Building Information Modelling (BIM) maturity-benefits assessment relationship framework for UK construction clients

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Contents

List of Figures

List of Tables

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DEDICATION

I dedicate this piece of research to my dearest wife Rasha Alhameedi and my Lovely children Maryam, Yousif, and Adham.

DECLARATION

This thesis is submitted to the University of Salford rules and regulations for the award of a PhD degree by research. While the research was in progress, some research findings were published in refereed journals and conference papers prior to this submission.

The researcher declares that no portion of the work referred to in this thesis has been submitted in support of an application for another degree of qualification of this, or any other university or institution of learning.

Ammar Dakhil

ABSTRACT

Building Information Modelling (BIM) is defined as an approach to building design, construction, and operation through modelling technology, associated sets of processes and people to produce, communicate and analyse building information models. The implementation of BIM is projected to improve the efficiency of the design, construction, and operation of an asset through 3D visualisation, integrated and automated drawing production, intelligent documentation and information retrieval, consistent data and information, automated conflict detection and automated material take off.

Despite the considerable value that BIM can add to any project, it has been noted that BIM prevented to be widely implemented due to the lack of clients' demand. The lack of BIM understanding and the initial cost of BIM implementation represent the main barriers which clients always hesitate to use BIM. To overcome these difficulties, clients have to understand their roles in the BIM implementation process and also provide the requirements that will enable them to use BIM effectively and realise the desired benefits of BIM. These requirements have been identified as competencies. The lack of using these competencies inside the UK has raised questions about why together with the suitability of using them within the UK. In addition, the lack of presenting these competencies with relation to the benefits increase clients concerns about the feasibility of having these competencies.

The aim of this research was therefore set out to support client organisations in the UK to implement BIM effectively by establishing BIM maturity competencies–BIM uses benefits assessment relationship for the UK construction client. The research engaged a multiple-case-studies approach to validate the proposed BIM maturity competencies list and online questionnaire to validate the relationship between BIM maturity competencies and BIM uses benefits. Data from each case was analysed by using a content analysis technique before being cross-analysed to determine the patterns of the interviews' manuscripts. In addition, the online questionnaire was analysed using correlation techniques. The findings were then discussed and theoretically validated to produce a conceptual framework.

The research reveals 19 competencies that can support clients in their BIM implementation. Furthermore, this research identified two key relationships. Firstly, the relationship between clients' roles and BIM maturity competencies and secondly, the relationship between BIM maturity competencies and BIM uses benefits. Finally, this research has resulted in the development a conceptual framework to assess the relationship between BIM maturity and BIM benefits.

Chapter 1: Introduction

1.1 Introduction

The construction industry has an active and important role in the UK economy (Department for Business Innovation & Skills, 2013) and is represented in the Government's first growth review in 2011 (UK Commission for Employment and Skills, 2013). The growth of the UK economy increased by 0.8% during the third quarter 2012, helped by a 2.5% growth in construction (Hayman, 2014). Meanwhile, in 2012 the gross value added (GVA) of the construction industry was £83 billion which equates to approximately 6.0% of the total UK economy (Rhodes, 2013; O. o. N. Statistics, 2011).

Despite its contribution to the economy's development, the UK construction industry is facing significant pressure from the UK Government to deal with all the factors likely to affect the demand for asset construction (Department for Business Innovation & Skills, 2013). These include reducing the capital costs, some modern challenges (such as globalization), demographic changes, the demand for green energy, and sustainable construction (Barton et al., 2013).

At the project level, activities are usually divided into purposeful areas, which are completed by different stakeholders (e.g. the client, architects, engineers, and contractors). Regularly, each discipline makes decisions without considering its impact on others (Love et al., 2011), which can create barriers. These barriers cause project delays that directly lead to an increase in the amount of time needed to complete the project; furthermore, additional resources are required to complete the project, thus productivity rates decrease and costs rise. The fragmented structure of the industry also contributes towards the productivity conundrum (Cox and Townsend, 1997; Proverbs et al., 2000). Egan (1998) reported how within this structure, each party involved has become less trusting, more self-interested and adversarial. Effectively, risks are passed down to the next layer in the supply chain in order to minimise exposure. As a result, there are many interfaces and possible conflicts that ultimately lead to increased cost, and reduced efficiency and productivity.

Much work has focused on improving construction productivity, including the use of information and communication technology (ICT) in construction (Onyegiri et al., 2011). This is an area worth concentrating upon because it can reduce the time for data processing, communicating information between stakeholders and can improve overall productivity. Modern technologies and processes applications, such as Building Information Modelling (BIM), provide examples where designing complex structures requires a high level of coordination between the electrical, mechanical, and structural stakeholders. Other applications such as estimation and planning can be completed in minimal time with a high level of efficiency (Chan et al., 2016; Ghaffarianhoseini et al., 2016; Peansupap and Walker, 2005; Shen et al., 2016).

The Construction Industrial Strategy in the UK emphasises the major progress being made in the implementation process of BIM, which will become mandatory for all public sector construction projects from April 2016 onwards (Department for Business Innovation & Skills, 2013; UK Commission for Employment and Skills, 2013). The main driver behind this strategy is that BIM could revolutionise the project process by transforming the whole industry. In that its approach to asset whole life value differentiates it from other technologies by combing the technology aspects with process aspects to optimise the end value of an asset (Haron, 2013). This is set not only on the advantages of 3D parametric modelling, but also on the structured information that is organised, defined, and exchangeable (Haron, 2013). The structured information will lead to more effective communication and collaboration between the project stakeholders throughout the project lifecycle (D. K. Smith and Tardif, 2012). In addition, the different construction industry stakeholders consider it as the main driver towards them gaining considerable value in their projects (Eastman, 2011). For example, the federal government in the USA has predicted savings of 5-12% from project costs when BIM is used (Jernigan, 2008). This new approach reduces the pressure on the construction industry and paves the road to achieving a high level of efficiency and productivity.

Despite the positive value that can be derived from BIM, there is still a fairly large proportion (43.4%) from UK contractors who state that they do not perceive it as a core competency because of client demand is a barrier to adoption of BIM (NFB, 2013). The overwhelming majority of respondents (contractors) said that they had not asked about BIM experience in PQQ or ITT when procuring suppliers, which clearly demonstrates a lack of drive and demand from the clients to the supply chain (Market, 2014; RICS, 2011). In addition, non-users trust that their clients are not using BIM, with 87% believing that clients are using it on 15% or less of projects which mean that clients in particular can play vital role in BIM implementation process. The factor that is important to project stakeholders for driving their BIM implementation is the impact of client demand. The highest percentage of stakeholders' view more client/owner/operators requiring BIM as important to increasing the business benefits they experience from BIM (Smart Market 2011).

Many factors may affect the process of BIM implementation in the UK industry. According to surveys held by Smart Market (2014)and RICS (2011), clients can play a vital role in the process of implementation. Client demands could be a significant motivation for the industry to start to implement BIM (Isikdag et al., 2012; Porwal and Hewage, 2013; Sackey et al., 2013). In addition to that, considerable research has stated that as one of the construction stakeholders, clients can stimulate the innovation to achieve the desired benefits of BIM (Gann and Salter, 2000; Getuli et al., 2016; Ghaffarianhoseini et al., 2016; C. Harty, 2005; K. Kulatunga et al., 2011; Manley, 2006; Jim Mason and Knott, 2016; R. Miller, 2009). Furthermore, widespread acceptance of BIM implementation has been hampered across the construction industry by client fears and a lack of full understanding of the benefits and the requirements (Erik Eriksson et al., 2008; Getuli et al., 2016; Ghaffarianhoseini et al., 2016; Brittany Giel and Issa, 2013c; Isikdag et al., 2012; Kassem et al., 2013; Jim Mason and Knott, 2016; Porwal and Hewage, 2013; Sackey et al., 2013; Succar, 2010b).

1.2 Problem statement and research justification

There is considerable literature that has focused on how to help construction industry stakeholders implement BIM in their organisations. However, there is a lack in considering clients are the real obstacle against BIM implementation across the construction industry (Yusuf Arayici et al., 2012; Azhar et al., 2008; Eastman, 2011; Hardin, 2011; Khosrowshahi and Arayici, 2012; D. K. Smith and Tardif, 2012; Yan and Damian, 2008). Smart Market Report (2012) stated that the client still has little trust in BIM compared to contractors and consultants, and is therefore still lagging behind contactors and designers in BIM implementation. Clients are facing difficulties on deciding whether or not to implement BIM based on understanding the perceive benefits to them (Barlish and Sullivan, 2012). In addition, there is a lack of understanding as to where, during the project lifecycle, BIM can provide benefits to the client, what some of the challenges are, and what the expected value is to the client (Becerik-Gerber et al., 2012).

The utilisation of BIM has not been empirically and clearly established to be beneficial to the overall outcome of a construction project (Barlish and Sullivan, 2012; Bradley, 2010; Bryde et al., 2013; Dowsett and Harty, 2013; J. Li et al., 2014; Qian, 2012). Clients are challenged with the problem of making a decision of whether or not to invest in utilising BIM based on unguaranteed benefits (Barlish and Sullivan, 2012; Talebi, 2014). The largest barriers to BIM implementation and acceptance across the construction industries are recognition and enforcement by the client (Succar, 2010, Chan, 2014, Eadieet al, 2014). There is a lack of awareness of possible benefits and challenges from a client perspective, as well as an absence of training in how to use BIM applications (Gu and London, 2010).

The main reasons behind the client's behaviour are that the benefits of BIM are not as clearly defined to clients compared to other construction industry stakeholders (Azhar, 2011; Barlish and Sullivan, 2012; Bryde et al., 2013; Hergunsel, 2011; Migilinskas et al., 2013; Yan and Damian, 2008). This is argued by Eastman et al. (2011) through a number of BIM applications along with the related benefits to the client. However, it is considered that the benefits presented by these authors are primarily project-based, i.e. improves the design and construction phase rather than supporting the business proposition of the client (Azhar et al., 2012; Codinhoto and Kiviniemi, 2014; Eadie, Browne, et al., 2013; Getuli et al., 2016; Ghaffarianhoseini et al., 2016; Jim Mason and Knott, 2016). Codinhoto et al. (2013) concluded that the emphasis on the design and construction benefits, explains the level of uncertainty in regards to the benefits of BIM beyond the handover stage.

In addition, the same emphasis is noted in relation to BIM capability maturity levels for facility management (Azhar et al., 2012; Codinhoto and Kiviniemi, 2014; Eadie, Browne, et al., 2013). According to Smart Market Report (2011), there is a relationship between the capability and maturity level and the benefits that can be achieved. However, the relationship between the BIM maturity level and the expected benefits are not clear and need to be addressed (Brittany Giel and Issa, 2013c; Kassem et al., 2013; Succar, 2015a). Also, there is a lack of consistency or methodology in measuring the benefits gained by implementing BIM and the maturity level of the organisations (HM Government 2012).

In the literature, the benefits of BIM are discussed without limited reference to their relationship to the project stages and the maturity level of the client organisation (Brittany Giel and Issa, 2013c; Kassem et al., 2013; Succar, 2015a). Hence, there are no clear guidelines for clients to follow in order to increase their chance to achieve their desired benefits of BIM. Therefore, there are no guidelines for clients to begin to assess whether they "have sufficient BIM capability and maturity to predict the BIM benefits in a more realistic and assured way". Moreover, this highlights the need for a clearer explanation of BIM benefits along with their relationship to levels of maturity level and the project phases to help clients to identify what they need to develop in order to achieve BIM benefits by optimising their current efforts.

This research, therefore, attempts to develop a framework for the implementation of BIM in a client organisation. The framework focuses on determining the relationship between BIM uses' benefits and BIM client maturity within a UK context. Furthermore, the framework will add more clarification about the requirements that the client needs to develop in order to use BIM in different areas across the project life cycle.

1.3 Aims and Objectives

This research aims to develop a conceptual assessment framework for a Building Information Modelling (BIM) benefit-maturity relationship for client organisations in the UK construction industry to assist clients in deciding which BIM maturity competency(ies) that their organisations need to achieve in order to access the desired benefits.

In achieving the aim, the following objectives are defined:

1. Identify the importance of BIM for UK construction clients and of client roles in the BIM implementation process.
2. Identify the possible areas where BIM can be used and the corresponding benefits and requirements for each BIM use from a clients' perspective.
3. Establish a BIM organisation maturity assessment model which can be used to evaluate UK construction clients.
4. Validate the proposed BIM maturity model and identify the relationship between client roles and the proposed BIM maturity competencies.
5. Establish, validate and produce a final assessment conceptual framework to explain the relationship between BIM maturity competencies and BIM uses benefits from the UK construction clients' perspective. This objective also includes an explanation as to how UK construction clients can use the conceptual assessment framework on a practical basis.

1.4 Scope of the Research

This research identified client organisations' roles in the BIM implementation process; these are developing the requirements and information validation, plus leading BIM implementation processes across their supply chain. Twenty-one potential areas have been identified in which BIM can be used throughout project lifecycle. Each area demands different types of requirements that clients need to provide in order to achieve the desired benefits of BIM. This research also proposes several critical success BIM competencies, which will support client organisations to improve their business via implementing BIM.

The study investigated each BIM use requirements and benefits to develop a conceptual framework that explains the relationship between BIM maturity and BIM benefits assurance for client organisations in the UK construction Industry. Both quantitative and qualitative data have been used to examine and validate the conceptual framework.

1.5 The Research Processes

The research processes designed to achieve the objectives of the research include: reviewing and synthesising current literature on the related fields of the research; developing a new concept to describe the area and subject of the research; empirically testing and presenting the findings in the form of new knowledge (Sarantakos, 2012). A schematic representation of the research is illustrated by Figure 1.1, and it can be seen that the research process includes five main phases, as follows:

1. **Phase one:** This phase includes the literature review that will help in developing the research aim and objectives. In addition, the research methodology will be established. The development steps of the draft conceptual framework that explains the relationship between BIM maturity competencies and BIM uses benefits from the client's perspective is also included in this phase.
2. **Phase two:** This phase contains the initial validation step which will be carried out through a pilot study. Based on the experts' views gathered from the pilot study, a draft version will be amended to produce the initial version of the conceptual assessment framework.
3. **Phase three:** This phase includes the first step of the validation process via the qualitative data analysis and discussion. This step will aim to validate the proposed BIM maturity competencies and develop their relationship with clients' roles in BIM implementation process.
4. **Phase four:** This phase comprises the second step in the framework validation process via quantitative data analysis and discussion. This step will aim to validate the proposed relationship between BIM maturity competencies and BIM uses benefits.
5. **Phase five:** The resulting amendments from the validation process will be used to produce the final version of the conceptual assessment framework. This phase also includes the development of a practical guide for client organisations when using the framework.

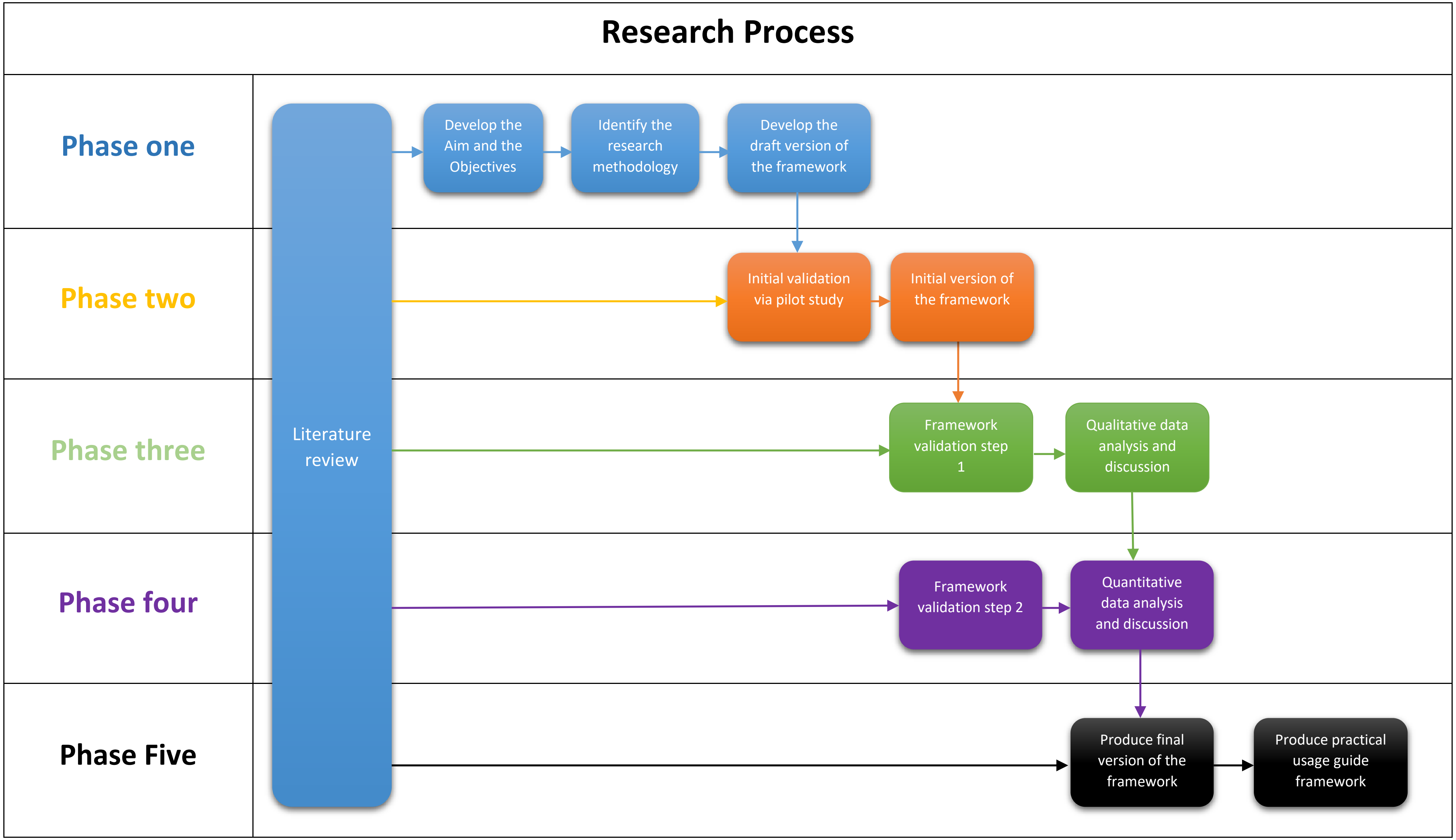

Figure 1.1: Schematic representation of research process

1.6 Structure of the thesis

This thesis is organised into the following 7 chapters:

- **Chapter 1:** This chapter includes an overview of the research problem and the justification. The research aim and objectives are discussed. The rationale and approach adopted to conduct this research are discussed. An overview of the research contribution is briefly discussed, and a brief summary of the organisation of the various chapters in this thesis is presented.
- **Chapter 2:** In this chapter, a critical review of the literature relevant to the focus of this study is discussed. These issues include the UK construction industry, clients' roles, information management, BIM, BIM for client organisations in terms of their requirements and benefits.
- **Chapter 3:** This chapter presents a critical review of the literature, relevant to existing BIM maturity assessment models, in order to identify the critical success competencies that UK construction clients have to develop in order to use BIM effectively.
- **Chapter 4:** An overview of the research methodologies available for the conduct of this research are presented and analysed. The use of the 'Research Onion' proposed by Saunders et al. (2009) in adopting the methodologies to conduct this research is discussed. Justifications for the choices made for each layer of the 'Onion' are presented. The data collection procedures and the associated data analysis procedures are also discussed and justified.
- **Chapter 5:** This chapter conceptualises the phenomenon under consideration by developing a framework to illustrate the key areas identified from the literature and expert opinion. It also identifies the issues that will provide the focus for the course of the study.
- **Chapter 6:** This chapter discusses the first process of validating the conceptual framework, which is based on a qualitative data analysis. The qualitative data have been collected via semi-structure interviews and documentary analysis. The main aim of this chapter is to validate the proposed BIM maturity competencies and investigate the relationship between BIM maturity competencies and BIM uses benefits.
- **Chapter 7:** This chapter discusses the process of exploring the relationship between BIM uses benefits and BIM maturity competencies through the data collection and analysis procedures for the questionnaire survey used in the validation process. Sixty-

five responses to the questionnaire survey are analysed and the conclusions drawn from the survey data are discussed.

- **Chapter 8:** An overall summary of the research presented in this thesis is discussed in this final chapter. A brief summary of the processes undertaken in the conduct of this research and the findings of the research are argued. The contribution to knowledge of this research, from both academic and industry perspectives, is discussed. The limitations in the pursuit of this research are illustrated, and a brief discussion is provided regarding future research that may be conducted in this area.

Chapter 2: Building Information Modelling for Construction Client Organisations

2.1 Introduction

The key purpose of this chapter is to explore several discussions regarding the main areas of the literature review. The main areas relate to the research themes where the concerns are associated with UK construction clients, such as the client's fears about BIM implementation and the lack of BIM understanding amongst client. They are the reason that the construction sector exists; therefore, clients are of great importance to the industry. In construction, however, it is doubtful that a client will be an individual as most clients are organisations or groups of people. It is vital to establish a definition of a client order to avoid misunderstanding. Client categories, what clients want, and the current challenges that clients are facing with project delivery will be discussed to help to understand the nature of the client and how they see the world; this will help to minimise the current barriers in deriving business benefits through construction projects. This chapter is thus essential in providing the rationale for BIM implementation from a client perspective, which is detailed in this literature investigation.

2.2 UK Construction Industry

Recent population growth statistics make the future of the construction industry prosperous. With the global population predicted to hit 9 billion by 2050, where two out of every three people could be living in cities, the demand for construction has never been greater. Worldwide, construction is already one of the largest industry sectors, accounting for more than 11% of the global GDP and expected to grow to 13.2% by 2020, according to the (PWC, 2014). However, concentrating on this strong demand obscures a more problematic reality. Underlying challenges in productivity, profitability, performance, labour, and sustainability could derail the industry's growth. Today, the construction industry is at a crossroads. On the one hand, organisations that address these challenges head on and reimagine their business processes will be poised for significant growth. On the other, businesses that fail to take these challenges seriously, will face an uphill battle for viability (Leeds, 2016).

