BIM productivity.	Equipment deployments are treated as BIM enablers. Investment in equipment is tightly integrated with financial plans, business strategies and performance objectives.	Existing equipment and innovative solutions are continuously tested, upgraded and deployed. BIM hardware become part of organisation's or project team's competitive advantage.
		Network: solutions, deliverables and security/ access control	Network solutions are non-existent or ad-hoc. Individuals, organisations (single location/ dispersed) and project teams use whatever tools found to communicate and share data. Stakeholders lack the network infrastructure necessary to harvest, store and share knowledge.	Network solutions for sharing information and controlling access are identified within and between organisations. At project level, stakeholders identify their requirements for sharing data/ information. Dispersed organisations and project teams are connected through relatively low-bandwidth connections.	Network solutions for harvesting, storing and sharing knowledge within and between organisations are well managed through common platforms (e.g. intranets or extranets). Content and asset management tools are deployed to regulate structured and unstructured data shared across high-bandwidth connections.	Network solutions enable multiple facets of the BIM process to be integrated through seamless real-time sharing of data, information and knowledge. Solutions include project-specific networks/portals which enable data-intensive interchange (interoperable exchange) between stakeholders.	Network solutions are continuously assessed and replaced by the latest tested innovations. Networks facilitate knowledge acquisition, storing and sharing between all stakeholders. Optimisation of integrated data, process and communication channels is relentless.

BIM COMPETENCY SETS		BIM Competency Areas at Granularity level 1	a INITIAL	b DEFINED	c MANAGED	d INTEGRATED	e OPTIMISED
	PROCESS	**Infrastructure:** physical and knowledge-related	The work environment is either not recognised as a factor in staff satisfaction or may not be conducive to productivity. Knowledge is not recognised as an asset; BIM knowledge is typically shared informally between staff (through tips, techniques and lessons learned).	The work environment and workplace tools are identified as factors affecting motivation and productivity. Similarly, knowledge is recognised as an asset; shared knowledge is harvested, documented and thus transferred from tacit to explicit.	The work environment is controlled, modified and it's criteria managed to enhance staff motivation, satisfaction and productivity. Also, documented knowledge is adequately stored.	Environmental factors are integrated into performance strategies. Knowledge is integrated into organisational systems; stored knowledge is made accessible and easily retrievable [refer to the 4 levels of knowledge retention (Arif et al., 2009)].	Physical workplace factors are reviewed constantly to insure staff satisfaction and an environment conducive to productivity. Similarly, knowledge structures responsible for acquisition, representation and dissemination are systematically reviewed and enhanced.
		Products & Services specification, differentiation, project delivery approach and R&D	3D models deliverables (a BIM product) suffer from too high, too low or inconsistent levels of detail.	A "statement defining the object breakdown of the 3D model" (Bouygues, 2007) is available.	Adoption of product/ service specifications similar to Model Progression Specifications (AIA, 2008), BIPS 'information levels' (BIPS, 2008) or similar.	Products and services are specified and differentiated according to Model Progression Specifications or similar.	BIM products and services are constantly evaluated; feedback loops promote continuous improvement.
		Human Resources: competencies, roles, experience and dynamics	There is an absence of defined processes; roles are ambiguous and team structures/ dynamics are inconsistent. Performance is unpredictable and productivity depends on individual heroics. A mentality of 'working 'around the system' flourishes.	BIM roles are informally defined and teams are formed accordingly. Each BIM project is planned independently. BIM competency is identified and targeted; BIM heroism fades as competency increases but productivity is still unpredictable.	Cooperation within organisations increases as tools for cross-project communication are made available. Flow of information steadies; BIM roles are visible and targets are achieved more consistently.	BIM roles and competency targets are imbedded within the organisation. Traditional teams are replaced by BIM-oriented ones as new processes become part of organisation's / project team's culture. Productivity is now consistent and predictable.	BIM competency targets are continuously upgraded to match technological advances and align with organisational objectives. Human resource practices are proactively reviewed to insure intellectual capital matches process needs.
		Leadership: innovation and renewal, strategic, organisational, communicative and managerial attributes	Senior leaders/ managers have varied visions about BIM. BIM implementation (according to BIM Stage requirements) is conducted without a guiding strategy. At this maturity level, BIM is treated as a technology stream; innovation is not recognised as a independent value and business opportunities arising from BIM are not acknowledged.	Senior leaders/managers adopt a common vision about BIM. BIM implementation strategy lacks actionable details. BIM is treated as a process-changing, technology stream. Product and process innovations are recognised; business opportunities arising from BIM are identified but not exploited.	The vision to implement BIM is communicated and understood by most staff. BIM implementation strategy is coupled with detailed action plans and a monitoring regime. BIM is acknowledged as a series of technology, process and policy changes which need to be managed without hampering innovation. Business opportunities arising from BIM are acknowledged and used in marketing efforts.	The vision is shared by staff across the organisation and/or project partners. BIM implementation, its requirements and process/ product innovation are integrated into organisational, strategic, managerial and communicative channels. Business opportunities arising from BIM are part of team, organisation or project-team's competitive advantage and are used to attract and keep clients.	Stakeholders have internalised the BIM vision and are actively achieving it (Nightingale & Mize, 2002). BIM implementation strategy and its effects on organisational models are continuously revisited and realigned with other strategies. If alterations are needed, they are proactively implemented. Innovative product/ process solutions and business opportunities are sought-after and followed through relentlessly.