The construction industry has an active and important role in the UK economy (Department for Business Innovation & Skills, 2013) and was represented in the Government's first growth review in 2011 (UK Commission for Employment and Skills, 2013). The growth of the UK economy, increased by 0.8% during the third quarter of 2012, helped by a 2.5% growth in construction (Hayman, 2014). Meanwhile, in 2012 the gross value added (GVA) of the construction industry was £83 billion, which equates to approximately 6.0% of the total UK economy (Rhodes, 2013; O. o. N. Statistics, 2011). However, currently the UK construction industry is officially in recession as both house building and infrastructure output fell in the second quarter of 2016. Economists believe this could be an early sign that the wider economy could enter a mild recession later this year (O. f. N. Statistics, 2016).

The fragmented nature of the construction industry has been identified throughout the literature as a primary factor that affects its overall performance and productivity (Adetunji et al., 2003; Shammas-Toma et al., 1998). Any construction project involves many stakeholders, including the client, architects, engineers, contractors, subcontractors and suppliers, in delivering a one-of-a-kind project, which requires a significant amount of coordination (Isikdag and Underwood, 2010). This involves collaboration between a number of organisations which are brought together for the period of the project to form the 'project team' (Adetunji et al., 2003; Cox and Townsend, 2009; Morton and Ross, 2008). These organisations often show a discrepancy in terms of size, capabilities, skills, practices, ICT systems, and so forth, and more often they are based in different locations. However, they need to work collaboratively and share the same project information (Cox and Townsend, 2009; Jones et al., 2006; Morton and Ross, 2008; Shammas-Toma et al., 1998). This imposes a great challenge in deriving value, which can be increased by improved function or reduced in terms of whole life cost. In addition, achieving Value for Money (VfM), as a concept, relates to the optimum balance between the benefits expected of a project and the resources expended in its delivery, and most importantly in meeting client requirements through better collaboration between the project stakeholders (Adetunji et al., 2003; Shammas-Toma et al., 1998).

A crucial period for the UK construction industry was between 1994 and 2009 during which a number of noteworthy government and industry reviews and reports were conducted. In addition, the industry also enjoyed considerable expansion throughout that period, as shown in Figure 2.1. Over the years, the construction industry has faced many calls for change. Clients have stated concerns about the impact of inefficient processes and waste on their commercial performance. In addition, health and safety has emerged as a major challenge; furthermore, climate change and the need for more environmentally friendly buildings have challenged the industry to change once again. The initiatives presented over this period are mostly acknowledged to have changed the way the industry works. These reviews include Latham (1994) 'Constructing the Team', Egan (1998) 'Rethinking Construction', and Wolstenholme (2009) 'Never Waste a Good Crisis'. Each report has motivated the industry to start to implement improvements and solve key issues, thus facilitating the sector's competitiveness by demanding efficiency, increasing client involvement and partnering, and introducing supply chain management approaches to construction projects and programmes (ECLLP, 2013).

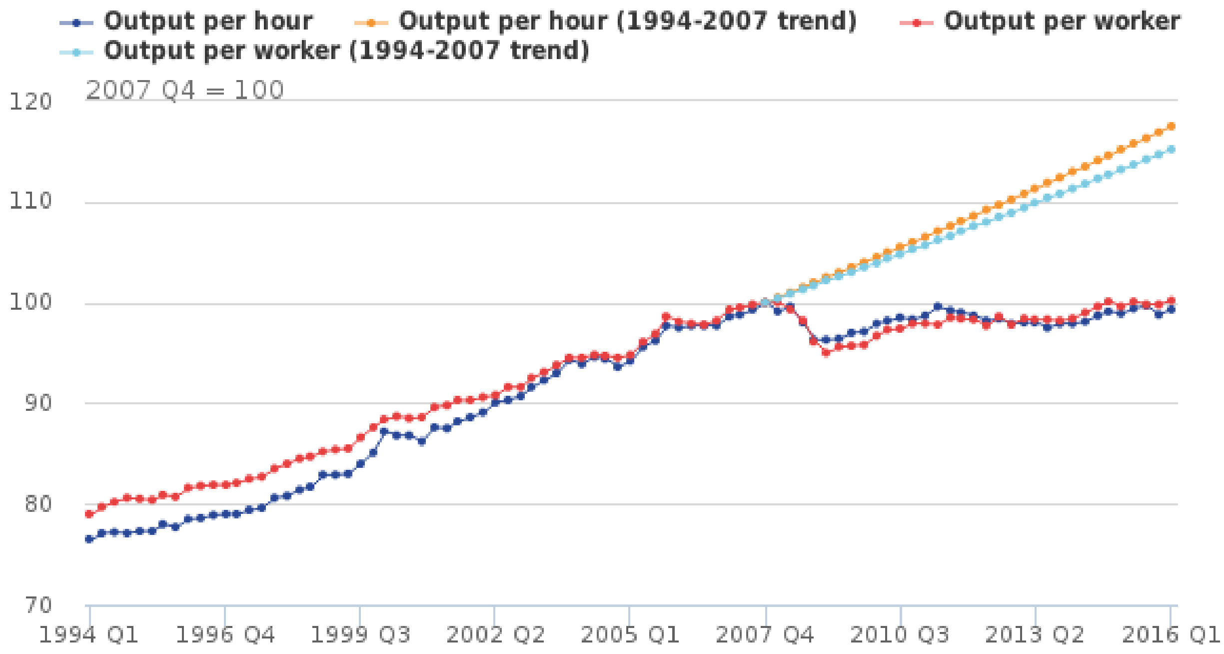

Figure 2.1: Output per hour and output per worker (Tucker, 2016)

Egan (1998), Latham (1994), and Levine at al. (1995) have identified the necessity for a number of important changes in the way construction services are obtained and supplied, and to increase value for money, which is mainly focused on the characteristics of the construction process. The aforementioned reports, in addition to Wolstenholme (2009), identified the factors that need to be considered in order to improve the UK construction industry's performance, and these are as follows:

- Giving extra importance to end-users in the design and construction stages of a project, plus any future needs. This highlights the importance of involving client organisations and their operation and maintenance teams in the early stages of project, which should consequently reduce conflicts and improve efficiency.
- Increasing integration between various stages in the construction process, from design, planning, construction and completion, to reduce waste and inefficiency. Here collaboration has been identified as a key success factor in improving the construction process.

- Enhancing partnerships between clients, contractors and consultants to address issues collaboratively, reduce project time and cost overruns, promote innovation, and improve quality.
- Establishing longer-term relationships with clients and contractors to encourage continuous improvement in the cost and quality of final products.
- Identifying that accepting the lowest tender price for the initial capital costs does not provide value for money, and that the operation and maintenance costs of a building need more attention. Thus it can be seen that the total cost is identified as the target cost rather than just the capital cost; this will motivate the client to implement sustainable solutions for long-term benefits.
- Reducing oppositional approaches between the industry and clients, which have produced high levels of litigation. This change will be achieved if the client and industry work in one environment with an ability to share the risks and benefits.
- Expanding the use of prefabrication and standardised building components in construction to improve quality and cost effectiveness.

To implement the aforementioned changes, which could be considered as innovative, the industry is in need of a 'champion' who can organise efforts to successfully utilise innovation potential (Nam and Tatum, 1997; Tookey et al., 2011). In the search for a champion to lead the construction industry, significant consideration has been paid to the potential role of the construction client (Blayse and Manley, 2004; Egemen and Mohamed, 2006; Gann and Salter, 2000; C. Harty, 2005; Lim and Ofori, 2007; Tookey et al., 2011). Egan (1998) also stated that clients should take the lead in driving construction innovation. Furthermore, stakeholders are increasingly focusing on innovation in construction projects as a necessity and there are indications that it could soon become the fourth competitive dimension after cost, time and quality (Nam and Tatum, 1997; Tookey et al., 2011). As one of the most influential persons in construction contracts, the client has a major role to play in reaping the benefits from innovations. (Fullerton and West, 1996; Gardiner and Rothwell, 1985; Mackay et al., 2000; Maklan et al., 2008; Martin et al., 1999). In order to understand the client's role and their capability to implement new innovation, the next section will consider the definition of client and client types in the UK construction industry.

2.3 Construction Clients

Every single construction project begins with an optimistic idea from a client regarding a proposed project, which a project team of designers, architects, and engineers expand on to deliver. Nevertheless, clients of any industry are not a consistent group, and it follows those different clients, or categories of clients, will require different, and probably discrete, solutions to their problems, which will also present different opportunities (Cheong et al., 2003; Kamara et al., 2000; Vennström, 2008; Vennström and Erik Eriksson, 2010). It is, therefore essential that, before addressing the technical, managerial and aesthetic challenges of the project, the identity, nature and characteristics of the client are accurately identified. In understanding the client, the project team can become fully aware of, and understand, the their needs (Masterman, 2003). However, it is not easy to find one definition of the term construction client. The term was first used as an official requirement for legal advice or protection (Boyd and Chinyio, 2008; Masterman, 2003; J. B. Miller and Evje, 1999). Nevertheless, clients can also be identified as the initiators of projects and those who contract with other parties for the supply of construction goods or service (Atkin et al., 1995; J. B. Miller and Evje, 1999). In construction, however, it is doubtful that a client will be an individual; most are organisations or groups of people (Boyd and Chinyio, 2008). Therefore, the establishment of a client definition is vital in order to avoid misunderstanding, and it is proposed that the following meanings will be used throughout this work:

1. According to Wiggins (2014), construction (design and management) regulation (CDM) defines a client as an individual or organisation who, in the course or furtherance of a business, has a construction project carried out by another or by himself.

2. According to Cabe (2003), a construction client has been defined as the person or group that 'owns' the building. The client initiates the project, employs the design and construction teams, and finds the resources to make it a reality. The client is sometimes referred to as the 'employer', 'champion' or 'manager'. The executive client is the name sometimes given to the most senior person in the client organisation. The lead client is the name of the senior person on the client project team.
3. CIOB defined a client as the owner and/or developer of the facility, and, in some cases, the ultimate user (Booty, 2002).

4. Kometa et al. (1994) simply define the client as the one who pays the bills. The client can be an individual or an organisation but is responsible for financing the project.
5. The construction client represents both owners and end-users who are responsible for ensuring that all the requirements of owners, customers, and wider society are met by a construction project, from its initial conception to the final implementation (Vennström, 2008).

Thus, a client needs to be seen as an organisation, involving a set of teams with different viewpoints and needs (Newcombe, 2003; Rowlinson et al., 1999; J. Smith and Love, 2004). Nevertheless, there are different categorisations of client, which are explored in the next section in order to understand the differences and similarities in their nature and needs.

2.3.1 Client Types

The key to successfully managing a diverse team of service providers is to be open and honest regarding the variable priorities and expectations of the respective client. Understanding that every client is unique will guide the approach of all participants before any ground is broken (Kamara et al., 1999); Masterman (2003) states that client organisations have traditionally been categorised in the literature and statistical data as 'public' or 'private', which is a reflection of the ownership or source of funding of the organisation. In addition, the characteristics of these two types of client differ, mainly as result of the funding source. Figure 2.2 presents a lateral view of the different types of clients in the UK construction industry, according to their funded source (Kometa et al., 1994).

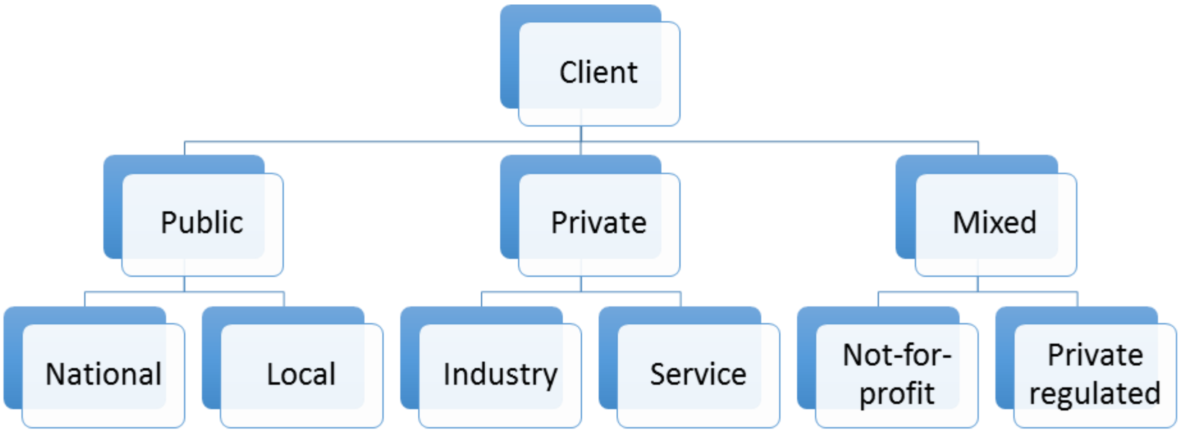

Figure 2.2: Client main types in UK construction industry (Boyd and Chinyio, 2008)

2.3.1.1 Public sector client

The public client is defined, basically, as a client who uses public funds to procure construction projects. In addition, all enterprises, agencies, and bodies are fully owned, controlled and run by the government, whether central, regional or a local (Shah, 2015). Therefore, government-based construction projects can be issued at three different levels:

Level 1: Local council

Level 2: State and territory government

Level 3: Central (federal) government

Local councils have the duty of constructing and maintaining services, and this includes the police, housing, and leisure; state governments may instruct major capital works, such as new public buildings, or significant infrastructure changes. The highest level is central government departments who manage massive building and infrastructure projects, such as ministries, courts, environmental assets, and prisons (Boyd and Chinyio, 2008).

A typical characteristic of these publicly financed bodies is the need to guarantee that the expenditure of taxpayers' money is secured by the adoption of risk-averse and conventional policies. Internal regulations, standing orders, and continuous control and auditing of expenditure are also used to ensure public accountability (Kometa et al., 1994; Masterman, 2003). There are substantial opportunities for central governments and the wider public sector to establish a solid lead through sustainable design, procurement, maintenance, and the operation of its built assets; in doing so, this also brings costs down for the rest of the market (Architecture and Environment, 2002). The public sector is considered the largest client sector of the construction industry, which works for the high-end life for the people by providing the following services (but not limited) to the people (Shah, 2015):

- Generation of employment opportunities
- Postal services
- Providing education and health facilities at low cost
- Providing security
- Railway service
- Road service

- Utilities services
- Leisure facilities

2.3.1.2 Private sector client

The private sector is the segment of a national economy that is owned, controlled and managed by private individuals. The private sector has a goal of making a profit, which can be achieved by forming a new initiative or privatising a public sector organisation. A large private-sector corporation may be privately or publicly traded. Businesses in the private sector drive down prices for goods and services while competing for consumers' money (Boyd and Chinyio, 2008; Drew et al., 2001).

Private clients tend to be exclusive traders or domestic clients who would like to have an asset improved, extended or maintained (Kometa et al., 1994; B. Li et al., 2005). They enter into private contracts with a builder to carry out the work. The private client may have an architect who has created the drawings if planning or building regulations call for this (Tang et al., 2010). The private sector clients can be categorised under one of two main sub-divisions: 1. industry, or 2. services, as shown in the Table 2.1. These sub-divisions are used in economic categorisations and with agencies, such as Business Link (Boyd and Chinyio, 2008).

Table 2.1: Private clients' categories

Private	
Industry	Service
• Agriculture and fishing • Biotechnology, medical and chemical • Construction and building • Energy and water • Manufacturing and engineering	• Business • Media • Financial • IT and telecom • Real state • Travel and tourism

Business entities within the private sector are generally established with the sole objective of making a profit and building brand reputation. They provide quality services to the community to win the trust and goodwill from people to survive in the long term and compete with other businesses. They are willing to implement policies that are more aggressive and take such commercial risks as are necessary to achieve their needs. Therefore, their projects are expected to serve the organisation's mission, vision, and goals (Shah, 2015). The major services provided by the private sector are as follows:

- Quality education
- Telecommunication services
- ICT services
- Courier Services
- Infrastructure development

2.3.1.3 Mix sector client

The final type of client is more complex and consists of a degree of mix between public and private enterprise (Boyd and Chinyio, 2008). Mixed clients can be classified into two main sub-divisions, namely not-for-profit and private regulated (Table 2.2). The not-for-profit client is a privately established organisation that offers a public service but channels its surpluses back into the service. Private regulated organisations carry out a public service, often with a monopoly, but are allowed to make a profit. The regulations define and monitor the service offered by this type of client and try to limit the profit by pricing control (Boyd and Chinyio, 2008).

Table 2.2: Mixed clients' categories

Mixed	
Not-for-profit	Private regulated
• Rail • Housing associations • Universities • Religious • TV and Radio (BBC) • Nuclear power	• Water • Airport • Ports • Electricity • Gas • Telecommunication

2.3.1.4 Similarities and differences

Noticeable differences and similarities exist between clients in relation to their types. The following highlights the major differences between the public and private sector (Boyd and Chinyio, 2008; Kamara et al., 1999; Masterman, 2003; Shah, 2015):

- The public sector is part of the country's economy where the control and maintenance are in the hands of the government. On the other hand, the private sector is owned and managed by private individuals and corporations. This leads to a significant difference in each client's needs and business targets.
- The aim of the public sector is to serve people whereas private sector clients are established with a profit motive. This basically means that each client type has different requirements that will affect his desire to implement any changes or new innovations.
- In the public sector, the government has full control over client organisations. Conversely, private sector companies enjoy less government interference. This explains why the public client has to follow government strategies without considering financial benefits for these strategies. However, private clients have the freedom to examine any new strategies from a financial benefits point of view before deciding whether to implement them.
- In the private sector, the working environment is extremely competitive; this is missing in the public sector where they are not established to meet commercial objectives. This can be considered a motivation to private clients to implement new innovations that maintain their competitiveness in the market. However, public clients show less interest in new innovations without government commitment.

Thus, different types of clients have different types of objectives; however, Egan (1998), Latham (1994), and Levine at al. (1995) suggested that a client's project requirements represent the similarities between clients regardless of type, and these include:

- obtaining value for money;
- ensuring the project is delivered on time;
- having satisfactory durability;
- incurring reasonable running costs;
- being fit for its purpose;
- being free from defects on completion;

• having an aesthetically pleasing appearance;

• being supported by meaningful guarantees.

Despite differing client types, clients should work with experts to deliver their asset projects. Although clients may not have subject expertise, their overriding role as the client is just as important. Client aspirations and vision should drive all project stakeholders to make sure they meet client requirements.

2.3.2 Construction Clients' roles

While being a client of an asset project is a vital role which can be both exciting and creative, it can also be difficult when a project is finished with unexpected results (Kurokawa et al., 2016; Sarkar et al., 2015). Taking on client responsibilities in most asset projects also combines with being the actual owner and manager after project completion. This means that client organisations will withstand the worst of any mistakes made that relate to the feasibility of the land and assets, its uses and the sustainability of its operation and management in the future. It is important therefore that this process allows for a focus on client requirements as the eventual owner and operator of the land and assets. Therefore, the preparation phase, where clients discuss asset requirements with the supply chain, is critical as major changes can be made to the project without incurring significantly large costs. If clients have any amendments to the design, it will be easy to meet them instead of having to wait to the construction phase when they see their project in real and examine it against their requirements where any change can demand substantial additional cost. This is shown in Figure 2.3 (Havenvid et al., 2016; Loosemore and Richard, 2015; Merschbrock and Munkvold, 2015).

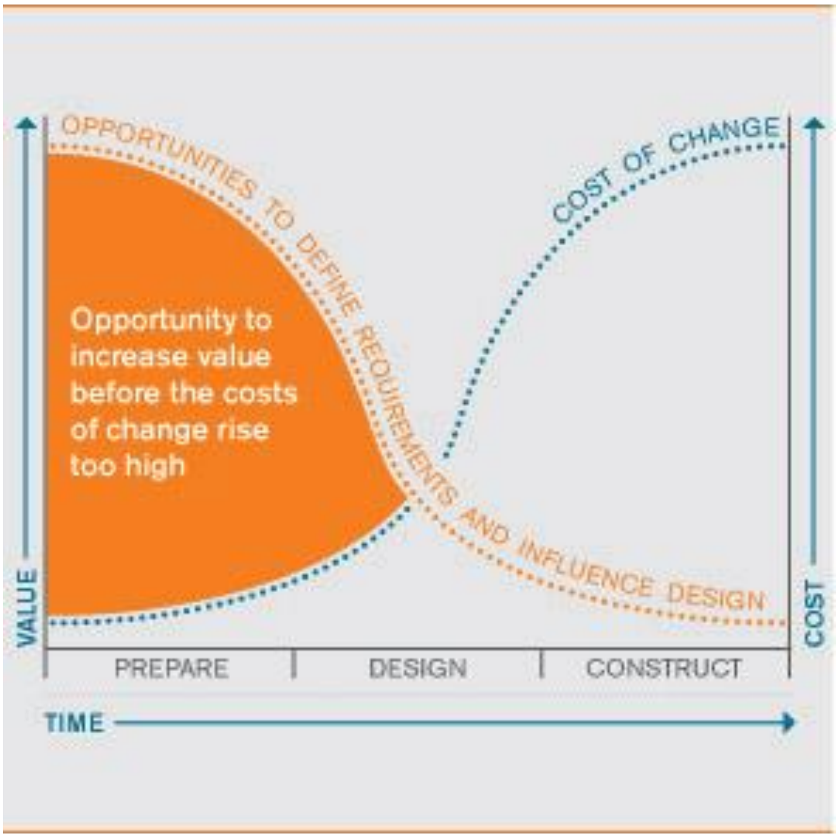

Figure 2.3: The client's opportunity to increase project's value (Kurokawa et al., 2016)

To ensure greater efficiencies and value for money in how assets are built and operated, the client's role is, more than ever, crucial in making sure the core requirements are maintained and communicated to the various parties involved (Wing et al., 2015). Therefore, providing accurate requirements is not enough without the validation of supply chain deliverables, which enables the client to achieve the desired benefits. Therefore, being the 'client' of a project is an important role which can provide opportunities for creativity through implementing new innovations and methods of delivery. However, it can also be a difficult and challenging role when the project is finished and it becomes apparent that the aims do not match the outcomes (Al-Harthi et al., 2014; Boyd and Chinyio, 2008; Doloi, 2012).

The increasingly popular move toward innovation implementations, such as BIM, to improve construction industry performance and productivity requires close collaboration between all involved parties, but particularly the client, designer and contractor (A. Robson et al., 2014). Both the designer's and the contractor's roles have received greater attention than that of the client in the delivery of the construction projects. Furthermore, research has so far given less attention to the changes in the client's role when new innovations, such as BIM, have been implemented (Maradza et al., 2014). This highlights the need to re-visit the client roles for BIM implementation. The Construction (Design and Management) Regulations 2015 (CDM, 2015) summarise the client's role as follows:

- Make suitable arrangements for managing their project, enabling those carrying it out to manage health and safety risks in a proportionate way. These arrangements include:

    a) Appointing the contractors and designers to the project (including the principal designer and principal contractor on projects involving more than one contractor) while making sure they have the skills, knowledge, experience and organisational capabilities
    b) Allowing sufficient time and resources for each stage of the project.
    c) Making sure that any principal designer and principal contractor appointed carry out their duties in managing the project.
    d) Making sure suitable welfare facilities are provided for the duration of the construction work.

- Maintain and review the management arrangements for the duration of the project.
- Provide pre-construction information to every designer and contractor either bidding for the work or already appointed to the project.
- Ensure that the principal contractor or contractor (for single contractor projects) prepares a construction phase plan before that phase begins.
- Ensure that the principal designer prepares a health and safety file for the project and that it is revised as necessary and made available to anyone who needs it for subsequent work at the site.

Based on in-depth study of each of the client roles, they can be classified into two main categories as follows:

1. **Developing project requirements**

This includes a client's duty to include; the specification for the proposed project, the scope of services required from the project supply chain, and an allocation of risk for unknown items. There are basically two main elements in the client's requirements. Firstly, the strategic (or outline/initial) element sets out the broad scope and purpose of the project and its key parameters, including the overall budget and programme (Beard, 1996; Wong et al., 2000; Worthington et al., 1995). Secondly, the project (functional) element which is a full statement of the client's functional and operational requirements for the completed project. However, it might also cover some secondary elements, for example, fit-out brief for fittings and furnishings, space-planning brief, and so forth (Beard, 1996; Wong et al., 2000; Worthington et al., 1995).

2. **Validating the deliverables**

This includes a client's duty to ensure that the project requirements have been met efficiently. The validation process has different levels of difficulty, ranging from the most simplistic that can be automatically checked by a computer, to the most complex that can only be performed with human expertise and judgment. Therefore, this role requires a certain level of knowledge and experience (S. Zhang et al., 2013).

Nonetheless, in all projects clients can provide leadership and ensure that the direction that the project is taking is acceptable. Client leadership is vital to the success of any project and in enabling the construction industry to perform to its best; this is because it enables a client to build the requirements that will optimise the proposed project's efficiencies and enable them to validate these project outcomes through all lifecycle stages (Senaratne and Samaraweera, 2015). Thus, clients establish the culture in which everyone performs, and from this evidence it can be concluded that a client needs a considerable level of knowledge and experience in order to fulfil these roles.

Therefore, it is the knowledge and skills of the client regarding the construction industry that drives any innovation goals in construction projects (K. Kulatunga et al., 2011). Whether a construction client is experienced or inexperienced is more vital than whether they function in the private or public sector. Informed clients (knowledgeable and experienced) are more likely to have invested in their capacity to fulfil their roles, thus delivering benefits for both themselves and their supply chain. Uninformed or inexperienced clients, on the other hand, are less likely to have an understanding of the construction sector challenges and the importance of their client roles. This poses greater risks for the successful delivery of construction projects (Havenvid et al., 2016; Kurokawa et al., 2016; Merschbrock and Munkvold, 2015; Sarkar et al., 2015). Therefore, experienced clients are those able to maintain a good level of knowledge and manage all their information. This highlights the importance of using information management inside client organisations to ensure they can call on any information whenever required. The growth of information management in the construction industry is expected to have an influence on the way construction is performed in the future (Eadie, Odeyinka, et al., 2013; Harris and McCaffer, 2013). Therefore, it could be considered that one of the main innovations that clients have to lead is in implementing information management in the UK construction industry (Loosemore and Richard, 2015; Senaratne and Samaraweera, 2015; Wing et al., 2015).

2.4 The role of information management in construction

The construction industry is facing a significant challenge through erroneous and untimely communications between project stakeholders, which unsurprisingly results in costly delays to construction projects (Al Ahbabi, 2014). Information is the foundation of every client organisation. Those with accurate, reliable and timely information have an economic advantage over their competitors. Best practices, found within best-in-class client organisations, dictate that information is treated in the same manner as other valuable assets and, regardless of their type, assets require careful management, thoughtful governance, and strategic consideration in their use and control (Kelly et al., 2014; Stewart and Mohamed, 2003; Wu et al., 2013). The UK construction industry acknowledges the importance of information management and has set aside an investment of up to £150 million over the next five years to support the reduction of construction times, improvement of quality, and development of more efficient built environment assets. Furthermore, £60 million is being invested in the Technology Strategy Board to support the UK construction industry in designing and developing more energy efficient buildings (Department for Business, 2015).

Information management has become the one of key factors in the success of all organisations in general and for client organisations in particular (Atherton, 2012; Stewart and Mohamed, 2003; Wijekoon et al., 2015; Wu et al., 2013). This is due to its effectiveness in maintaining the large amount of information required to support decision-making processes. Information and Communication Technologies (ICTs) facilitate management in sharing knowledge and information; thus, ICTs have a prominent role within information management initiatives. In the current business environment, the implementation of information management projects has become easier with the help of technological tools. As such, knowledge sharing is facilitated through information and communication technologies, including computers, telephones, e-mail, databases, data-mining systems, search engines, video-conferencing equipment, and so forth. Construction is one of the most information dependent industries, with its multiplicity of forms of information, which consist of detailed drawings and photos, cost analysis sheets, budget reports, risk analysis charts, contract documents, and planning schedules (Kelly et al., 2014; Stewart and Mohamed, 2003; Wu et al., 2013). The amount of information produced and exchanged throughout a project lifetime could be significant, even for small-sized construction projects (Baskerville and Wood-Harper, 2016; Lalonde and Adler, 2015; Schwalbe, 2015). Therefore, it is important that the information sharing can be managed as efficiently as possible in order to improve project productivity and quality. For the construction industry to take full advantage of ICT, it must make the fundamental change to become an information environment and embed information management in its current processes (Amor et al., 2002). The requirements of an information environment include (Baskerville and Wood-Harper, 2016; Lalonde and Adler, 2015; Schwalbe, 2015):

- The technology to process data into information. The technology must have the capability to manage a changing database without a redesign of the technology. This minimises systems that have a set order of decision processes;
- Performance information databases should be shared among facility owners, constructors and designers;
- There is a need for education within the construction industry on information management and how to use it to improve construction performance.

One of the main uses of information management innovation is Building Information Modelling (BIM), which is represented as the practical application of information management in terms of technology and process (Eastman, 2011; Reddy, 2012; Tardif, 2015; J. Underwood, & Isikdaq, U., 2009). BIM is able to deliver value from better quality information which has led to improved efficiencies of the asset lifecycle processes, providing a safer and more productive environment for its occupants, and more operational competence for its owners throughout the building lifecycle (Eastman, 2011; Reddy, 2012; Tardif, 2015; Underwood, 2009). The UK Government BIM strategy emphasises that the major progress being made in the implementation process of BIM, which has become compulsory for all publicly procured construction projects since 2016 (Department for Business Innovation & Skills, 2013; UK Commission for Employment and Skills, 2013). The main reason/driver for this strategy is to derive better value through publicly procured assets by securing better quality information to reduce the whole life cost and CO2 emissions. This can be achievable by implementing BIM, where its approach to asset design, construction, and operation differentiates it from other innovations regarding elements such as technology, process, people, and information management (Haron, 2013). This shows not only the advantages of 3D parametric modelling, but also of structured information that is organised, defined, and shared amongst the project supply chain via effective technology and processes (Haron, 2013). The next section will discuss the definitions of BIM definitions before considering BIM for client organisations.

2.5 BUILDING INFORMATION MODELLING

This section discusses the associated literature regarding Building Information Modelling (BIM) in order to explore, appraise, and synthesise the definition, concept, and information on BIM for client organisations in terms of the benefits and requirements.

2.5.1 BIM Definitions

During the information and communication technology (ICT) boom, the construction industry experienced a massive paradigm shift as the use of personal computers became widely available (Ahmad Latiffi et al., 2014; Chong et al., 2013; Issa and Suermann, 2009; Wijekoon et al., 2015). This, in turn, gave the construction industry supply chains a new tool to work with, which resulted in the development of many different types of software that aimed to improve the efficiency of a range of tasks. Within the construction industry, traditional methods of designing and drawing were instead replaced with computed aided design (CAD). This has greatly increased productivity and efficiency and paved the way for more sophisticated, complex, and grand designs amongst ambitious architects and engineers who strive to outdo one another (Ahmad Latiffi et al., 2014; Chong et al., 2013; Issa and Suermann, 2009; Wijekoon et al., 2015). However, developers have been requested for more than just the use of CAD for 2D or 3D designs. The initial philosophy of BIM evolved from CAD in 1987, where, instead of having only the design of the building, developers requested additional dimensions and data to the basic designs, such as costs, quantities, time, environmental data, and so forth (Grilo and Jardim-Goncalves, 2010; Niculescu and Gu, 2012). The philosophy of adding these supplementary dimensions meant designers had a greater insight into not only what their designs would look like, but also how their design would function and meet the specific requirements and needs in the industry. Therefore, BIM has been described as a modelling tool where different dimensions, information, and data can be added as deemed fit. In bringing this information together, many different parties are required to work together and make these information and data available in forming the model. This brings the construction industry to the next philosophy of BIM, which is to encourage greater collaboration and communication among different parties in the construction project, whether within the construction industry or among different industries where a prior conventional approach has relied on numerous exchanges of 2D drawings and documents in fostering collaboration between project stakeholders (Singh et al., 2011). Interoperability is the key for effective implementation and collaboration in BIM projects (Cerovsek, 2011). It encourages interaction in terms of communication, coordination, cooperation, collaboration, and channel (Grilo and Jardim-Goncalves, 2010).

From an academic point of view, the BIM concept was initiated by Professor Charles Eastman at the Georgia Tech School of Architecture in the late 1970s (Latiffi et al., 2014). The increased demand and interest in using building information modelling (BIM) is now a global trend in architectural, engineering, construction, and operations (AECO) sectors. This is influenced by the enhancement and development of the technical and non-technical aspects of BIM (Al Ahbabi and Alshawi, 2015; Patacas et al., 2015). The technical aspects comprise the emergence of user-friendly software, tools, libraries, and high performance computers (Laakso and Kiviniemi, 2012); while the non-technical aspects, such as processes, people, and information, consist of continued research and development as well as the actual implementation of BIM within the industry. Research into BIM is continuing and has received significant attention from academics and researchers around the world; for instance, 130 BIM related articles were published in 2003, which rapidly increased to approximately 700 in 2012. Since its development, it has been expanded and used in different areas throughout the asset life cycle. These areas are; design visualisation, cost estimation, construction process, asset life cycle, asset performance and operation, and the areas in which BIM can be used continues to grow. The purposes of BIM implementation in any construction projects vary throughout the construction project phases, namely, pre-construction, construction and post-construction (Isikdag et al., 2012; Sackey et al., 2013).

The terms 'Building Information Model' and 'Building Information Modelling' (including the acronym "BIM") were not popularly used until 2003 (Succar et al., 2013). In 2002, Autodesk released a white paper entitled ‘Building Information Modelling’, and following these other software vendors also started to assert their involvement in the field. The term BIM represents different things to different people, which includes tools, people, information management, and process (Hossain et al., 2013). Some people consider BIM a modern technology that helps them visualise and control a project model, whilst others consider it a new process to design, construct and maintain built environment assets. Others yet consider BIM a combination of technology and process and describe its underlying intention to lead the AEC Industry to a greater level of efficiency. Reflecting this complexity in views, the different definitions are provided below:

1. The National Building Specification (Specification, 2012) defines BIM as a, '*rich information model, consisting of potentially multiple data sources, elements of which can be shared across all stakeholders and be maintained across the life of the building from inception to recycle.*'
2. HM Government (2012); (MacLeamy, 2012) state that BIM is a, '*collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets.*'
3. Associated General Contractors of America (2006) define BIM as, '*the development and use of technology to simulate the construction and operation of the facility from which views and data appropriate to various users' needs can be extracted and analysed. This data is then used to generate information for making a decision that improves the process of delivering the facility.*'
4. According to the National Institute of Building Science (Sciences, 2007), BIM is defined as, '*a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle.*'
5. BIM can also be seen as a new technology which boosts the communication between all project participants, in accordance with the entire project lifecycle (D. K. Smith and Tardif, 2012).

According to the research aim, BIM can be defined as the technology; people; information; and process that enable a client organisation improve to the efficiency and productivity of its construction projects. As the UK represents the research context for this study, the next section will illustrate what BIM means inside the UK construction industry.

2.5.2 Building Information Modelling (BIM) in UK construction Industry

Improving the efficiency in construction has been on the UK Government-Industry agenda for many years (Wolstenholme, 2009). Various initiatives have been documented, addressing different aspects of the construction industry (Banwell, 1964; Egan, 1998; Emmerson and Emmerson, 1962; Latham, 1994; Simon, 1944). Recent initiatives, such as BIM, lean construction and offsite construction, aim to reduce costs through improved resources and enhanced data management (Vasileios Vernikos, 2012; VK Vernikos et al., 2013). In recent years, BIM has been increasingly applied within the UK construction industry (Eadie, Browne, et al., 2013) and its implementation is occurring via a 'push–pull' process as it is slowly becoming embedded in various forms and methods in many current construction projects (National BIM Report, 2013).

The UK Government has recognised the potential for BIM to transform the construction industry as a whole and is pursuing a strategy, which requires collaborative 3D BIM (with all project and asset information, documentation and data being digital) on all its projects by 2016. The UK strategy is considered by many to be the most ambitious and advanced centrally driven BIM strategy in the world (HM Government, 2012). The UK Government's support for BIM is acting as a motivating factor, providing energy to the development of the common standards and protocols that are an essential part of the BIM process (BIM TaskGroup, 2013). The quality and effectiveness of the UK BIM standards have been considered a reference for many construction industries around the world. For example, the Canadian BIM protocol has been developed based on the AEC (UK) protocol (NFB, 2013). In addition, the UK BIM protocol and standards have been used to formulate the first version of BIM standards in Hong Kong, Russia, Germany, and Australia (Gomes et al., 2013; RICS, 2011). This widespread specification gives the impression that it will help all the project supply chain to gain their desired benefits, especially the client.

BIM in the UK has been classified as a number of different levels of maturity, as shown in Figure 2.4 (BIMTalk, 2010). These levels will be explained below along with the related available standards:

- **Level 0**

  Unmanaged CAD, in 2D, with paper (or electronic paper) data exchange.

- **Level 1**

  Managed CAD in 2D or 3D format with a collaborative tool providing a common data environment with a standardised approach to data structure and format. Commercial data will be accomplished by standalone finance and cost management packages without integration.

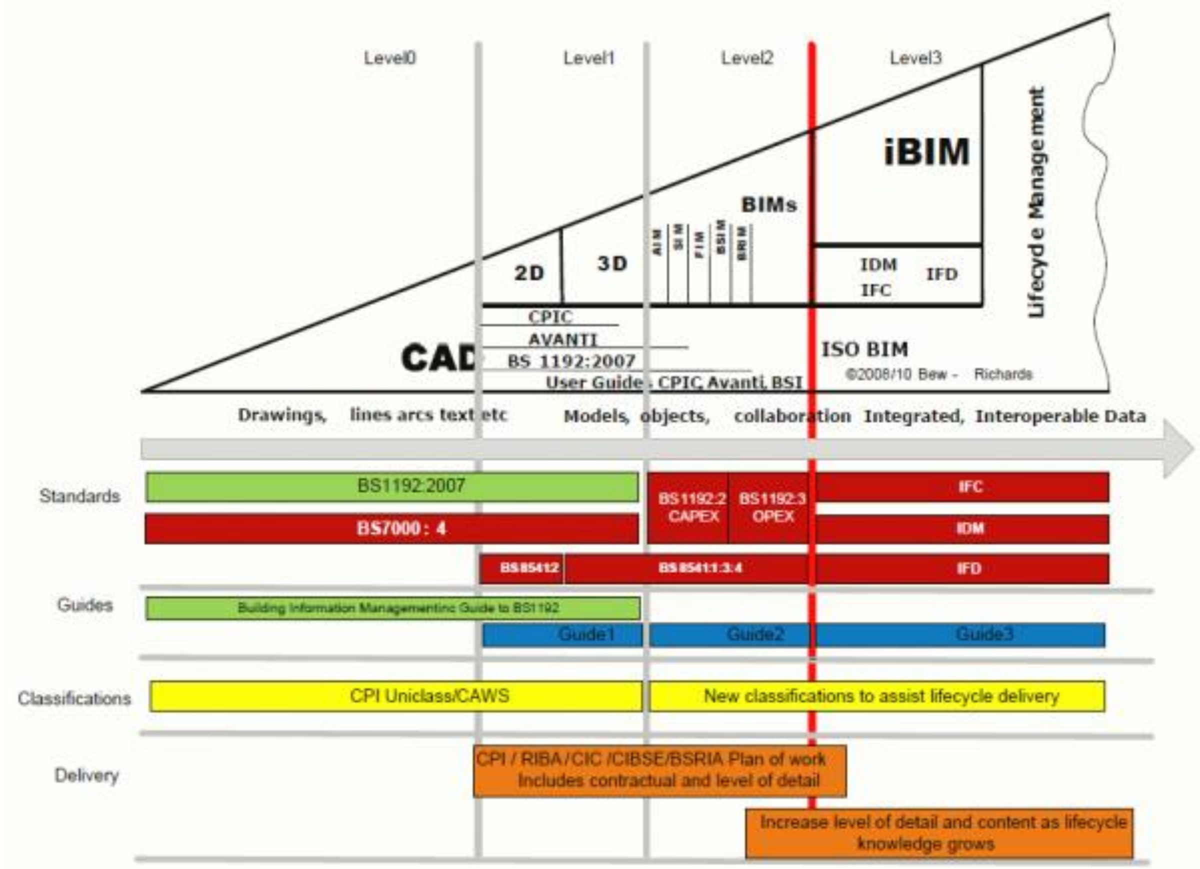

Figure 2.4: BIM maturity levels in the UK (BIMTalk, 2010).

- **Level 2**

A managed 3D environment detained in separate discipline 'BIM' tools with data attached. Commercial data will be managed by initiative resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may utilise 4D construction sequencing and/or 5D cost information. The Government's BIM Strategy calls for the industry to achieve Level 2 BIM by 2016.

Following the original Government report in 2011, the definition of Level 2 in the UK has been described by the publication of a set of 8 documents (pillars of BIM), which include standards, protocols, classification systems, and a toolkit. These documents are as follows:

- PAS 1192-2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling.

- PAS 1192-3:2014 Specification for information management for the operational phase of assets using building information modelling.

- BS 1192-4 Collaborative production of information. Part 4: Fulfilling employer information exchange requirements using COBie – Code of practice.
- BS 1192-5 Specification for security-minded building information modelling, digital built environments and smart asset management.
- Building Information Model (BIM) Protocol.
- GSL (Government Soft Landings): A UK government framework that maximises the benefit of BIM for whole life building effectiveness applying principles of 'soft landings'.
- Digital Plan of Work: A UK Government BIM Task Group draft document on concepts and detail of the management of built asset data derived from BIM.
- Classification: A standardised system, which is being developed to ensure that data can be indexed and structured to make it easily accessible in a common format integrates with the Digital Plan of Work.

This suite of standards, the BS1192 family, plus additional documents, have been created to allow customers and all parties involved in the creation of physical built assets, to define processes and procedures around the electronic exchange of data sets (Reed, 2016).

To fully deliver Level 2 BIM on a project, the team is required to adopt all of these documents. However, in many cases, all of the documents are often considered but not necessarily adopted and so the project is often described as working 'in the spirit' of Level 2. This is often due to clients' fear and lack of understanding, which can prevent them adopting all the aforementioned documents at the same time. Equally, there is flexibility in the Level 2 guidance as these documents allow project teams to 'pick and choose' the precise way they decide to deliver on the requirements which therefore mean that the user ability to use BIM level 2 standards can be affected by his level of BIM knowledge and understanding.

Models produced using Level 2 BIM point out that solutions are ultimately exported and imported into disconnected systems. Under Level 2 BIM, with no integrated system to leverage BIM data, builders and suppliers are removed from fully collaborating on the model and are left to absorb the cost of the rework (A. Robson et al., 2014). BIM Level 2 tools tend to focus on design coordination problems, and do not maintain much of a role in construction processes (Eadie, Browne, et al., 2013; Eadie et al., 2015; Ganah and John, 2014; Porwal and

Hewage, 2013). It is widely acknowledged that, despite the benefits of Level 2 BIM, the most significant change will come with the adoption of Level 3, collaborative BIM (BSI, 2011).

The creation and implementation of BIM Level 2 was a bold step and an acknowledgment, by the government, of the construction industry's importance to the UK economy (Ganah and John, 2014; Ojo et al., 2015). This support has been maintained through the revised Government Construction Strategy 2016–2020 and the Construction 2025 strategy (Alwan et al., 2016; Office, 2016; Stocks, 2016).

The 2016 Budget Report went further, supporting the development of BIM Level 3 as outlined in the February 2011 Digital Built Britain strategy, and stating '*the government will develop the next digital standard for the construction sector – Building Information Modelling 3 – to save owners of built assets billions of pounds a year in unnecessary costs, and maintain the UK's global leadership in digital construction*' (B. Report, 2016).

BIM Level 3 is the approach that fully connects the asset information from start to finish, helping to create end-to-end efficiencies. It is often stated that Level 3 will represent a paradigm shift requiring a re-engineering of the process and mindset within the industry (Charalambous et al., 2013). An adoption and implementation documents, equivalent to that of Level 2 does not yet exist. One of the major differences between Level 2 and Level 3 BIM is the use of a 'collaborative model server' (BSI, 2011). The use of online collaboration platforms to host a central model is a solution for this BIM maturity step. The challenge remains in placing the structured, integrated building information model as the focal unit of communication (Andersson et al., 2016; Kouider et al., 2016; Pansegrouw, 2016).

- **Level 3**

  Based on the savings delivered by the BIM level 2 initiatives, Level 3 will empower the interconnected digital design of different elements in a built environment. It will also support the augmented delivery of smart cities, services and grids (Jim Mason and Knott, 2016; Ward, 2016). BIM Level 3 is defined as a fully integrated and collaborative process enabled by 'web services' and compliant with emerging Industry Foundation Class (IFC) standards. This level of BIM will utilise 4D construction sequencing, 5D cost information and 6D project lifecycle management information in a fully collaborative environment, which is absent in BIM Level 2. BIM Level 3, (Digital Built Britain Strategy), '*will extend BIM into the operation of assets over their lifetimes*' (Carbonari et al., 2015). It will also deliver reductions in whole-life costs and carbon emissions, whilst improving productivity and capacity by using intelligent building information models, sensing technology, and secure data and information infrastructure. It will also help to deliver other Government digital transformation objectives, such as smart cities, cyber and physical security, and sensors through the Internet of Things (Jim Mason and Knott, 2016; Ward, 2016). Under BIM Level 3, the full collaboration between all disciplines involved in a construction project will encourage facilities managers to become more involved with the modelling technology. Researchers have only recently started to look at the possible integration of BIM and FM, but the main focus is on new constructions rather than on existing buildings (Ravetz, 2008).