BIM COMPETENCY SETS		BIM Competency Areas at Granularity level 1	a INITIAL	b DEFINED	c MANAGED	d INTEGRATED	e OPTIMISED
	POLICY	**Regulatory**: rules/ directives, standards/ classifications, guidelines/ benchmarks and codes/ regulations	There are no BIM guidelines, documentation protocols or modelling standards. There is an absence of documentation and modelling standards. There is informal or no quality control plans; neither for 3D models nor for documentation. There are no performance benchmarks for processes, products or services.	Basic BIM guidelines are available (e.g. training manual and BIM delivery standards). Modelling and documentation standards are well defined according to market-accepted standards. Quality targets and performance benchmarks are set.	Detailed BIM guidelines are available (training, standards, workflow, exceptions...). Modelling, representation, quantification, specifications and analytical properties of 3D models are managed through detailed modelling standards and quality plans. Performance against benchmarks is tightly monitored and controlled.	BIM guidelines are integrated into overall policies and business strategies. BIM standards and performance benchmarks are incorporated into quality management and performance improvement systems.	BIM guidelines are continuously and proactively refined to reflect lessons learned and industry best practices. Quality improvement and adherence to regulations and codes are continuously aligned and refined. Benchmarks are repetitively revisited to insure highest possible quality in processes, products and services
		Contractual: responsibilities, rewards and risks	Dependence on pre-BIM contractual arrangements. BIM risks related to model-based collaboration (differ in each market) are not recognised or are ignored.	BIM requirements are recognised. "Statements defining the responsibility of each stakeholder regarding information management" (Bouygues, 2007) are now available.	There is a mechanism to manage shared BIM intellectual property, confidentiality, liability and a system for BIM conflict resolution.	Organisation are aligned through trust and mutual dependency beyond contractual barriers.	Responsibilities, risks and rewards are continuously revisited and realigned to effort. Contractual model are modified to achieve best practices and highest value for all stakeholders.
		Preparatory: research efforts/ deliverables, educational programmes/ deliverables and training programmes	Very little or no training available to BIM staff. Educational/ training mediums are not suitable to achieve the results sought.	Training requirements are defined and are typically provided only when needed. Training mediums are varied allowing flexibility in content delivery.	Training requirements are managed to adheres to pre-set broad competency and performance objectives. Training mediums are tailored to suit trainees and reach learning objectives in a cost-effective manner.	Training is integrated into organisational strategies and performance targets. Training is typically based on staff roles and respective competency objectives. Training mediums are incorporated into knowledge and communication channels.	Training is continuously evaluated and improved upon. Training availability and delivery methods are tailored to allow multi-modal continuous learning.