The Digital Built Britain programme comprises three main components, which are;

1. Level 2 legacy activity, to continue to drive Level 2 uptake and realise further benefits;
2. Treating those development needs, which can be complex and time-consuming; these are grounded in current knowledge and understanding (for example, developing new construction contracts, IPR protocols, and some aspects of data interoperability);
3. Areas that are going beyond our current understanding and requiring the interaction of differing technologies.

However, doubts among construction industry professionals that the UK will meet the Government targets for the use of BIM on projects are increasing, according to surveys by NBS National BIM Report 2015 and Masons (2015). Although 94% of survey respondents were aware of the Government's stated commitment to use 'Level 2' collaborative 3D BIM on all centrally-procured government projects by 2016, 71% said they believed the industry would not be ready. This view was also reported by 63% of respondents for the same survey last year. There was also a significant increase in the number of respondents believing that the lack of understanding of BIM further down the supply chain was the main reason for this attitude (Ashworth et al., 2016a; Hong et al., 2016).

Despite the considerable value of the Level 2 BIM suite of standards, they focus primarily on BIM implementation requirements from the project side and also lack explanation regarding the BIM implementation requirements from an organisational point of view (Calderisi, 2013; Dakhil, 2015; Eadie et al., 2014; Mom and Hsieh, 2012; Succar, 2015b). Therefore, the type of requirements that organisations need to meet to implement BIM effectively is lacking. Such requirements may help organisation to manage the change in people, processes, and technology. In addition, despite the importance of the client organisation in the BIM implementation process, the differences between the client and other organisations, in terms of BIM implementation, are not elaborated effectively (Drew et al., 2001; Dwairi et al., 2016; Lindblad and Vass, 2015; S. Zhang et al., 2013). For instance, client organisations in particular need to practice strong BIM leadership to turn BIM deployment to their advantage and ensure that clear plans are set for all project stakeholder compliance (Y Arayici et al., 2011; Eastman, 2011). Clients should adopt BIM to facilitate and encourage greater collaboration between all stakeholders leading to design and construction optimisation, energy saving, and waste reduction, whilst also meeting time and cost targets and ensuring higher quality projects. In addition, BIM software and hardware in client organisations do not have the same level of importance compared with the supply chain organisations (Y Arayici et al., 2011; Eastman, 2011). The next section will consider BIM implementation from the perspective of the client organisation and demonstrate what the client needs to provide in order to utilise BIM on their projects as well as the benefits of adopting BIM for the client organisation.

2.6 BIM for client organisation

Initially, the significance of the client lead is strongly recognised as bringing change through better collaboration between project stakeholders (Drew et al., 2001; Maradza et al., 2014; A. Robson et al., 2014). Therefore, the implementation of BIM, which requires substantial change, needs to be fully client led. Without this support and push from the client, the end result may never reach its full potential (ED Love et al., 2015; Lindblad and Vass, 2015; Market, 2014). This is becoming more important with the adoption of the Level 2 BIM process and the need for a knowledgeable and experienced representative within the client organisation; this forms an important part of the role requirements in regard to BIM. Clients, in particular, can significantly benefit by adopting BIM as a process and tool to guide their delivery process to higher quality and performance for a whole asset life cycle (Eastman, 2011). BIM changes the methods of design and build (Yan and Damian, 2008), which leads to a reduction in the total cost and time as a direct benefit (Love et al., 2013). Y Arayici et al. (2011) concluded that collaboration among stakeholders will expand the client's organisational boundaries that may lead to an improved performance of the project during the different stages of the lifecycle. BIM can help in creating this new collaborative environment, where all the project stakeholders can sit together and exchange information in the early stages of the project lifecycle (Y Arayici et al., 2011; Dado, 2011; Eastman, 2011; Laine et al., 2007; Reddy, 2012).

This new process of sharing information will provide some directly valuable benefits for the client, specifically a full project understanding (Azhar et al., 2012; Bryde et al., 2013; Eastman, 2011; Succar, 2009).

There are also other advantages for clients through the BIM process and by gathering and using reliable project data. Models can be investigated from the feasibility stage and tested more accurately than under 2D processes, and this helps in approving the outline business case. BIM can also offer better programme (4D) and cost (5D) certainty at an earlier stage compared with the traditional process, which will provide a degree of assurance to the developer not currently available. Notably, reliable digital data across a portfolio will also let a client compare project outcome data from project to project in a far more detailed and accurate way than previously possible (P. Wilkinson, 2013). Nevertheless, despite BIM's great value for a client organisation, the lack of client demand is one of the top five reasons that prevents it from being accepted and more widespread (McGraw-Hill, 2012; NBS, 2014; RICS, 2014) (Figure 2.5).

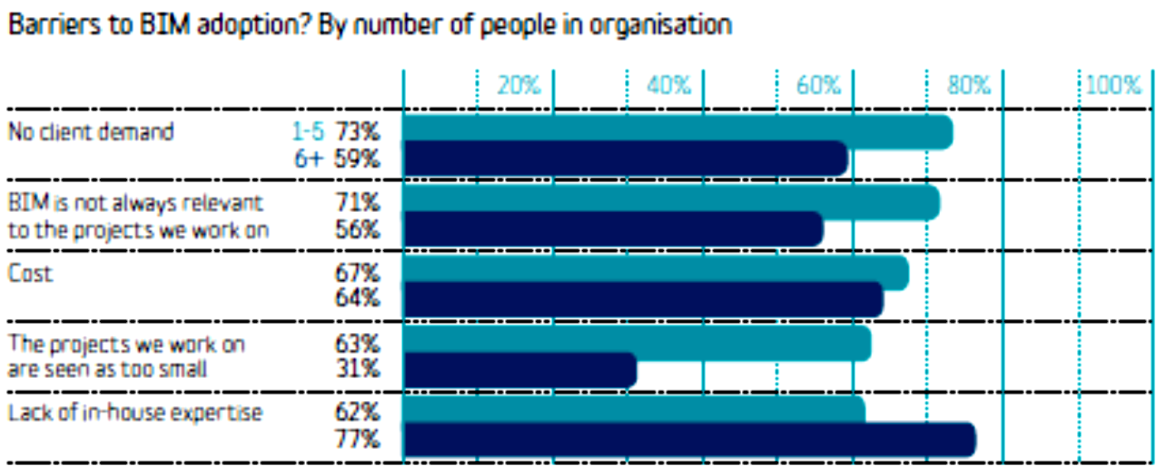

Figure 2.5: Barriers to BIM adoption (NBS, 2014)

Client quality control and quality assurance are mostly absent as BIM requirements, deliverables, standards, roles and responsibilities, and BIM applications, and so forth, are not clear and/or are not specified in contracts. In turn, this can explain some of the main prejudices behind client behaviour against BIM implementation (Eadie et al., 2015; ED Love et al., 2015; Lindblad and Vass, 2015; Jim Mason and Knott, 2016). One of the BIM Level 2 documents, namely PAS1192-3, highlighted the importance of client organisational requirements by explaining Organisation Information Requirement (OIR). This document aims to support client organisations in transferring their business targets to BIM requirements, and will be discussed in detail in the following sub-section.

2.6.1 Client organisation information requirements

PAS 1192-2 (BSI, 2013) states that the start of the BIM process should provide a, '*clear understanding of the client`s OIR and Asset Information Requirement (AIR)*' and that one of the '*fundamental principles of level 2 information modelling is the provision of a clear Employer Information Requirement (EIR)*' (Ashworth et al., 2016b). The relationship between these three important documents is shown in Figure 2.6.

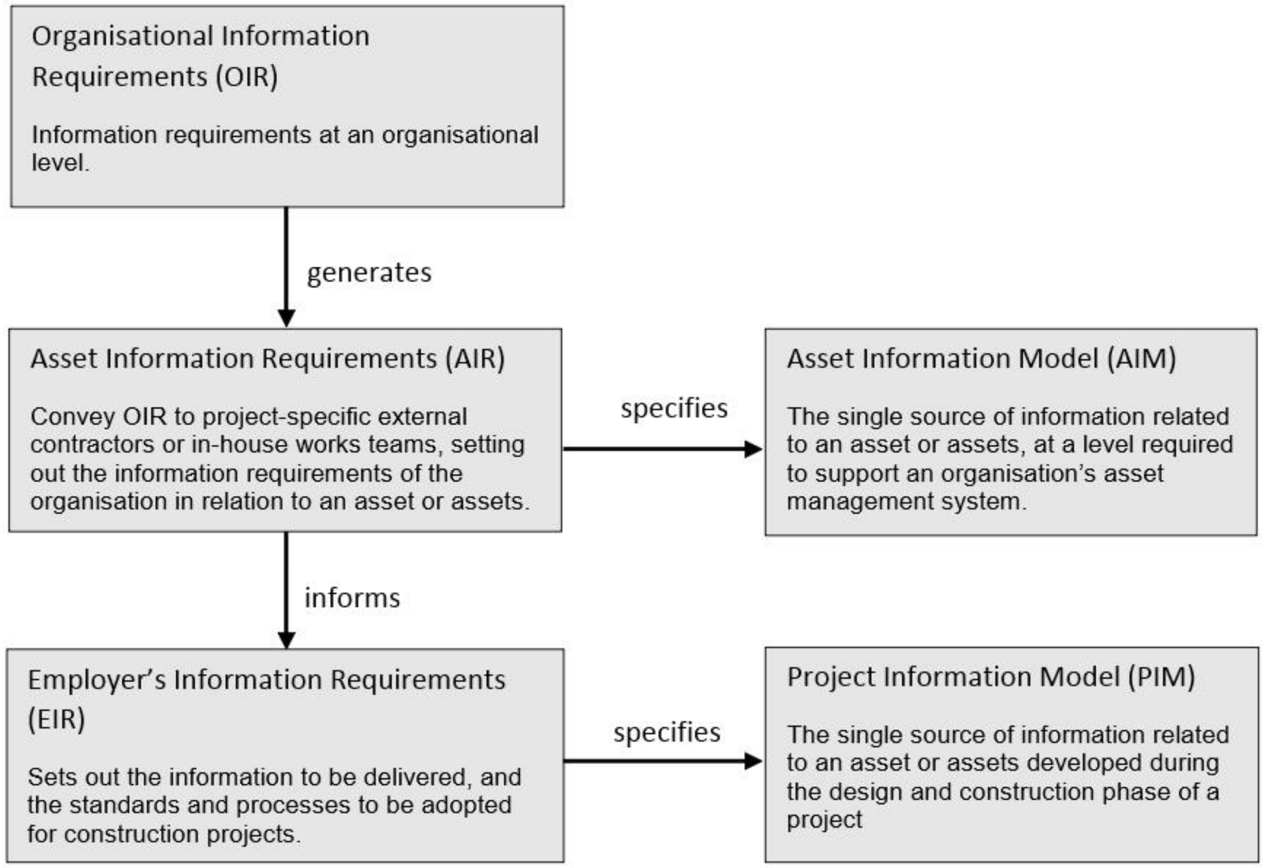

Figure 2.6: The relationship between OIR, AIR, and EIR

From the Figure it can be seen that the organisation works to first decide on its Organisation Information Requirements (OIR). OIR drives the identification of Asset Information Requirements. AIR are the detailed pieces of information required about the asset that, when placed in context, can answer the questions raised in the Organisation Information Requirements. Following this, it is necessary to consider from which of a multiplicity of sources an organisation will obtain that information. PAS 1192-3 (BSI 2014) describes the ultimate purpose of the BIM process is to, '*provide information into the client Asset Information Model*

(*AIM)*’ which should be ‘*the single source of approved and validated information related to the asset(s)*’ (Ashworth et al., 2016b). This enables facility managers to achieve optimum performance more quickly, reduce running costs, and refine target outcomes (BIM Task Group, 2015). However, clients/FMs are the only stakeholders that ultimately understand the client needs, and can specify these for the EIR at the start of the BIM process. One of the key documents that clients must adopt to request BIM uses in their projects is EIR.

The Employers Information Requirements (EIR) has been defined by the BIM task group as, ‘*a key contractual addendum document in any asset improvement, replacement or new build project where any form of Building Information Modelling (BIM) or digital information is being requested by the client (Employer).*’ EIR represents the first step in the information delivery cycle as shown in Figure 2.7.

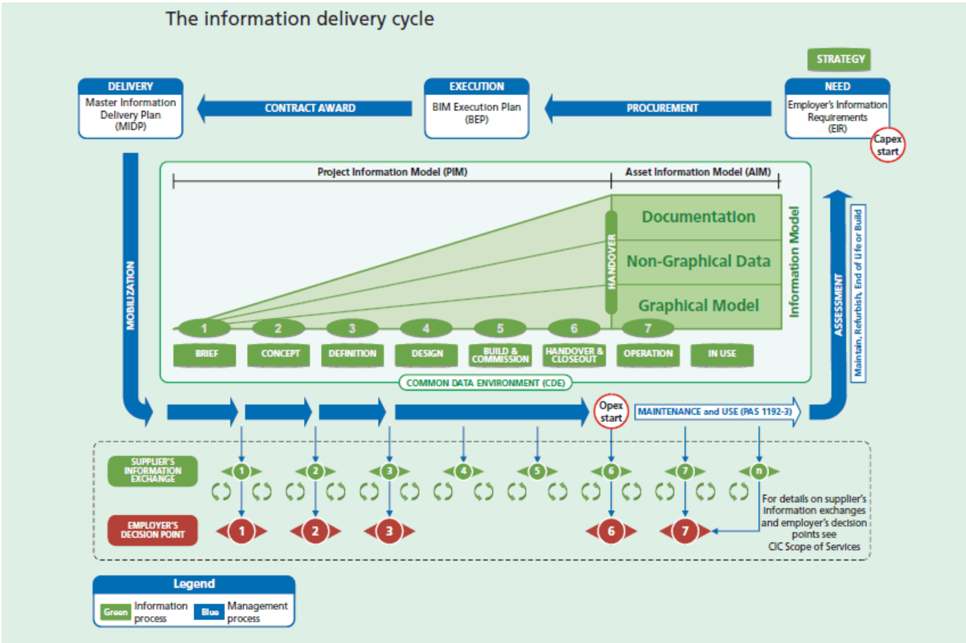

Figure 2.7: Information delivery plan (Task Group, 2013)

EIR is a vital element of a project’s BIM Implementation as they are used to set out clearly to the bidder what models and information are mandatory and what the commitments of the models will be (Al Ahbabi and Alshawi, 2015; Patacas et al., 2015). These requirements will be written into the BIM Protocol and implemented through the BIM Execution Plan (BIM Task Group, 2013). This document has considerable importance in that it reflects the client’s capability to accept, validate and use digital information (Barnes and Davies, 2014; Ojo et al., 2015). The EIR and BIM specific requirements will adapt and change over time depending on the project team's BIM capability; this has a strong bearing on the scope and format of the project EIR and the information requirements specified (Toolkit, 2012).

An EIR reflects the client's BIM understanding and can reveal much more about their effectiveness in using BIM. A client's ability to use BIM in their project can be expressed by their BIM competency (Al-Harthi et al., 2014; Al Ahbabi, 2014; Al Ahbabi and Alshawi, 2015; Atkin et al., 1995; Boyd and Chinyio, 2008). The concept of BIM competency represents a BIM user's ability to satisfy a BIM requirement or generate a BIM deliverable (Succar, 2009). The EIR document includes several items, which can reflect the client's maturity; for example, current client standards, collaboration extents, software and hardware specifications, roles and responsibilities, data drop specifications, and levels of detail (LOD) (Barnes and Davies, 2015; M. Hafeez et al., 2015; Navendren et al., 2015). Therefore, clients need to identify how BIM can produce benefits for their business. This means adopting BIM to ascertain improvements in quality, processes, efficiency, and profit rather than because of a mandate (Ganah and John, 2014; Howe, 2015; Ojo et al., 2015).

Due to the importance of clients in the BIM implementation process across the construction industry, it is important to investigate the benefits that clients may achieve through adopting BIM throughout the project lifecycle and what clients need to provide to implement BIM efficiently to enable them to achieve their desire benefits. The next sections will investigate these two elements from the client's perspective.

2.6.2 BIM Benefits for client

The definition of benefit, in general, is, '*an outcome of change which is perceived as a positive by stakeholders*' (Bradley, 2010). Haron (2013) stated that achieving the benefits of BIM will enhance a full BIM understanding, by helping organisations to approach their action plan for BIM implementation in terms of meeting their needs. With BIM-based processes, a client can potentially realise a greater return on investments as a result of the improved integrated design, construction, and operation process, which increases the value of project information in each phase and allows for greater efficiency within the project team. Simultaneously, a client can reap dividends in a project's quality, its cost, and the future operation of the asset (Bryde et al., 2013; Dowsett and Harty, 2013; Eadie, Browne, et al., 2013; J. Li et al., 2014). Due to the considerable impact that BIM can potentially have on traditional construction project problems, like cost overrun, schedule delays, and quality issues (Jackson 2002;

Eastman 2011), the client is in a position to benefit most from its use. The drivers that motivate all type of clients to adopt BIM include (Table 2.3):

1. **Improved information control**

   BIM is information driven comprising graphical, non-graphical and document data. Through its internal databases, BIM software allows for immediate access to this data for any element of a project. External links, such as websites, images, data sheets and manuals, to name a few, can also be associated with elements to minimise information duplication and ultimately improve information control; indeed, improvements are only limited by the information entered into the models. This information can then be used to assist with facilities management, and operation and maintenance issues once a project has been completed and handed over.

2. **Improve project planning**

   Planning and monitoring is an extremely important part of any construction project through all lifecycle stages. The project manager can use various 4D BIM enabled tools to enhance the quality control process of project planning. Overall, construction planning and monitoring with 4D BIM is a helpful process when building a facility according to the designed model. Enhancing a project delivery plan with rich information will reduce any delays that may generate additional cost to the client.

3. **Improved communications**

   BIM also helps to increase communication and understanding with potential stakeholders. High quality digital mock-ups can be created to give potential stakeholders a clear picture of what an asset will look like and how it will impact on the surrounding areas. With a better understanding of the project, stakeholders are more likely to buy-in. Therefore, BIM can improve design communication between architects and their clients because it deals with the activity of compounding and understanding the information associated with the three main concerns of a client: cost, function, and the building aesthetics. BIM's improved design communication creates a strong client-architect relationship.

4. **Enhanced integration of processes**

   BIM implementation can provide solutions to acquire, manage and make use of information and processes from various project and enterprise level systems and integrate them with asset models. In addition, it can play the role of a unifying platform that captures, integrates and shares the object-based information generated by BIM-based authoring, analysis, and simulation applications.

5. **Improve project quality**

   In this context, BIM-based quality control can be defined as ensuring that business quality requirements are confirmed through automated (namely, computerised) inspection and evaluation. BIM-based quality checking (Seo, Kim and Kim, 2012) is a platform for validating the design, construction, and other phases of BIM models from the viewpoint of quality control.

6. **Improve decision-making process**

   BIM offers, throughout all stages of project life cycle, an opportunity, as a process tool, to enable a more informed decision-making process by providing the right information with the right details and at the right time. Also, it will help client organisations to optimise decision-making processes through the design and construction stages.

7. **Improve overall project duration control**

   Visual simulation and the understanding of program change are further client drivers. Being able to see the impacts of design changes on the program is traditionally quite difficult. Firstly, identifying changes can be time-consuming and then finding the tasks affected in the program's Gantt chart can also be difficult. When BIM is introduced with the automated mapping between construction elements and tasks, the process becomes much quicker, easier and more visual with the ability to run scenarios across multiple program versions (for example, baseline versus current actual). This yields significant benefits for the planner and allows a focus on value-adding work rather than handling fragmented, disconnected data.

8. **Improve project cost control**

   Adding time and cost information as fourth and fifth dimensions to the BIM three-dimensional model will improve cost management outcomes. BIM can visually confirm the material mobilisation time and resource consumption within its schedule scope, whilst reducing storage cost and unnecessary material loss to a large extent, and conducting dynamic project cost management. Thus, BIM technology has an important position in the cost management of engineering projects.

9. **Reduce the number of Request For Information (RFI's) in the construction stage.**

   The ability to store both information about all elements in the model and the model itself develops at the initial phase of the project; it is possible to provide relevant information to all stakeholders at the construction stage. Studies show that the number of RFI's reduced considerably at the construction stage when BIM was utilised; due to the sharing of information among all project stakeholders.

10. **Lower number of CO (Change orders)**

    Digital technology can speed up and streamline the change order process by providing a secure, fast, and simple way to share and send these orders. It is worthwhile for owners to invest in a digital take-off and estimating software that supports the ability to draw a comparison (overlay). Investing in BIM technology is even more beneficial to owners. Though BIM technology is still emerging, the value addition brought to the owner through BIM may be much more than just the management of change orders.

11. **Reduced costs of materials**

    Visualisation using BIM helps clients and other project stakeholders to understand complex projects. Reduced uncertainty and improved predictability from the visualisation of the construction project over time helps to ensure an uninterrupted workflow and increased productivity. BIM generates accurate material quantities and helps to ensure a reliable delivery schedule, which is important in reducing material costs.

12. **Reduced re-work**

    Reworks due to design changes and clashes with different disciplines can be avoided as a client approves the design and facilities after visualising the model. In addition, clashes are removed while modelling.

13. **Improved relationship with project stakeholders**

    BIM serves as a collaborative platform for all stakeholders to share their knowledge resource and information, and sufficient information increases communication effectiveness. Effective communication allows stakeholders to exchange accurate, updated and clarified information so that decision makers can form a reliable decision.

14. **Improved data availability/accessibility**

    BIM can offer data availability and accessibility for all project stakeholders throughout the project life cycle. Providing such features will improve the project's overall quality and reduce the time taken in sharing this information.

15. **Enhanced accuracy and validity of information**

    Information quality, in terms of accuracy and validity, plays a critical role in the construction industry. BIM dimensions that include technology, workflow and human resource aspects have been considered as solutions that impact upon information quality. This can result in an increase in the speed of transmitted information, a reduction of costs associated with a lack of interoperability, an automation of checking and analysis, and an unprecedented support of operation and maintenance activities.

16. Less service works required

BIM can help create and maintain facilities that are more efficient, have lower carbon emissions, cost less to run, and are better, more effective, and safer places to work. The availability of built environment information that is inherent to the model helps the generation of reports that may be provided to the client as value-added services.

Table 2.3: BIM benefits for client organisations

	BIM main benefits	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Sources																
1	(Eastman, 2011)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
2	(Azhar, 2011; Azhar et al., 2012)	√	√		√			√	√			√		√	√	√	
3	(Becerik-Gerber and Kensek, 2009)	√		√	√	√	√			√		√	√	√	√	√	√
4	(Succar, 2010b)				√	√	√	√				√	√	√	√	√	√
5	(HM Government 2012)				√	√	√	√				√	√	√	√		√
6	(Dado, 2011)	√	√	√	√		√	√		√	√	√			√	√	
7	(B. K. Giel, 2009)		√	√	√		√					√	√	√	√	√	√
8	(Yan and Damian, 2008)	√	√	√	√	√		√	√			√			√	√	√
9	(Hardin, 2011)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
10	(Hergunsel, 2011)	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√
11	(Sullivan, 2007)				√	√	√					√	√		√	√	
12	(Rodriguez, 2011)	√	√		√	√	√	√		√	√		√	√	√	√	√
13	(J. Underwood, & Isikdaq, U., 2009)	√	√	√	√	√	√	√				√	√	√	√	√	√
14	(McGraw Hill Construction, 2009)	√	√	√	√	√	√	√				√		√	√	√	
15	(National BIM Standard, 2011)		√	√	√	√	√			√		√	√	√		√	√
16	(Bryde et al., 2013)	√	√		√			√	√	√		√	√	√	√	√	
17	(Yusuf Arayici et al., 2012)	√	√	√	√		√		√	√		√	√	√	√	√	√
18	(Barlish and Sullivan, 2012)	√	√	√	√	√	√	√	√	√	√	√	√	√			√
19	(Migilinskas et al., 2013)	√	√	√	√		√					√			√	√	√
20	(Ahamed et al., 2010)	√	√	√	√		√			√		√	√	√	√	√	√

21	(SUERMANN, 2009)			√	√		√				√	√	√		√	√	√
22	(Gilkinson, 2010)	√	√		√		√	√	√			√	√	√	√	√	√
23	(Lorime, 2011)	√	√	√	√	√	√					√		√	√		√
24	(Morrison, 2010)	√	√	√	√		√			√		√	√			√	√

The aforementioned benefits are considered direct outcomes from using BIM in different areas across the project lifecycle. Selecting areas where BIM should be used in order to achieve the desired benefits represents a challenging task to a client organisation. This task requires knowledge regarding each BIM use and the requirements that the client needs to meet in order to use BIM in a certain area (Bryde et al., 2013; Dowsett and Harty, 2013; Eadie, Browne, et al., 2013; J. Li et al., 2014). In December 2009, a survey was taken to help determine the frequency by which organisations adopt each use and the benefit to the project of each use. While the BIM uses of 3D coordination and design reviews were both the most frequently implemented and most beneficial based on the survey results, all of the uses in the survey were being employed to a degree on projects, and are perceived as beneficial; as shown in Figure 2.8 (Kreider et al., 2010). Within the literature, 21 areas have been identified where BIM can be used and produce different types of benefits for client organisations. Some of these areas are fit for just certain stages of the project life cycle while others extend over different stages, as shown in Figure 2.9. Furthermore, Appendix A presents the areas where BIM can be used from a client's perspective, and the corresponding benefits with supporting references.

BIM USE	Frequency	Rank	Benefit	Rank
	%	1 to 25	-2 to +2	1 to 25
3D Coordination	60%	1	1.60	1
Design Reviews	54%	2	1.37	2
Design Authoring	42%	3	1.03	7
Construction System Design	37%	4	1.09	6
Existing Conditions Modeling	35%	5	1.16	3
3D Control and Planning	34%	6	1.10	5
Programming	31%	7	0.97	9
Phase Planning (4D Modeling)	30%	8	1.15	4
Record Modeling	28%	9	0.89	14
Site Utilization Planning	28%	10	0.99	8
Site Analysis	28%	11	0.85	17
Structural Analysis	27%	12	0.92	13
Energy Analysis	25%	13	0.92	11
Cost Estimation	25%	14	0.92	12
Sustainability LEED Evaluation	23%	15	0.93	10
Building System Analysis	22%	16	0.86	16
Space Management / Tracking	21%	17	0.78	18
Mechanical Analysis	21%	18	0.67	21
Code Validation	19%	19	0.77	19
Lighting Analysis	17%	20	0.73	20
Other Eng. Analysis	15%	21	0.59	22
Digital Fabrication	14%	22	0.89	15
Asset Management	10%	23	0.47	23
Building Maint. Scheduling	5%	24	0.42	24
Disaster Planning	4%	25	0.26	25

Figure 2.8: BIM Application ranking according to their benefits (Penn State, 2012)

<table>
<tr><th>Stage 0</th><th>Stage 1</th><th>Stage 2</th><th>Stage 3</th><th>Stage 4</th><th>Stage 5</th><th>Stage 6</th><th>Stage 7</th></tr>
<tr><td>Appraisal</td><td>Design Brief</td><td>Concept Design</td><td>Design Development</td><td>Technical Design</td><td>Construction</td><td>Handover</td><td>In use</td></tr>
<tr><td></td><td></td><td colspan="6">Existing Condition Modelling</td></tr>
<tr><td></td><td></td><td colspan="6">Cost Estimating</td></tr>
<tr><td></td><td></td><td colspan="4">Phase Planning</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Design Authority</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Design Review</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Engineering Analysis</td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td colspan="2">Energy Analysis</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Sustainability Evaluation</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Code Validation</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="4">3D Coordination</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Construction System Design</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Site utilization Planning</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Digital Fabrication</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>3D control and Planning</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Record Model</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Building Maintenance Scheduling</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Building Systems Analysis</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Asset Management</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Space Management and Tracking</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Disaster Management</td></tr>
</table>

Figure 2.9: location BIM uses in project life cycle (RIBA, 2013)

The benefits of BIM are often sold with an emphasis on the design and construction phase, followed by the significant savings during the operational stage (Eadie et al., 2015; Lindblad and Vass, 2015; Jim Mason and Knott, 2016). However, it is necessary to ascertain whether clients actually know what to ask for at the start of the project to ensure that the data they procuring for post-handover is of value. To drive the best value from the entire BIM process, clients need to understand the fundamental principles of BIM so that they are able to request and issue the right information, at the right time and to the right level of quality. This understanding is important, as the supply chain will only provide what they are asked for. Hence, BIM requirements need to be clearly defined for stakeholders in order to provide high quality, relevant information. If clients do not prepare detailed Employer Information Requirements (EIR), the project delivery teams are unable to respond and provide the asset data that the client actually needs due to unclear requirements; this will mean creating too much or too little data and wasting time and fees (Sharp, 2015). Therefore, clients need to meet certain types of requirements in order to use BIM in different areas throughout the project lifecycle; these requirements will enable clients to achieve the desired BIM benefits by reviewing and planning for a valuable investment in BIM aligned with the specific project focal points or strategic business interests.

2.6.3 Client roles regarding the BIM implementation process

In the same context, clients can play a vital role in the BIM implementation process through the construction industry (Lindblad and Vass, 2015; J. Underwood et al., 2016). It is crucial that clients understand their roles in the BIM implementation process so they are able to request and issue the right information, at the right time and to the right level of quality. Without detailed Asset Information Requirements (AIR) from the client, project delivery teams are unable to provide the asset data that the client will need; thereby creating too much data, and wasting time and fees (Lindblad and Vass, 2015; J. Underwood et al., 2016). Following the same client role classifications, which have been derived from literature, clients' roles in the BIM implementation process can also be classified into two main categories:

1. **Developing Employer Information Requirement (EIR)**

According to PAS 1192-2 (2013), any project where BIM has been implemented must start with an EIR, which is developed by the clients and sent to the supply chain. Therefore, it is fundamental to client organisations to develop an EIR as a first and essential step in the BIM implementation process. According to the UK Government standard EIR, clients must be able to develop their requirements according to three main areas, which are; technical, management, and commercial (Ashworth et al., 2016a; Dwairi et al., 2016). Developing a BIM EIR is not an easy task and requires considerable knowledge and experience in BIM. However, the relationship between a client's ability to build BIM requirements and the required level of BIM knowledge and experience inside a client organisation is still not clear from current research and there is a need for further investigation to explore this (Dwairi et al., 2016; M. A. Hafeez et al., 2015; Lindblad and Vass, 2015). Providing such a relationship will help clients identify what types of proficiency they need to offer, which will enable them to build their own BIM requirements (Ashworth et al., 2016).

2. Information validation

Also, PAS 1192-2 and 3 explains the client's role in validating the information being procured from the supply chain through several data drops located throughout the project lifecycle. Therefore, it is important that clients have the ability to validate the information being procured from the supply chain, and to ensure it meets their requirements. This role also demands a certain level of BIM knowledge and experience to enable clients to make sure that their supply chain is efficiently following their BIM requirements (Chong et al., 2016; Ciribini et al., 2015; Getuli et al., 2016). The same situation can be found in the relationship between a client's ability to validate the BIM model outcomes and the required level of BIM knowledge and experience inside a client's organisation, which is still not described clearly and explicitly in the literature. If such a relationship is clear, it will facilitate clients to identify what type of proficiencies they need to offer to enable them to achieve the required BIM model outcomes (Chong et al., 2016; Ciribini et al., 2015; Getuli et al., 2016).

The capabilities of clients to fulfil these roles highlights the extent of their readiness to lead a BIM implementation process within the construction industry; this readiness is considered essential in optimising the desired benefits of BIM, as shown in Figure 2.10. Therefore, such BIM leadership represents the optimum BIM knowledge and experience that enables a client's organisation to lead the BIM implementation through its project supply chain. Despite several studies which focus on the importance of client leadership, there is a lack of research into BIM leadership characteristics in terms of the particular competencies and proficiencies that clients need in order to lead a BIM implementation process throughout a supply chain (Loosemore and Richard, 2015; Senaratne and Samaraweera, 2015; Wing et al., 2015).

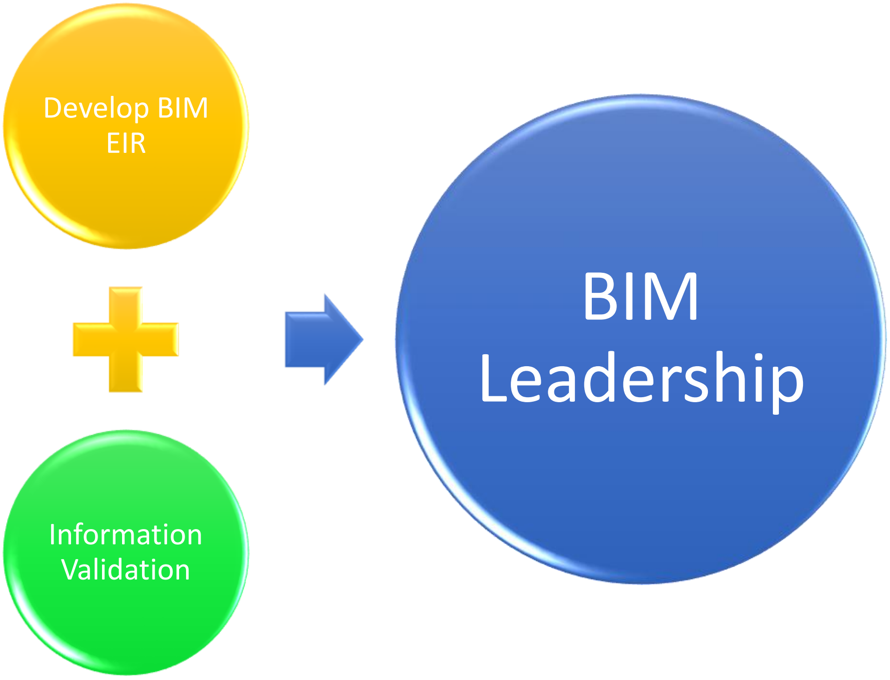


Figure 2.10: Clients' roles in BIM implementation process

2.6.4 BIM uses requirement

Using BIM in different areas across the project lifecycle needs a set of requirements to ensure that it runs effectively, and thus achieves the desired benefits from its use (Penn State, 2012). Failure to meet these requirements, or only enabling a part reflects directly on the benefits of the uses (Becerik-Gerber et al., 2011). The BIM uses requirements are not constant but rely entirely on the user; for example, BIM used by the designer will differ in its aims and purposes from the contractors and client (Mayo et al., 2012; Penn State, 2012). Furthermore, when using BIM in the area of cost estimating, the client needs to provide a set of requirements that include; the ability for staff to manipulate the model, having a quality assurance system, defining the best level of detail, defining the roles and responsibilities, and selecting the compatible software and hardware (Sabol, 2008b, 2008d). The different types of requirements that clients need to meet to be able to use BIM in different areas across the project life cycle are identified through the literature, as follows (Appendix B):

1. Staff are able to manipulate navigate, and review a 3D model.
2. Familiarity with Building Information Model authoring tools.

3. Ability to determine what is the optimum level of detail that may able to add 'value' to the project.
4. Technology (software and hardware).
5. Quality assurance system to check design deliverables.
6. Roles and responsibilities.
7. Collaboration.
8. Ability to define specific design modelling deliverables.
9. Project planning team must be familiar with construction project scheduling and the general construction process.
10. Staff have sufficient experience in design and construction means and methods.
11. Standards.
12. Staff have at least basic knowledge about the BIM model applications for facility updates.
13. Ability to extract digital information for fabrication from 3D models.
14. Staff are able to interpret if the model data is appropriate for the layout and equipment control.
15. Staff have at least basic knowledge about building operations and ambience in order to check the input information.
16. Staff are able to manipulate an asset management system.
17. Staff are able to integrate the record model with facility management applications in order to update the final record model.

Table 2.4 presents the requirements that clients need to develop for each BIM use. Identifying these requirements will help clients to understand what they have to provide to use BIM effectively in different areas. However, the requirements are generic and the link between providing these requirements and the client's roles in the BIM implementation process is absent. For instance, one of the common requirements is that, '*client staff are able to manipulate navigate, and review a 3D model.* 'However, it is unclear as to how meeting this requirement can help clients to fulfil their role in building their EIR, or their validation process which may help to lead their BIM implementation process. In addition, in terms of excellence, it is unclear as to what level clients must have to provide this requirement to achieve the desired benefits. Furthermore, providing these requirements and their implications for BIM benefits are still generic and without any valuable relationship. All of these gaps increase the complexity regarding BIM implementation and potentially the clients' fear around it.

Table 2.4: BIM uses and client

No	**BIM Uses**	**Requirements**																
		01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	Existing condition modelling	√	√	√	√													
2	Cost Estimate			√		√	√	√	√									
3	Phase Planning	√			√					√								
4	Design Authority	√	√		√	√		√			√							
5	Design review	√			√		√				√	√						
6	Engineering analysis	√									√	√						
7	Energy analysis	√		√	√	√	√	√			√	√						
8	Lighting analysis	√		√								√						
9	Sustainability Evaluation	√			√						√	√						
10	Code Validation				√	√	√	√				√						
11	3D Coordination	√	√	√	√			√					√					
12	Construction System Design	√			√						√		√					
13	Site analysis	√			√													
14	Digital Fabrication	√		√	√							√		√				
15	3D Control and Planning	√			√						√							
16	Record Modelling	√	√	√	√	√	√	√			√	√	√				√	√
17	Asset Maintenance Scheduling	√		√	√							√	√	√	√	√	√	√
18	Asset Systems Analysis	√		√		√					√					√	√	√
19	Asset Management	√			√	√								√	√	√	√	√
20	Space Management and Tracking	√			√	√									√	√	√	√
21	Disaster management	√			√	√										√	√	√

2.7 Summary

This chapter has presented a review of the literature on the current construction industry challenges in the UK. It has highlighted the vital role for clients in leading innovation implementation in the UK construction industry. The review focused on BIM uses in the execution of construction business and gaining a competitive advantage from a client perspective. The insight gathered all BIM uses benefits and the requirements that clients need to provide to implement BIM. However, the link between the identified requirements and client roles in establishing the EIR, the validation of incoming BIM information, and the lead in the BIM implementation process is still unclear and needs further investigation. There are an existing number of evaluation models that can help clients assess themselves against several criteria regarding BIM implementation process; this represents their ability to provide BIM implementation requirements to be able to use BIM effectively throughout project life cycle. The next chapter will investigate these models in relation to their ability to address the client roles and their suitability to evaluate a client's organisation in the UK.

Chapter 3: BIM Client Maturity

3.1 Introduction

The main aim of this chapter is to investigate the available BIM assessment models described in the literature to examine their suitability in evaluating a client's organisation in the UK. These models use the term competency to express the proficiency required to implement BIM, and the term maturity to evaluate these competencies in terms of excellence. Therefore, it is important to clarify the meanings of these terms before investigating any competency and maturity related models. The outcomes from this chapter are vitally important in developing an assessment model that is able to assess clients in terms of their BIM implementation in the UK. In addition, it will clarify the relationship between client roles and the achievement of BIM benefits.

3.2 Organisational competencies

The term competency has no broadly known, particular definition (Jubb and Robotham, 1997; Strebler, 1997). Indeed, researchers and practitioners have developed a number of meanings that function as a focus for their efforts and thus adapt an approach to competency to their particular work. This has resulted in the formation of a multi-faceted conception, called competencies. It will be maintained that the underlying principle for the use of competencies will determine the definition given to the term (Fejfarová and Urbancová, 2015; Khoshgoftar and Osman, 2009). Separate meanings and new labels for the term have recently advanced through common usage. Within specialist groups in the UK, for example, Strebler (1997) suggested that two different meanings of the term competency have been established. Competencies may be '*expressed as behaviours that an individual needs to demonstrate*'', or they may be `'*expressed as minimum standards of ...performance*'' (Strebler, 1997). Table 3.1 summarises a review of the literature showing the main positions taken on a definition of the term competency. It can be seen from the table that competency can be defined as the applied skills and knowledge that enables people to successfully perform their work while learning objectives are specific to a course of instruction.

Table 3.1: Competency definitions from different sources

Author	Definition
Marrelli (1998)	Competencies are measurable human capabilities that are required for effective work performance demands.
D. D. Dubois (1998)	Competencies are those characteristics- knowledge, skills, mindsets, thought patterns, and the like that, when used either singularly or in various combinations, result in successful performance.
Boyatzis (1982)	Boyatzis described competencies as the underlying characteristics of an individual, which are casually (change in one variable cause change in another) related to effective job performance
Selby et al. (2000)	Selby described competency as an ability expressed in terms of behaviour
(National SurveyN. S. Report, 1994)	The National Vocational Council for Vocational Qualifications described competency as performance standards, the ability to perform work roles or jobs to the standard required in employment
(Perrenored, 2002)	A capacity to mobilise diverse cognitive resources to meet a certain type of situation
(Le Boterf, 1998)	LeBoterf says that competencies are not themselves resources in the sense of knowing how to act, knowing how to do, or attitudes, but they mobilise, integrate and orchestrate such resources. This mobilisation is only pertinent in one situation, and each situation is unique, although it could be approached as an analogy to other situations that are already known
(Schuler and Jackson, 2003)	Competencies are defined as '*the skills, knowledge, abilities and other characteristics that someone needs to perform a job effectively*'
(Intagliata et al., 2000)	Most fundamentally, competencies provide organisations with a way to define in behavioural terms what their leaders need to do to produce the results the organisation desires and do so in a way that is consistent with and builds its culture. They should provide the 'North Star' by which leaders at all levels navigate in order to create synergy and produce more significant and consistent results.

The concept of organisational competencies is one of the most misunderstood and misapplied concepts in organisational management (Ahmed et al., 2003; Chaston et al., 2001; Munck and Borim-de-Souza, 2012; Murray and Donegan, 2003). Organisational competencies are often thought to be simply employee skills rather than the compelling cross-company core competencies that drive integrated business execution and management alignment (Chaston et al., 2001; Munck and Borim-de-Souza, 2012; Murray and Donegan, 2003). A broader definition of organisational competencies focuses on the first word, namely 'organisational'. Under this definition, it is the organisation as a whole that must perform and not just an individual employee. In accordance with this approach the organisation must step outside itself and evaluate what things it does on an ongoing, systemic basis that enables it to achieve its mission vision (Balint and Kourouklis, 1998; Chaston et al., 2001; Gabbott et al., 2002; Munck and Borim-de-Souza, 2012; Murray and Donegan, 2003). Therefore, in identifying organisational competencies, the process cannot be confused with the qualities of individuals or, what human resource management literature refers to as, 'competencies' (Draganidis et al., 2006). These relate more to the skills, knowledge, experience and behaviour of individuals. Instead, organisational competencies in a strategy context, refers to the aggregated capabilities of the organisation (namely, what the organisation is able to do through the combined and integrated efforts of many) providing it with sustainable value and broad applicability across the business (Sanchez and Levine, 2009).

Identifying, developing, and monitoring any type of competency, including organisational competencies, is called the competencies lifecycle (Hijazeh, 2011; Lawler, 1994; Mansfield, 1996). The competency lifecycle is the combination of four macro-phases, which aim at the continuous improvement and development of individual and organisational competencies. The four macro-phases are shown in Figure 3.1, which includes mapping, diagnosis, development, and monitoring (Fejfarová and Urbancová, 2015; Khoshgoftar and Osman, 2009). Competency *mapping* aims to deliver the organisation with an overview of all the essential competencies with the aim of fulfilling its targets; these are explained by the organisational business plan, the project requirements, the group needs, and the job role requirements. The necessary proficiency level for each job profile is also defined in this phase. The second phase is competency *diagnosis*, meaning an example of the current situation regarding the competencies and equivalent proficiency level that each employee holds. A skills gap analysis is also essential in this phase, in order to outline the gap between the number and level of competencies that the employees possess, in comparison with the number and level of competencies required by the organisation according to job roles. Competency *development* is the third phase and it deals with the scheduling of activities so as to raise the number and proficiency level of the competencies that an employee should have, according to the previous two phases and the skills gap analysis. The last phase is the *monitoring* of competencies, namely, a continuous examination of the results achieved by the competency development phase.