			a	b	c	d	e
			INITIAL	**DEFINED**	**MANAGED**	**INTEGRATED**	**OPTIMISED**
BIM CAPABILITY STGAES	STAGE 1	**Object-based Modelling**: single-disciplinary use within a Project Lifecycle Phase	Implementation of an object-based tool. No process or policy changes identified to accompany this implementation.	Pilot projects are concluded. BIM process and policy requirements are identified. Implementation strategy and detailed plans are prepared.	BIM processes and policies are instigated, standardised and controlled.	BIM technologies, processes and policies are integrated into organisational strategies and aligned with business objectives.	BIM technologies, processes and policies are continuously revisited to benefit from innovation and achieve higher performance targets.
	STAGE 2	**Modelling-based Collaboration**: multi-disciplinary, fast-tracked interchange of models	Ad-hoc BIM collaboration; in-house collaboration capabilities incompatible with project partners. Trust and respect between project participants may be lacking.	Single-thread, well-defined yet reactive BIM collaboration. There are identifiable signs of mutual trust and respect among project participants.	Multi-thread proactive collaboration; protocols are well documented and managed. There are mutual trust, respect and sharing of risks and rewards among project participants.	Multi-thread collaboration includes downstream players. This is characterised by the involvement of key participants during projects' early lifecycle phases.	Multi-thread team included all key players in an environment characterised by goodwill, trust and respect.
	STAGE 3	**Network-based Integration**: concurrent interdisciplinary interchange of nD models across Project Lifecycle Phases	Integrated models are generated by a limited set of project stakeholders - possibly behind corporate firewalls. Integration occurs with little or no pre-defined process guides, standards or interchange protocols. There is no formal resolution of stakeholders' roles and responsibilities.	Integrated models are generated by a large subset of project stakeholders. Integration follows predefined process guides, standards and interchange protocols. Responsibilities are distributed and risks are mitigated through contractual means.	Integrated models (or parts of) are generated and managed by most project stakeholders. Responsibilities are clear within temporary project alliances or longer-term partnerships. Risks and rewards are actively managed and distributed.	Integrated models are generated and managed by all key project stakeholders. Network-based integration is the norm and focus is no longer on *how* to integrate models/ workflows but on proactively detecting and resolving technology, process and policy misalignments.	Integration of models and workflows are continuously revisited and optimised. New efficiencies, deliverables and alignments are actively pursued by a tightly-knit interdisciplinary project team. Integrated models are contributed to by many stakeholders along the construction supply chain.
ORGANISATIONAL SCALES	MICRO	**Organisations**: dynamics and BIM deliverables	BIM leadership is non-existent; implementation depends on technology champions.	BIM leadership is formalised; different roles within the implementation process are defined.	Pre-defined BIM roles complement each other in managing the implementation process.	BIM roles are integrated into organisation's leadership structures.	BIM leadership continuously mutates to allow for new technologies, processes and deliverables.
	MESO	**Project Teams** (multiple organisations): inter-organisational dynamics and BIM deliverables	Each project is run independently. There is no agreement between stakeholders to collaborate beyond their current common project.	Stakeholders think beyond a single project. Collaboration protocols between project stakeholders are defined and documented.	Collaboration between multiple organisations over several projects is managed through temporary alliances between stakeholders.	Collaborative projects are undertaken by inter-disciplinary organisations or multidisciplinary project teams; an alliance of many key stakeholders.	Collaborative projects are undertaken by self-optimising interdisciplinary project teams which include most stakeholders.
	MACRO	**Markets**: dynamics and BIM deliverables	Very few supplier-generated BIM components (virtual products and materials representing physical ones). Most components are prepared by software developers and end-users.	Supplier-generated BIM components are increasingly available as manufactures/ suppliers identify the business benefits.	BIM Components are available through highly accessible/searchable central repositories. Components are not interactively connected to suppliers' databases.	Access to component repositories are integrated into BIM software. Components are interactively linked to source databases (for price, availability, etc...).	Dynamic, multi-way generation and interchange of BIM components (virtual products and materials) between all project stakeholders through central or meshed repositories.

H- Multiple-Case Study Procedure

Yin (2014) Multiple-Case Study Procedure.