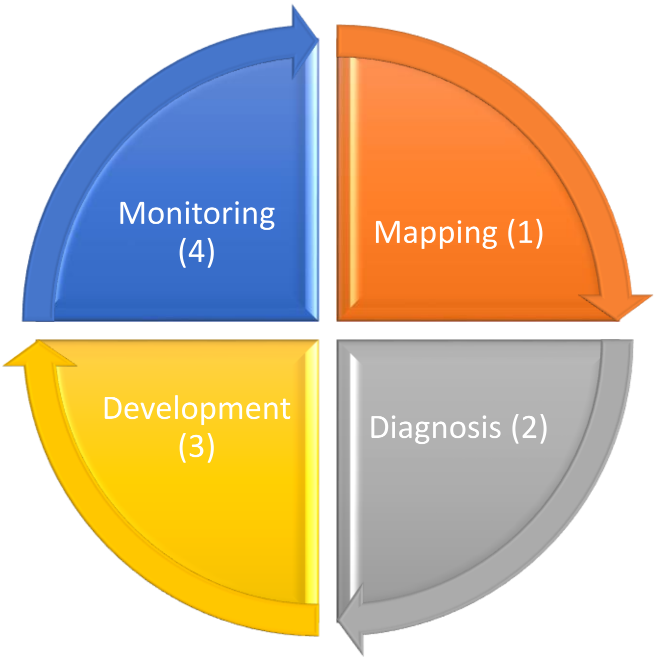


Figure 3.1: Competencies lifecycle phases (Fejfarová and Urbancová, 2015; Khoshgoftar and Osman, 2009)

While this research aims to identify the relationship between BIM maturity competencies and BIM uses benefits, only the mapping step will be adopted to identify the core organisational competencies which are vital at this stage of the research. The other steps which represents the practical competency implementation will be used later to explore how the identified BIM competencies will be adopted. BIM is classified as a system innovation, as defined by Slaughter (1998), as it uses multiple innovations to achieve new levels of industry performance. However, the growing use of BIM has highlighted the importance of collaboration and culture change within the industry and across its stakeholders. Whilst these are significant challenges, highlighted through Government reports (Simon, 1944; Latham, 1994; Egan, 1998), it is considered likely they would have been addressed in due course, and that BIM has merely been the precipitator of the solution. As such, there has been growing opinion across BIM literature that there has been scant regard for the importance of stakeholder competency in implementing BIM and how further exploration of this area may produce some valuable insights (Y Arayici et al., 2011; Lindblad and Vass, 2015; Tse et al., 2005). Moreover, Linderoth (2010) confirms that the adoption and use of BIM could be shaped by the interplay between the technology and the social context in which it is adopted and used. Such studies indicate that a significant reason for the poor adoption and implementation of BIM is the failure to recognise the user competencies required to manage BIM (Succar, 2015).

Before identifying the core organisational competencies for BIM implementation inside the organisation, it is necessary to understand the term maturity, which represents the proficiency level of competency. This is significant because the identification of BIM competencies depends mainly on existing BIM maturity models which have been validated and used instead of wasting time and effort in re-inventing the BIM competencies. The next section will add explore the term maturity and its importance in measuring the quality, repeatability and degree of excellence of BIM competency.

3.3 Maturity definition

In recent years, there has been increasing interest in maturity models in management related disciplines; this reflects a growing recognition that becoming more mature and having a model to guide the route to maturity can help organisations in managing major transformational change (Almarabeh and AbuAli, 2010; Benson et al., 1993; Khoshgoftar and Osman, 2009; Paulk, 1995). The definition of maturity is the state of being fully developed, or of the development having reached its optimum. Many researchers have attempted to define maturity in different ways, and some of the definitions are as follows:

- Paulk et al. (1993) define maturity as, '*the extent to which a specific process is explicitly defined, managed, measured, controlled, and effective. Maturity implies a potential for growth in capability and indicates both the richness of an organisation's process and the consistency with which it is applied in projects throughout the organisation*.'
- Organisational maturity is, '*the extent to which an organisation has explicitly and consistently deployed processes that are documented, managed, measured, controlled, and continually improved*' (Cooke-Davies and FAPM, 2004a).

- Appleby et al. (2007) state that maturity is, '*a comparative level of advancement an organisation has achieved with regard to any given process or set of activities. Organisations with more fully defined and actively used policies, standards, and practices are considered more mature*.'
- '*The degree to which an organisation practices project management measured by the ability of an organisation to successfully initiate, plan, execute, monitor and control individual projects*.' (Project Management Institute (PMI), 2003).

From the above, the common aspect in most of the definitions is the idea of consistent and repeated practice, measurement, and improvement or advancement. According to (Paulk et al., 1993), as an organisation matures, the predictability, effectiveness, and control of an organisation's processes are expected to develop. Furthermore, according to Chrissis et al. (2003), a matured process is well understood throughout a mature organisation; this is commonly achieved through documentation and training, and the process is constantly monitored and improved by its users. The term 'process maturity' suggests that the productivity and quality resulting from an organisation's use of a process can be improved over time through consistent achievements in the discipline, and accomplished by using the process (Almarabeh and AbuAli, 2010; Benson et al., 1993; Khoshgoftar and Osman, 2009; Paulk, 1995). A mature organisation has an organisation-wide ability for managing initiatives based on standardised and defined management processes. In such organisations, activities are carried out according to defined processes and plans, and roles and responsibilities are well defined and understood (Almarabeh and AbuAli, 2010; Benson et al., 1993; Khoshgoftar and Osman, 2009; Paulk, 1995).

As maturity improves, the unpredictability of real results around targeted results decreases. For instance, in an immature organisation, delivery dates for projects of similar sizes are unpredictable and vary widely (Seow et al., 2006; Vaidyanathan and Howell, 2007). However, similar projects in a matured organisation can expect to be delivered within a much smaller range. This narrowed variation happens at the highest maturity levels because virtually all projects are performing within organised parameters approaching the organisation's process capability (Paulk et al., 1993).

Although achieving a maturity target would not essentially guarantee that a project would be successful (Seow et al., 2006; Vaidyanathan and Howell, 2007), it could increase a project's chances of being successful. It should be noted that the processes of reaching maturity are not one-time experiences that are accomplished by declaring a methodology and structure, nor is it a quick fix for immediate tactical problems. Instead, it is a consciously planned and properly managed continuous improvement effort that can be measured and monitored via maturity models (Kaya and Iyigun, 2001; Saiedian and Kuzara, 1995; Supić, 2005).

Maturity models are process models (measurement tools) that are established to assess the maturity of an organisation's (which can also be a business unit, department, or individual) processes and practices to identify opportunities for improvement and figure out the strengths and weaknesses. Maturity models are also used as frameworks to guide improvement efforts (Cleland and Ireland, 1994; Jugdev and Thomas, 2002). Furthermore, maturity models differ from one another in the concepts they embody and the suggestions they make as to what the path to maturity looks like.

The majority of maturity models have adapted the Capability Maturity Model (CMM) five levels or stages of maturity, beginning with the lower level or initial (Level 1), to the highest level or continuous improvement (Level-5) (Azzouz et al., 2015; McCuen et al., 2011; Morlhon et al., 2015; Sebastian and van Berlo, 2010). According to (Chrissis et al., 2003), the commonly used concept of five stages, or maturity levels, goes back to Crosby's 1979 study entitled '*Quality Is Free*' (Ahern et al., 2004), which described a five-level scale with 'world-class' as level 5. Figure 3.2 shows a typical five level maturity model, where level 1 represents initial, and level five represents full development. Each level has been defined in Table 3.2 in which it can be seen that each level describes the characteristics of a certain process and the reflection on the organisation's goals and objectives.

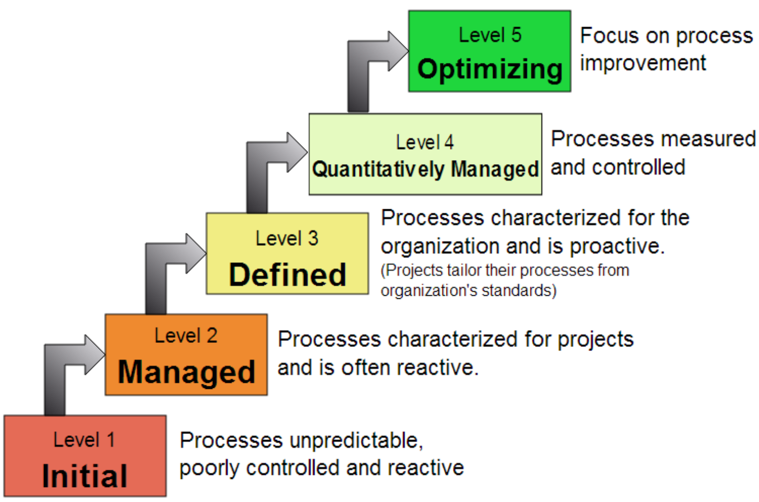


Figure 3.2: Typical five level maturity model (Chrissis et al., 2003)

Table 3.2: Maturity level explanation (Succar, 2010a)

Maturity Level	**Explanation**
(1) Initial	At this maturity level, a process produces results in which the specific goals are satisfied, however, they are usually ad hoc and chaotic. There is no stable environment to support processes with the inability to repeat such and possible abandonment in time of crisis.
(2) Managed	At this maturity level, a process is planned and executed in accordance with policy; employs skilled people having adequate resources to produce controlled outputs; involves relevant stakeholders; is monitored, controlled, and reviewed; and is evaluated for adherence to its process description.
(3) Defined	At this Maturity level, a process is tailored to the organisation's standard processes according to the organisation's guidelines; has a maintained process description; and contributes process related experiences to the organisational process assets
(4) Quantitatively Managed	This maturity level, a process is managed using statistical and other quantitative techniques to build an understanding of the performance or predicted performance of processes in comparison to the project's or work group's quality and process performance objectives, and identifying the corrective action that may need to be taken.
(5) Optimising	At this maturity level, a process is continually improved through incremental and innovative processes and technological improvements based on a quantitative understanding of its business objectives and performance needs and tied to the overall organisational performance.

Therefore, to implement BIM in a construction project successfully, all project participants, as BIM users, must have minimum BIM capabilities to show their (cap)ability to use BIM efficiently (Brittany Giel and Issa, 2013c). BIM maturity assessment models have been development and used for self-assessment and to assess project stakeholders against the BIM capabilities levels in terms of excellence (Brittany Giel and Issa, 2013c). The next section will outline existing BIM maturity models in order to identify the core organisational BIM competencies by investigating their ability to assess UK construction clients.

3.4 BIM maturity

As previously explained, BIM implementation requires substantial change in terms of people, process, technology, and strategic planning. Adopting maturity models can produce valuable benefits to BIM users, including client organisations, by managing these required changes, which can be simplified into levels that can be followed to achieve the desired BIM benefits (Brittany Giel and Issa, 2013b; Nepal et al., 2014; Succar, 2010a). The range of levels that this form of BIM modelling can take in terms of excellence is described as maturity (Cooke-Davies and FAPM, 2004b; Khoshgoftar and Osman, 2009; WIKI, 2014). Therefore, BIM maturity represents the quality, repeatability and degrees of excellence in delivering a BIM model (Succar, 2010a).

There continous be a growing number of BIM maturity evaluation models (Chen et al., 2012; B Giel and Issa, 2012; Mom and Hsieh, 2012; Succar, 2010a) where the benchmarks are performance improvement milestones (or levels) that teams and organisations aspire to or work towards. In general, the progression from low to higher levels of maturity indicate; (i) better control through minimising variations between performance targets and actual results, (ii) better predictability and forecasting by lowering variability, incompetency, performance and costs, and (iii) greater effectiveness in reaching defined goals and in setting new, more ambitious ones (Lockamy III and McCormack, 2004; McCormack et al., 2008). As each stakeholder has different performance targets and goals, maturity models must reflect these targets. Some existing BIM maturity models have been designed for certain users' organisations, such as contractors, designers, or clients, while others have been considered generic maturity models for all types of organisations (Chen et al., 2012; B Giel and Issa, 2012; Mom and Hsieh, 2012; Succar, 2010a). All of the existing evaluation models in the literature are intended to measure BIM maturity for organisations, projects, or individuals.

As has been illustrated through the literature, client organisations are a major driver in the BIM implementation process by stimulating the innovation to achieve the desired benefits of BIM (Gann and Salter, 2000; C. Harty, 2005; K. Kulatunga et al., 2011; Manley, 2006; R. Miller, 2009). Therefore, it is important for client organisations to understand the required competencies from BIM implementation and the corresponding benefits. Consequently, the next section explores the existing maturity models that have the ability to assess client organisations against a BIM implementation.

3.5 BIM client maturity models

As mentioned, Building Information Modelling Maturity (BIMM) represents a ranking system that includes all the important areas of an effective processes that are required to deliver an expected BIM product/service (Succar, 2010a). Industry practitioners and academics have developed several models to evaluate BIM implementation and performance in the construction industry (Brittany Giel and Issa, 2013b; Nepal et al., 2014; Succar, 2010a). These models could be classified into three main categories according to their target in the evaluation process (Brittany Giel and Issa, 2013b). The first category involves project assessment models (PAM), which rate the maturity of asset projects based on the use of different competencies. The second includes organisation assessment models (OAM), which measure the maturity of organisations that implement BIM in their processes. Finally, the last category is designed to assess individuals as a BIM user. These categories are shown in Figure 3.3.

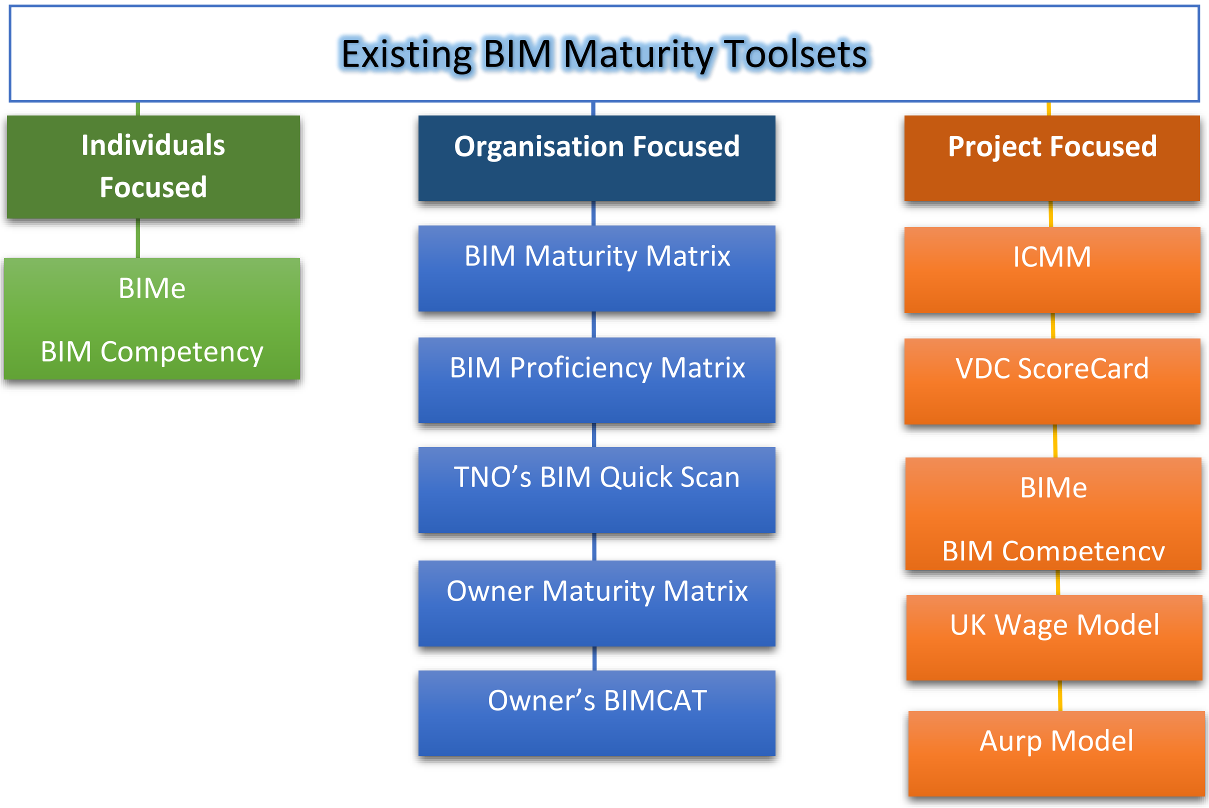


Figure 3.3: Existing BIM maturity assessment methods

As this research aims to identify the maturity method most suitable for assessing a client organisation, only OAMs will be covered in the comparison process. Table 3.3 represents the characteristics of each of the 5 OAMs that have been identified from the literature. These models include Succar's BIMMI, TNO's BIM QuickScan, IU's BIM proficiency matrix, CIC Research Programs Owner Matrix, and Owner's BIMCAT. It can be seen that each model has different kind of criteria for assessment with different level of maturity. Therefore, all these models will be further investigated in order to assess their suitability to measure client BIM maturity within the UK context.

Table 3.3: The summary of BIM maturity evaluation model

Model properties	Succar's BIMMI	TNO's BIM QuickScan	IU's BIM Proficiency Matrix	CIC Research Program's Owner Matrix	Owner's BIMCAT
The beneficiary	Designers, Contractors, and Clients	Designers, Contractors	Designers, Contractors	Clients	Clients
Number of maturity levels	5	Percentage of 100	4	6	6 (Competency levels)
Key elements and category	Technology Process Policy	Strategic Organisation Resources Partners Mentality Culture Education Information flow Open Standards Tools	Physical accuracy of the model IPD methodology Calculation mentality Location awareness Content creation Construction data As-Built modelling FM data richness	Strategy Uses Process Information Infrastructure Personal	Operational Strategic Administrative
Evaluation Method	Multi-method	Self-online evaluation	Evaluate stakeholder's competency.	Self-evaluation	Self-evaluation

These BIM maturity assessment models will be evaluated according to three key criteria, which reflect the aim and objectives of the research. These criteria are:

1. **Suitability of these models for client organisations in particular**

   The maturity model must be designed to evaluate client organisations due to the clear differences in business needs and objectives between client organisations and other stakeholders, such as design organisations or contractors, (Erik Eriksson et al., 2008; Brittany Giel and Issa, 2013a; Sebastian, 2011). The needs of client organisations exceed the project design and construction stages to also include operation and maintenance, which affect the type of competencies they should have. It is important that their competencies reflect these needs in developing the requirements and validating the BIM model outcomes (Erik Eriksson et al., 2008; Brittany Giel and Issa, 2013a; Sebastian, 2011).

2. **Availability of their evaluation methodology**

   The availability of the maturity model philosophy and methodology will help to understand the competencies selection criteria, evaluate their suitability for the client organisation, and determine the importance for each. The absence or unclear of such philosophy and methodology may lead to exclude of the maturity model from analysis.

3. **The ability to integrate UK standards**

   Some types of maturity model have been designed according to a certain national standard. Therefore, the ability to integrate UK standards in a maturity model will be considered in the evaluation process. This integration will help client organisations to understand the proposed BIM maturity model more easily because they are already familiar with the UK BIM standards.

In order to understand the existing BIM maturity models, each model will be explained in detail. After that all models will be evaluated against the aforementioned factors.

3.5.1 Succar's BIM Maturity Matrix (BMMI)

Succar developed a BIM Maturity Matrix that offers a comprehensive evaluation framework based on technology, process, and policy (Chen et al., 2012). His model is suitable for different organisation types and size and uses five maturity levels based on the 12 Key Maturity Areas (KMAs) shown in Figure 3.4. One of the main concepts proposed by Succar is the difference between BIM capability and BIM maturity across organisations, and the different capability stages that organisations work through on their BIM implementation roadmap. In addition, Succar defines BIM capability as, '*the ability to perform a task or deliver a BIM service/product*'; whereas, BIM maturity might refer to, '*the quality, repeatability, and degree of excellence with which BIM services are executed*' (Brittany Giel and Issa, 2013b). Therefore, the UK BIM maturity model is actually a BIM capability model where there is wide misunderstanding among UK construction industry regarding this issue (Succar, 2015a).

Unfortunately, some areas of information management such as quality assurance system are not covered in the competency sets, although data usage, storage, and exchanges are included (Chen et al., 2012). In addition, if this model is not used to evaluate the client organisation in particular, the evaluation system needs to be modified to protect the privacy of the client organisation from the rest of the organisations, through the benefits and requirements of the BIM implementation process.

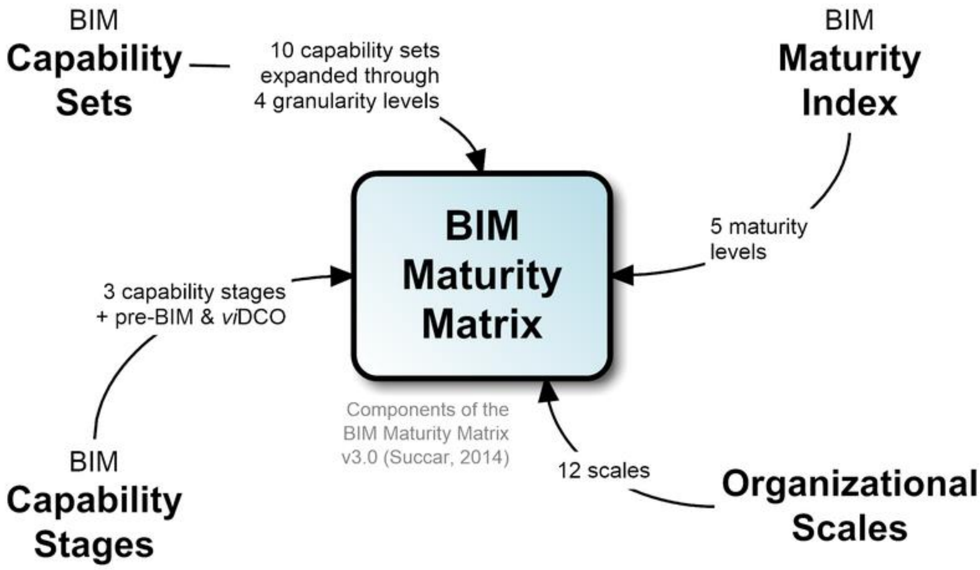


Figure 3.4: BIM maturity matrix components (Succar, 2015a)

3.5.2 CIC Research Program's Owner Matrix

The Building Information Modelling (BIM) Planning Guide for Facility Owners V2.0 was released in 2013 to support project teams by directing them through a planning process for BIM implementation. A fundamental principle of the planning procedure was to highlight the need for facility owners to understand and communicate their goals for implementing BIM throughout the lifecycle of the asset. This guide contains 6 key BIM planning elements, which are: strategy, uses, process, information, infrastructure, and personal (Figure 3.5). In addition, it provides a simple description for each of the maturity levels identified within the planning elements. The maturity levels start with zero (0), which represents the non-existence or non-use of that element within the organisation, and continues to level five (5) in which the planning element is optimised (Penn State, 2012). This model is considered one of the most effective models for evaluating a client's BIM maturity because it is designed especially for their organisations, and the evaluation methodology has been explained clearly in the BIM planning guide for facility owners V2.0.

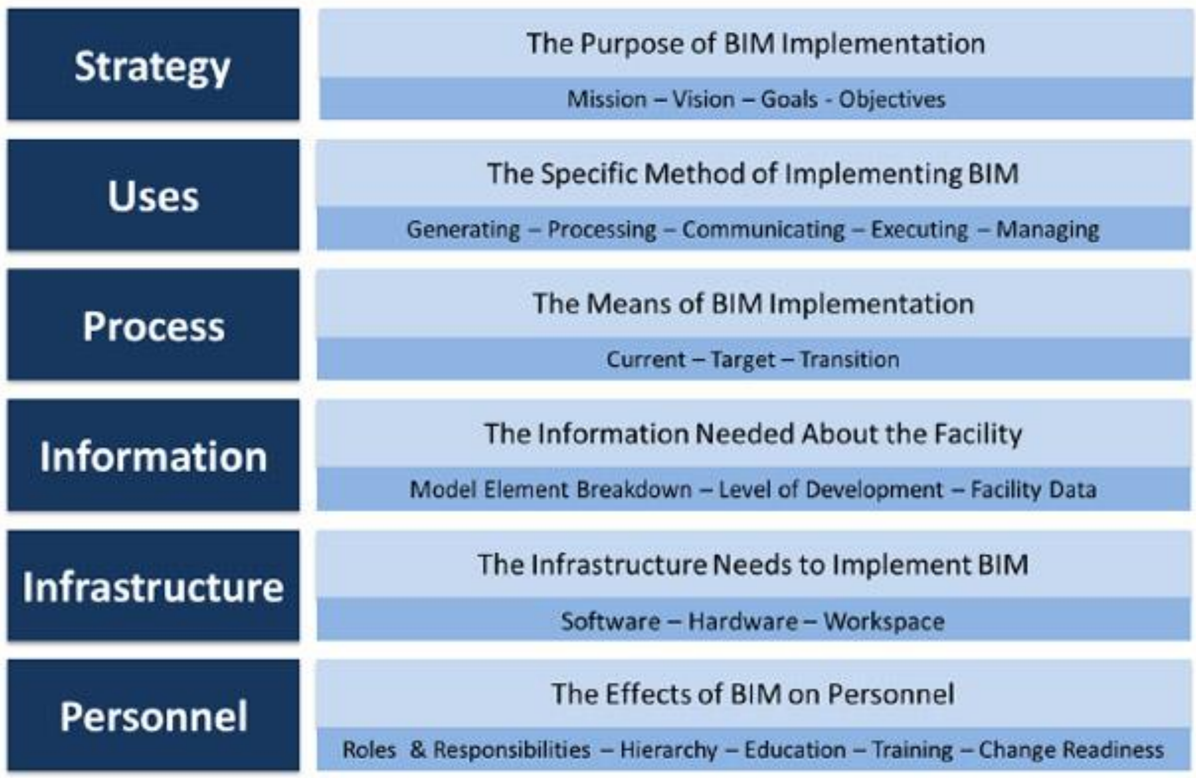


Figure 3.5: BIM Planning Guide for Facility Owners (Penn State, 2012)

3.5.3 Owner's BIMCAT

The Owner's BIMCAT has been divided into three main competence categories, namely: operational, strategic, and administrative. Each of these categories is also split into sub-branches, as shown in Figure 3.6. This model covers most of the key evaluation criteria, including the geometric requirements that are not included in the other models. The model that was developed by Giel and Isaa in 2013 has six competency levels. However, the significant number of details that need to be evaluated have affected the quality of the model, and most of this information may be incomprehensible to the immature BIM client. Therefore, the simplicity of the other models is absent here, which prevents clients assessing their organisation in more comprehensive way.

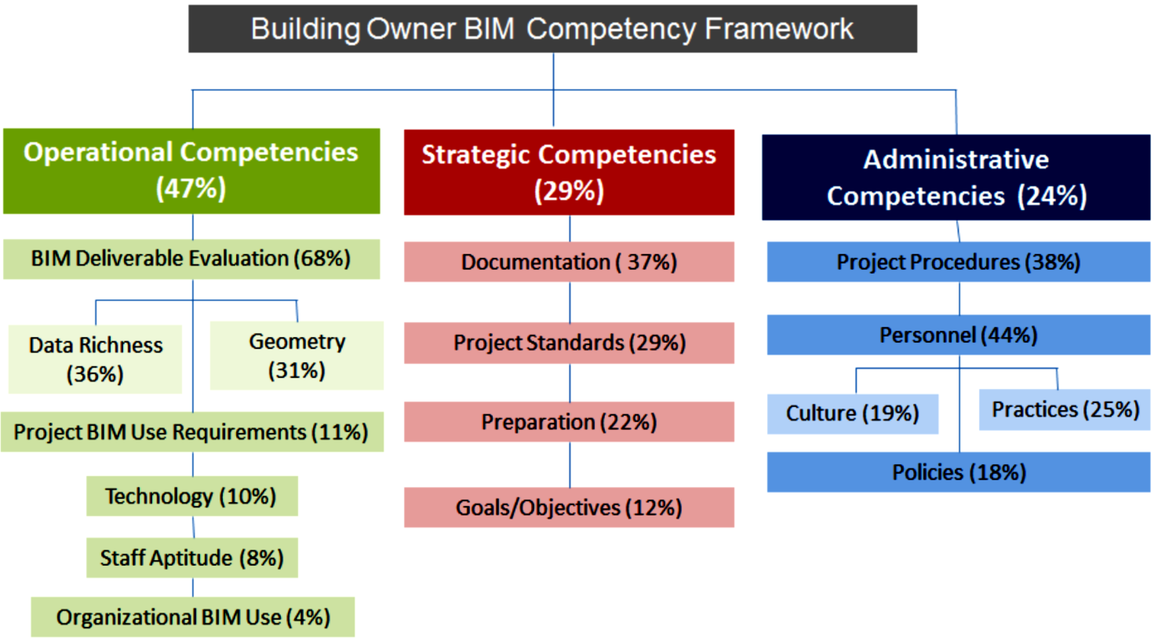


Figure 3.6: BIMCAT maturity model components (Brittany Giel and Issa, 2013b)

3.5.4 TNO's BIM QuickScan

This model was developed by the Netherlands' Organisation for Applied Scientific Research, TNO, in 2012. It has been classified into four distinct chapters of criteria, including organisation and management, mentality and culture, information structure and information flow, and tools and applications. In the evaluation process, questions are categorised into ten specific aspects including strategic, organisation, resources, partners, mentality, culture, education, information flow, open standards, and tools (Figure 3.7).

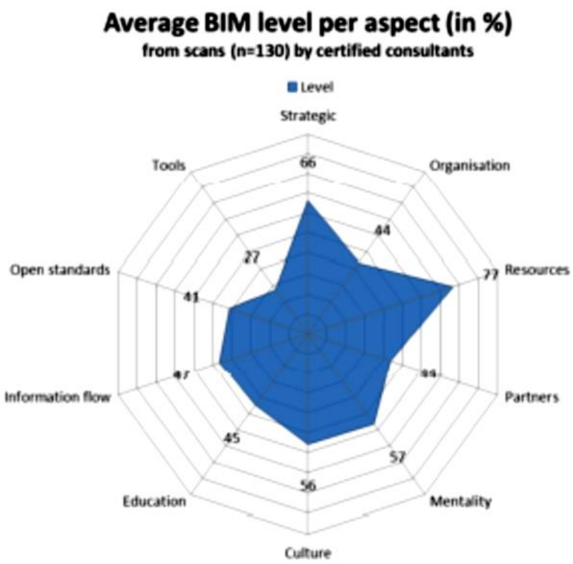


Figure 3.7: TNO's BIM Quick-scan Evaluation process categories (Van Berlo et al., 2012)

This model has been designed for the Netherlands construction industry but does not explain its methodologies and philosophy which make it difficult to understand why they select these criteria in particular for evaluation. In addition, this model is used to evaluate design and contractor companies and is not suitable for client organisations.

3.5.5 Indiana University's BIM Proficiency Matrix

This model was developed by Indiana University in 2009. It is classified into eight categories of interest against four areas of maturity. As shown in Figure 3.8, the main categories are the: physical accuracy of the model, IPD methodology, calculation mentality, location awareness, content creation, construction data, as-built modelling, and FM data richness. This model is used by client organisations to evaluate the BIM experience level of designers and contractors; therefore, it cannot be used to evaluate client organisation itself.

IU BIM Proficiency Matrix

Category Number	A - Physical Accuracy of Model	B- IPD Methodology	C - Calculation Mentality	D - Location Awareness	E - Content Creation	F - Construction Data	G - As-Built Modeling	H- FM Data Richness
1	Basic Model Geometry A.1	Creation of A BIM Execution Plan B.1	Basic Model Information Export (Discipline) C.1	Site Orientation D.1	Geometrically Correct Content E.1	Quantity Takeoffs F.1	Post Bid Model Documentation G.1	Space Management Data H.1
2	Design Requirements A.2	Introduction of Structural and MEP Model B.2	IPD Integration C.2	Existing Environment Awareness D.2	Manufacturer's Specific E.2	Object Scheduling F.2	Coordination Modeling G.2	Asset Management H.2
3	Design Side Collision Detection A.3	Model Managers Role Defined B.3	Interdisciplinary Calculations C.3	Global Accuracy D.3	Design Intent E.3	Material Procurement F.3	Recapturing Design Intent G.3	Manufacturer Specific Information H.3
4	Model Accuracy Innovation A.4	IPD Methodology Innovation B.4	Calculations Innovation C.4	Location Innovation D.4	Content Innovation E.4	Construction Innovation F.4	As-Built Innovation G.4	FM Data Innovation H.4

BIM Maturity

Category	Points Achieved	BIM Maturity Score	BIM Standard		
A - Physical Accuracy of Model	0	0	BIM Score Between 0-12	=	Working Towards BIM
B- IPD Methodology	0		BIM Score Between 13-18	=	Certified BIM
C - Calculation Mentality	0		BIM Score Between 19-24	=	Silver
D - Location Awareness	0		BIM Score Between 25-28	=	Gold
E - Content Creation	0		BIM Score Between 29-32	=	Ideal
F - Construction Data	0				
G - As-Built Modeling	0				
H- FM Data Richness	0				

Figure 3.8: Indiana University's BIM Proficiency Matrix (Kang et al., 2013)

3.6 Existing BIM maturity model evaluations

These selected models have been evaluated through two main steps. Firstly, comparison analysis has been done which will help to explore the similarities and differences among all models in term of BIM maturity competencies. This analysis will help to select the proposed BIM maturity competencies for UK construction client. Secondly, each model will be examined to figure out its weakness and strengths in term of its suitability to assess UK construction clients regarding the previous explained criteria.

1. **Comparison analysis**

All of the models have been compared to each other to identify the differences and similarities in terms of competencies (Table 3.4). From the comparison analysis of the BIM maturity models, it is concluded that:

a) Each model implements different types of competencies, which reflect the philosophy and target users. Some are designed to evaluate just client organisations while others can be used for different types of organisations such as BIM Execution Plan (BEP).

b) Even though some models use the same sort of competencies, they have different expressions. For example, roles and responsibilities have been expressed in different formats, such as human resources, BIM manager roles, and the distribution of roles and tasks.

2. **Strength and weakness analysis**

Each model has been evaluated for their suitability to evaluate the UK construction client, as explained previously. Table 3.5 shows the analysis results in terms of strengths and weaknesses. While different types of weaknesses are found in each of the models, these can be compensated for and improved from the strengths identified of the other models. For instance, a lack of competencies related to the client organisation within the Succar model can be overcome by adding the competencies from the CIC model, which is designed particularly for the client organisation. However, there are also common weaknesses across the existing models that need to be addressed to increase the efficiency of these models for the client organisation as follows:

a) The relationship between maturity competencies and client roles in developing the EIR, a validation of the information, and the lead BIM implementation process is lacking. Providing such a relationship will improve the usability of the maturity model from a client's point of view due to the connection with their actual roles and responsibilities.

b) The relationship between BIM maturity and BIM benefits is also lacking, which makes it difficult for clients to determine the level of competencies' development in term of degree of excellence that would bring them the desired benefits, especially when they have limited time and budget.

Based on the evaluation criteria and the evaluation of the five organisation BIM maturity models, the Succar, CIC have been selected to identify the required competencies that client organisations must develop to implement BIM efficiently. The selection of only two of these models (i.e. Succar and CIC) depends on three main factors, as shown below:

1. The assessment philosophy and methodology are explained in detail for each model in order to provide a full understanding of the BIM competencies and maturity levels. Other models do not support their selection criteria with any explanation or guide; this may be due to commercial benefits.
2. These two models can be used to assess a client organisation against a BIM implementation as they consider the client organisation in their assessment methodology.
3. These two models are not designed specifically for the construction industry, which makes it easier to integrate UK standards as they did not align with any particular BIM standards to develop their models, which increases their applicability for use around the world and it makes them more generic.

This research study will use these models to proposed set of BIM maturity competencies and suggests a different approach to assessment which incorporates BIM uses benefits as main element in BIM maturity evaluation.

Table 3.4: Comparison between existing BIM organisation maturity model

No	Competencies	Maturity assessment tools				
		2009 Succar: BIMMI	**2009 IU: BIM Proficiency Matrix**	**2009 TNO: BIM QuickScan**	**2012 Penn State's CIC Research Program: Owner Maturity**	**Owner's BIMCAT (Giel and Issa 2013)**
1	Organisation Mission				Organisational Mission and Goals	
2	BIM Vision	Leadership: BIM vision		Vision and Strategy	BIM Vision and Objectives	Goals and objectives
3	Standards	Regulatory: BIM Guidelines and standards documentation			Standards	Documentation BIM Guidelines and standards
4	BIM Execution Plan		Creation of a BIM Execution Plan			Standards/ BEP Template
5	Quality Assurance system			Quality assurance		Standards/ BIM QC plan
6	Software	Software		Type of software and BIM tools used	Software	Software
7	Hardware	Hardware			Hardware	Hardware
8	Network	Network Changes		Use of model server and type and capacity of the server		Network
9	Physical Space				Physical space	Physical Space

10	Organisation Hierarchy			Organisation Structure	Organisational Hierarchy	Support Staff buy-in
11	Role and responsibilities	Human Resources	Model manager's roles defined	Distribution of roles and tasks	Roles and Responsibilities	
12	Management support	Leadership			Management Support	
13	BIM champion			Presence and influence of BIM coordinator	BIM Champion	
14	BIM Skills	Human Resources' competencies				Staff Evaluation
15	Change readiness			BIM acceptance among staff and workers and group and individual motivation	Change readiness	Change readiness of staff
16	Education	Preparatory: education and research			Education	Education
17	Training	Preparatory: training		Knowledge management and training	Training	Training
18	Knowledge management and sharing	Infrastructure: How BIM knowledge is shared and retained within an organisation		Knowledge management & knowledge and skills		Knowledge management

19	Risk Management	Risk Management strategies				Risk management
20	Organisational Process				Organisational Processes Mapped	
21	Project Process				Project Processes mapped	
22	BIM Capability Stages	BIM Capability Stage				BIM Capability
23	BIM Uses			Use of modelling	Project Uses of model	BIM uses
24	Operational Use				Operational Uses of model	Lifecycle View
25	BIM committee				BIM committee	

Table 3.5: The strengths and weakness of the selected BIM maturity models

No	BIM maturity model name	Strengths	Weakness	References
1	Succar's BIMMI	• Clear evaluation methodology. • Covering most of organisation BIM competency. • Including different organisation scales.	• Not design for client organisation only. • Absent of some competencies that client organisation needs them for model validation like BIM committee, and quality assurance system. • Maturity-benefits relationship absents.	Section 3.5.1
2	Vico's BIM Score	• Easy to use. • Covering most of organisation BIM competency.	• Evaluation methodology is not clear. • Not design for client organisation only. • Not covering all BIM uses. • Maturity-benefits relationship absents.	Section 3.5.4
3	CIC Research Program's Owner Matrix	• Clear evaluation methodology. • Covering most of organisation BIM competency.	• Designed according to USA BIM resources only like GSA, US Department of Veterans Affairs, US Army Corp of Engineers, and others. • Maturity-benefits relationship absents. • Maturity- client role relationship absents	Section 3.5.2
4	Owner's BIMCAT	• Covering most of organisation BIM competency.	• Evaluation methodology is not clear. • Maturity-benefits relationship absents. • Maturity- client role relationship absents	Section 3.5.3

5	UK BIM Maturity Model	• Clear evaluation methodology.	• Designed for projects BIM maturity evaluation only. • Maturity-benefits relationship absents.	Section 2.5.2

3.7 Clients' BIM competencies selection

From the Succar and CIC, 19 competencies have been identified as essential for the client organisation to develop in order to gain the desired benefits of BIM. These competencies represent a combination of the two models with the exclusion of all project evaluation competencies (namely, capability competencies). Each competency will be discussed in details which collected via literature as follow(Chunduri et al., 2013; Brittany Giel and Issa, 2013a, 2013c; Isikdag et al., 2012; Kassem et al., 2013; Sackey et al., 2013; State, 2012; Succar, 2010a):

1. Organisation mission

A mission is a fundamental purpose for the existence of an organisation. Goals are specific aims that the organisation wishes to accomplish. Mission goals might be to have a completely coordinated design reflecting construction and operation requirements during the design phase and to use BIM to improve the coordination process, therefore, reducing the number of field clashes and conflicts to zero. In addition, mission goals might be include using BIM to create a high-quality visualisation.

2. BIM vision

A vision is a picture of what an organisation is striving to become. Objectives are specific tasks or steps that, when accomplished, move the organisation toward their goals. A vision might be focus on technology implementation to establish and validate clients' project requirements – top management delegating BIM responsibilities (technology focused vision), a clear vision to improve project performance through BIM covering PLC – top management plays a strong role in driving BIM Strategy across the organisation, and an organisational performance improvement through high collaboration among the supply chain to deliver higher quality services/products with lower cost and time.

3. BIM champion

A BIM Champion is a person and /or group who is technically skilled and motivated to guide an organisation to improve their processes by pushing adoption, managing resistance to change, and ensuring the implementation of BIM. BIM champion role must lead to utilise the following, support organisation system transfer to be able to implement BIM as a technology and process, make sure that the process of delivering information is running smoothly, and maintain a significant level of communications with the supply chain. In addition, BIM champion might be lead to deliver the required quality standards in one or more of the following performance quality areas: Design, Technical, Community, and IT in accordance with the current organisation Quality Management Procedures.

4. Data sharing method

This competency defines clients' ability to share a different type of information among their stakeholders. This includes but not limited to data exchange, data interoperability, data federation, data integration, data sharing hybrid, and data protection.

5. Management support

This competency represents to what level does management support the BIM planning process. This includes financial support, human resources support, legal support, and change management support.

6. BIM committee

The BIM Planning Committee is responsible for developing the BIM strategy of the organisation. This committee will responsible on planning the adoption and implementation of BIM, report findings and deliverables, report recommendations and action plans, and enhance decision-making process regarding BIM implementation

7. Standards

BIM Standards define all project delivery, legal issues, and risk mitigation. This includes (but not limited) modelling, presentation, quantification, specifications, data structure, and processes and analytical properties of 3D models

8. Organisation hierarchy

An arrangement of personnel and group into functional groups within the organisation. This includes team structure, cross collaboration between different teams, and joint problem solving and optimisations.

9. Training

Training is to teach so as to make fit, qualified, or proficient in a specific task or process. Training programs may contain (but not limited) BIM technology/authoring tools, standards, methods and procedures, and the commercial aspect.

10. Education

Education sessions are to formally instruct about a subject which may include BSc in BIM and other related topics, MSc in BIM and other related topics, and PhD or professionals in BIM

11. Role and responsibilities

Roles are the primary function assumed by a person within the organisation and responsibilities are the tasks or obligations that one is required to do as part of that role. This includes responsibility lies with each person and BIM roles are embedded within the organisation.

12. Change readiness

The willingness and state preparedness of an organisation to integrate BIM. This competency includes readiness assessment, existing of change agent, risk aversion, early user involvement, open communication and information sharing.

13. BIM skills

BIM skills that client should develop in order to best utilise BIM may include technically-based skills at project level- focused on technology enthusiasts, BIM management concept, BIM applications over, QA/QC, role of standards – at project level – work focused within project delivery departments only, and BIM oriented teamwork (high collaboration/integration), adopting new business processes, performance and collaborative mindset, adding business value and meeting business objectives – at organisational level.

14. Software

The programs and other operating information used by a computer to implement BIM. This includes all software are able to (but not limited) exchange and sharing data, exploring BIM models, communication and collaboration, and interoperable and integrated.

15. Hardware

Physical interconnections and devices required to store and execute (or run) BIM software which should include store enormous amount of data, back-up features, and update features.

16. Physical space

Functional areas within a facility used to properly implement BIM within the organisation, the competency can provide demonstrate different solutions and enhance the decision-making process, meeting areas with the supply chain with supporting technical facilities, and enhance staff motivation, satisfaction and productivity.

17. Network

Solutions, deliverables and security/ access control. Network solutions are continuously assessed and modified against. This competency can provide networks facilitate data, storing and sharing between all stakeholders.

18. BIM Execution Plan (BEP)

BEP is a core approved document which defines the BIM strategy and processes for the successful completion of the EIR. This document outlines the following to support collaborative processes to produce the information required by clients responsibilities, requirements and processes, best practices, methods and protocols, relevant business processes, supporting software requirements.

19. Quality assurance system

A way of preventing mistakes or errors and avoiding problems when accepting BIM model which ISO 9000 defines as 'part of quality management focused on providing confidence that quality requirements will be fulfilled'. BIM performance benchmarks are incorporated into quality management and performance improvement systems throughout the project lifecycle.

The proposed BIM maturity competencies can be classified in to four main fields strategic, people, process, and technology (Figure 3.9) (Chen et al., 2012; B Giel and Issa, 2012; Mom and Hsieh, 2012; Succar, 2010a). Competencies classification will help to add more clarification on where certain competency has its main effects. However, this classification will not affect the research aim to establish the relationship between BIM maturity competencies and BIM uses benefits due to its main purpose to add just more illumination.

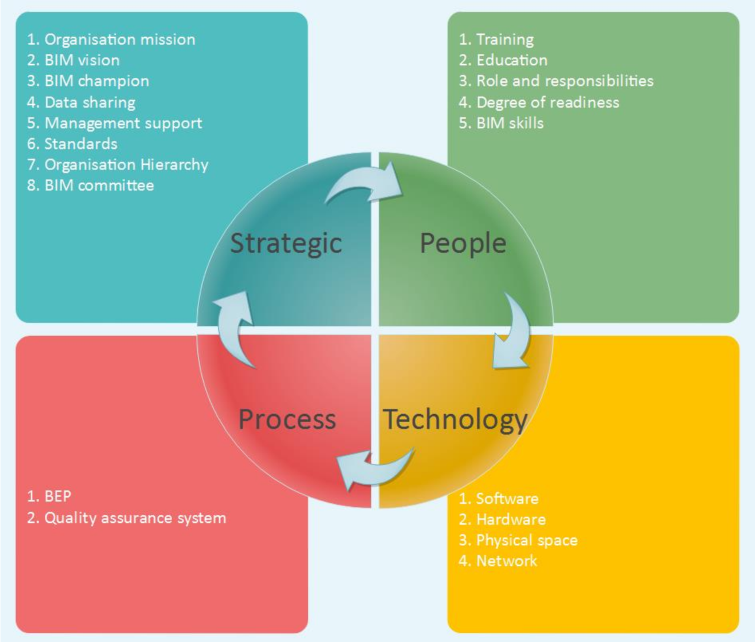


Figure 3.9: Proposed BIM maturity competencies fields

3.8 Summary

This chapter has explained the terms competency and maturity, which have been used previously in the literature to manage and assess different types of innovations in the construction industry, which can be used to assess BIM implementation across the UK construction industry. In addition, the chapter identified that several maturity assessment models have been used to assess different types of BIM users against their BIM implementation. However, it was established that only a number of them can be used to assess client organisations in particular. The Succar (2009) and CIC (2012) models have the potential to assess client organisations in the UK, and from these, 19 competencies were selected to represent client proficiency within BIM implementation based on these two models. However, the connection between these competencies and client roles and BIM uses benefits is still lacking. Therefore, the focus of this research is to address these gaps by finding the relationship between BIM maturity competencies and client roles. Also, it will provide a maturity-benefit relationship assessment framework that will help the client to identify the optimum maturity level to enable them to achieve the desired benefits. The following chapter will introduce and discuss the research methodology used in this research and how it has been designed to achieve the research aims.

Chapter 4: Research Methodology

4.1 Introduction

This chapter presents the research methodology and the research paradigm regarding what establishes knowledge and how it is established. The chapter also discusses the range of research methods, the data collection techniques adopted to gather the required primary data appropriate for analysis, and the achievement of the requirements set by the research questions. In addition, this chapter aims to establish a suitable connection between the adopted paradigms and methods.

The methodology in this study has been implemented in order to achieve the research aim. To explain the methodology, the chapter is divided into two main connected sections, namely the research methodology theory and the research design specific to this study. The theory section provides a review of the various philosophical concepts that should be clearly understood in order to confidently and appropriately design the research approach. The second part focuses on the research design and identifies the particular theoritical concepts that inform the design of the study, and achieve the aim and objectives of this research. Therefore, this chapter will cover; the philosophical research paradigm, various research approaches, the research choice and strategy, the time horizon, research techniques, and research ethics.

4.2 Research methodology

The Oxford dictionary (n.d.) defines the term 'research' as, '*The systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions.*' The logic and approach to the principles and procedures of scientific research is the 'research methodology' (Fellows and Liu, 2009). According to Fellows and Liu (2009), a research methodology refers to the principles and procedures of a logical thought process that is applied to a scientific investigation. Kumar and Phrommathed (2005) similarly suggest that the research methodology comprises the philosophy and science that support the investigation. In addition, according to Fellows and Liu (2009), research consists of a careful search and a systematic investigation that contributes to the sum of knowledge. The research methodology, therefore, can be considered as the overall strategy used in the scientific investigation which consists of the philosophy, approach, and techniques (Haron, 2013).

There are two main approaches to research methodology. The first was developed by Kagioglou (1998) and is a nested approach to research where the selection of techniques/tools adopted is reached by a process of narrowing down from the philosophical stance adopted to selecting an appropriate paradigm,(Figure 4.1). A nested approach has just three layers, which can make it easier to follow. Alternatively, the second approach was developed by Saunders at el. (2011) and represents a research methodology in different layers, like that of an 'onion'. As shown in Figure 4.2, the main layers, from outer to inner, include; research philosophy, research approach, research strategies, time horizon, and data collection methods.

To better understand the components of a research methodology, this study adopted the latest version of the 'Research Onion' (Saunders (2011), as it could provide assistance in understanding all research components and in selecting an appropriate tool to achieve the research aim. As can be seen in Figure 4.2, the outer ring represents the unifying research philosophy, which guides and energises the research approaches and methodological choices, while the research strategy, time horizon, and research techniques form the corresponding layers. The structure of this chapter will follow the sequence of each layer and discuss how these support the research objectives and aims.

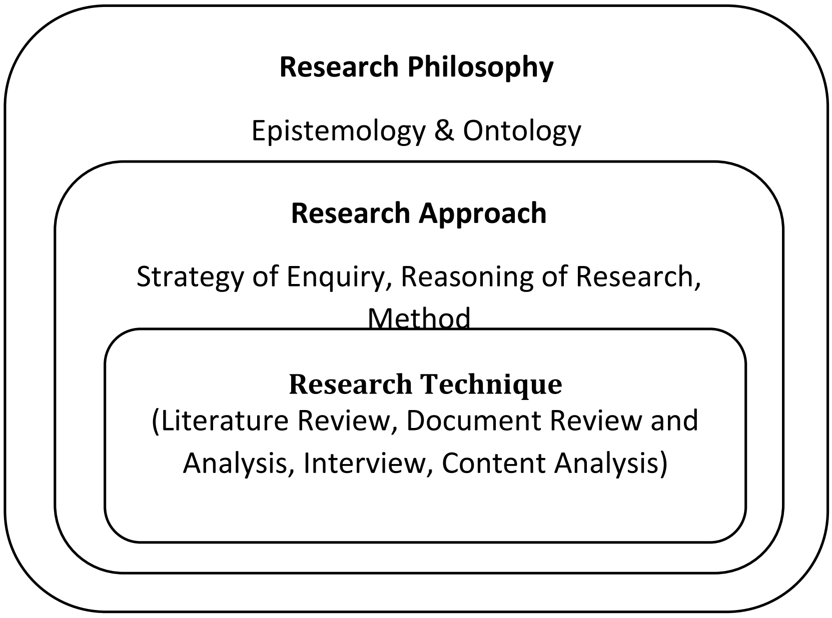


Figure 4.1: Nested research methodology approach (Kagioglou, 1998)

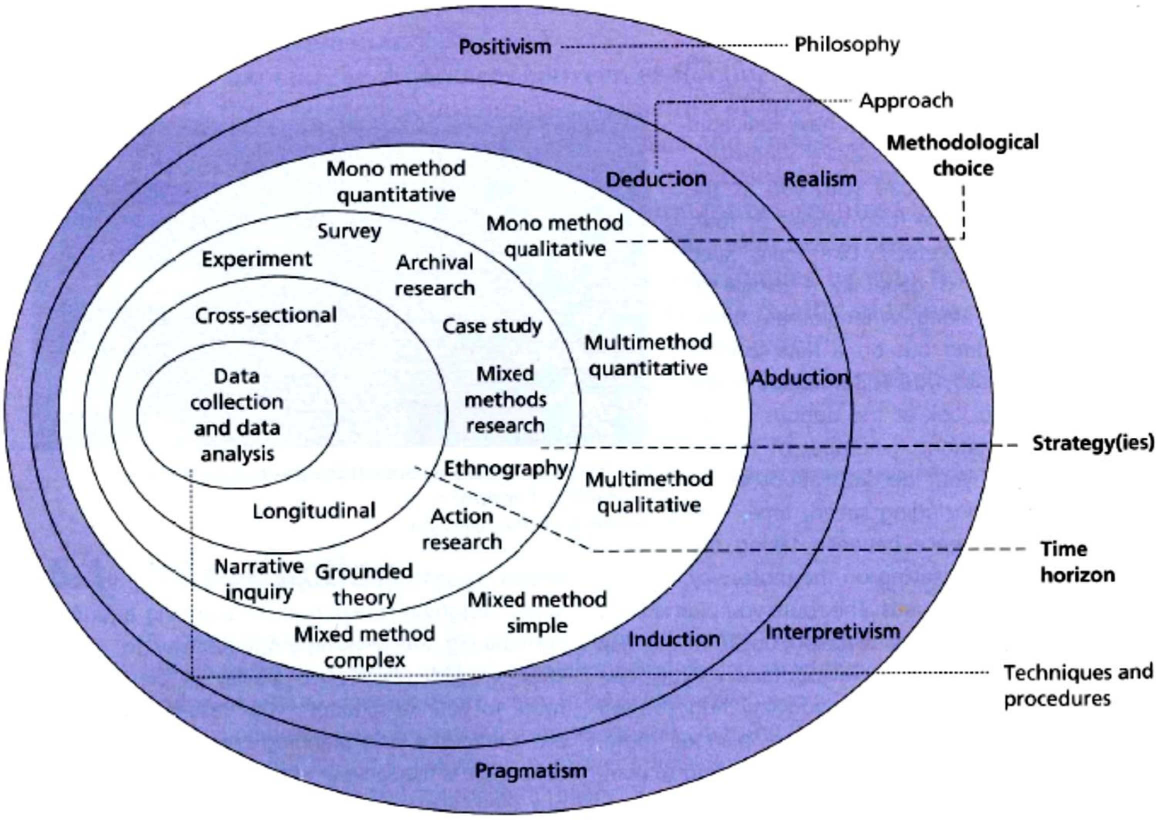


Figure 4.2: Onion research methodology approach (Saunders, 2011)

4.3 Research Philosophy

When conducting research, an underlying theoretical perspective should be implemented by the researcher (Gray and Malins, 2004). This underlying theoretical perspective is referred to as the 'philosophical paradigm' (Collins, 2010; Fellows and Liu, 2015; Saunders, 2011; Trochim and Donnelly, 2001). As reported by Saunders et al. (2011), the research philosophy explains the essential assumptions regarding the style in which a researcher sees the world. The required assumptions will support the choice of research strategy and methods used in achieving the objectives. The key impact is the specific views of the relationship between knowledge and the process employed in creating it. Philosophical positions can be considered under three main categories that guide the design of any research, namely: epistemology, ontology and axiology (Saunders et al., 2011). Furthermore, Sexton (2003) argues that contrasting viewpoints on research philosophies are characterised by the contrasting views taken on the ontological, epistemological and axiological assumptions, which are illustrated in Figure 4.3.

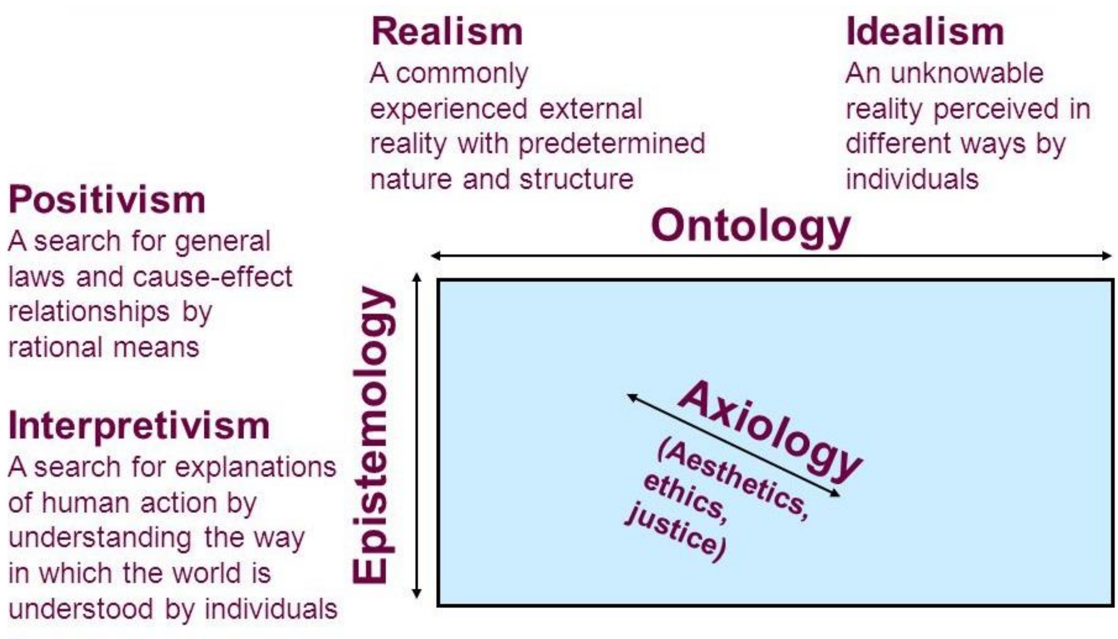


Figure 4.3: The dimension of the research philosophy (Sexton, 2003)

The selection of the research philosophy also precepts the assumptions on how the world at large is observed by the researcher (Collins, 2010). These assumptions will underpin the research strategy (Creswell et al., 2007); for example, a positivist approach is frequently quantitative and is often employed for classic scientific research. This approach understands that an objective reality exists external to the persons involved and that new knowledge becomes supplementary to existing knowledge in a consecutive and augmented manner through the eradication of wrong hypotheses (Näslund, 2002). A phenomenological approach is commonly characterised by a qualitative style of a research and is regularly used for administering social research, which often is built on observations (Wahyuni, 2012).

Fumerton (2008) defines ontology, epistemology, and axiology as three divisions of philosophy. In the context of social research, Bryman (2015) defines ‘ontology’ as the reflection of reality with respects to social units and ‘epistemology’ as the reflection of the adequacy of knowledge. Meanwhile axiology is defined as a branch of philosophy that studies judgment about the value (Saunders, 2011).

4.3.1 Ontology

Ontology is a philosophical attitude influenced by what is known or what comprises social reality. Creswell and Clark (2007) state that ontological assumptions hold a diverse range of viewpoints of social realities but they have to be placed within political, cultural, historical and economic value systems to establish the differences. An ontology contains two main characteristics, namely, ‘objectivism’ and ‘subjectivism’ which can be described as poles of a continuum. Objectivism signifies the position where social objects exist on the exterior to social actors concerned with their existence (Crotty, 1998). Subjectivism adopts social phenomena from the views and resulting actions of social actors concerned with their existence (Saunders et al., 2011). Essentially, ontology clarifies what knowledge is and the relative assumptions about reality (Creswell, 2013). Most researchers adopt stances that fall somewhere between these two extremes, embracing a varied degree of commitment to objectivism and subjectivism which mainly depends on specific research aims (Uhl-Bien and Ospina, 2012).

4.3.2 Epistemology

Epistemology is influenced by what creates satisfactory knowledge in a specific field of study (Saunders et al., 2011). There are three perspectives to epistemology, which include 'positivism' and 'interpretivism' as well as 'realism'. Positivism proposes the practice of quantitative experimental methods to test hypothetical-deductive generalisations, while interpretivism proposes the practice of qualitative and naturalistic approaches to inductively and holistically understand and explain a certain phenomenon. According to Creswell and Clark (2007), interpretivism aims to increase the overall understanding of the subject in which the research developments, through the collection of rich data, are induced. Realism is another philosophical position related to scientific enquiry. The essence of realism is that what humans sense is reality and that objects have an existence independent of the human mind (Crotty, 1998; Saunders, 2011).

4.3.3 Axiology

Heron and Reason (1997) suggest that our values are the control and reason behind all human actions. They further argue that the researcher demonstrates an axiological attitude by expressing their values as an origin for constructing judgements regarding what research they are conducting and how they decide to do it. In addition, Sexton (2003) also emphasises that this assumption is about the nature of values and the foundation of value judgments. The spectrum extends from 'value-free', where the researcher does not impose any value judgments on the subject of the research, to 'value-laden', where value judgments are involved. At all stages of the research process, the researcher will be demonstrating their values.

Mingers (2001) argues that a research study is not usually a single, discrete event but a process that typically proceeds through a number of phases and that these phases pose different tasks and problems for the researcher. Using this argument, the different phases of the research are illustrated in Figure 4.4.

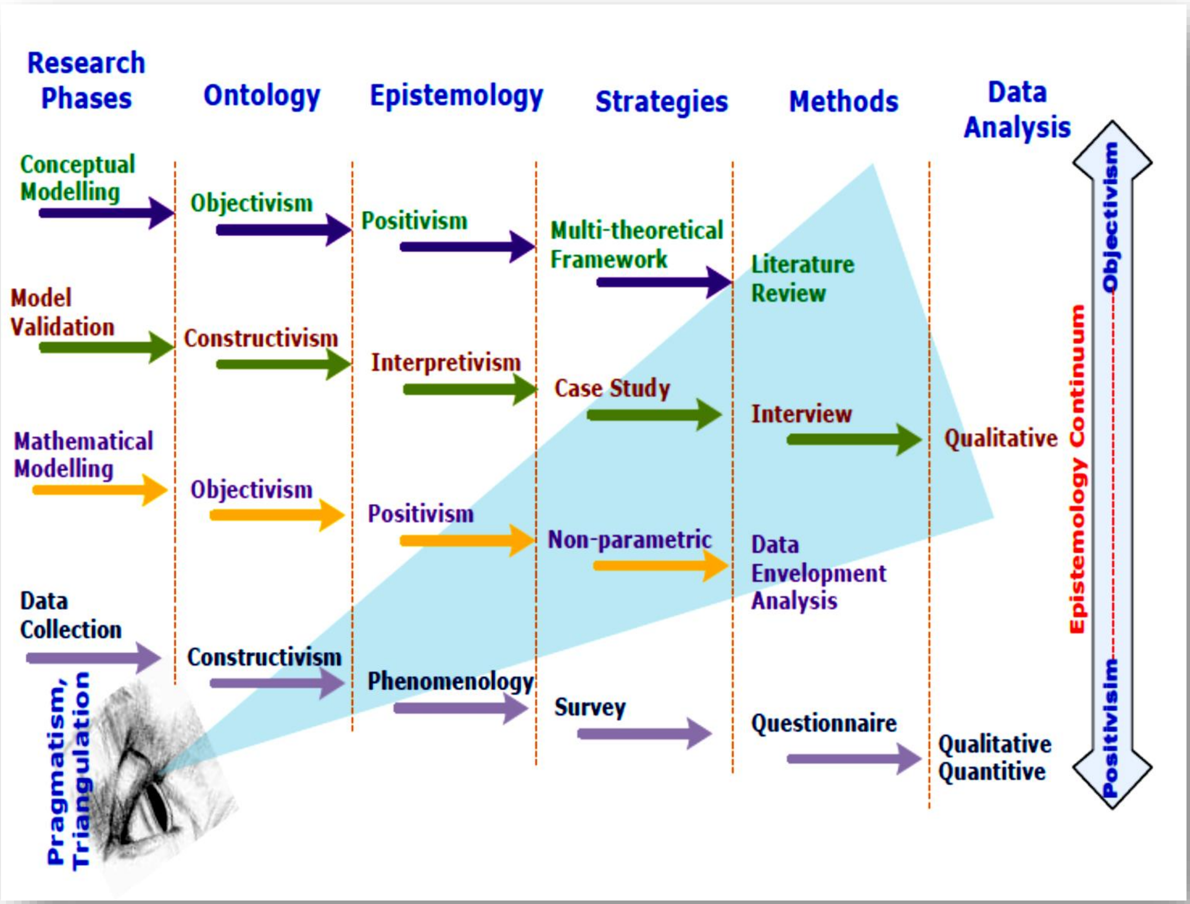


Figure 4.4: Typical phases for the research process (Kassim et al., 2010)

As set out in the aim and objectives, this study aims to identify and understand the different views of client organisations in relation to the BIM competencies and their relationship with client roles in the BIM implementation process. Concerning the ontological philosophical position, this mainly involves a subjectivist position due to the client organisations' BIM experience will definitely affect their view regarding BIM implementation process and with regard to epistemological philosophical position the research involves interpretivism position because the researcher tries to understand client organisations views and mainly try to find answers to question why client need to implement BIM. In addition, the study aims to also establish the relationship between BIM maturity competencies and BIM uses benefits throughout the project life cycle; this is reflected in the objectivist philosophical approach because this relationship has been already existing regardless client organisations concerned to this relationship and positivist philosophical approach due to aim to produce a generalisation regarding this relationship. Therefore, this research mainly falls between a combination of interpretivist and the positivist paradigms from epistemology part and fall between objective and subjective paradigms regarding ontology philosophy part. Having identified the philosophical stance, the next section looks into the research approach pertaining to the study.

4.4 Research Approach

Saunders (2011) describes the research approach as how theory is established, and suggests that this can be categorised as mainly deductive, inductive, or abductive. In the deductive approach, researchers develop a theory and hypothesis (or hypotheses) and design a research strategy to test the hypothesis. While in the inductive approach, the researcher gathers data and develops a theory as a result of data analysis (Saunders et al., 2011). Saunders (2011) states that a deductive approach is close to positivism and inductive to interpretivism. The abductive approach is a form of logical inference which goes from an observation to a theory and accounts for the observation, ideally seeking to find the simplest and most likely explanation (Yin, 2009). Each approach will be discussed individually in the following sub-sections.

4.4.1 Deductive Approach

A deductive approach includes the progress of a theory that is methodically tested. It is a commonly used approach for an objectivist ontology and is broadly used in the natural sciences where laws form the origin of the clarification of a phenomenon (Collis and Hussey, 2013). The early development of the theory regularly leads to the expansion of a hypothesis which is then subject to testing and may help to validate or further adjust the theory when the process is repeated. Trochim and Donnelly (2001) believe that deductive thinking works from the broader to the more particular, and in some cases, this is called a 'top-down' methodology (Hyde, 2000; Johnson-Laird, 1999; Rice and Ezzy, 1999). The initial step is to identify a theory related to a topic of interest, and this theory is then narrowed down into a more specific hypothesis that can be assessed before narrowing down further by collecting observations to address the hypotheses. This ultimately leads to the testing of the hypotheses with specific data that helps to confirm (or not) the original theory (Hyde, 2000; Johnson-Laird, 1999; Rice and Ezzy, 1999). The steps of deductive reasoning are illustrated in Figure 4.5.

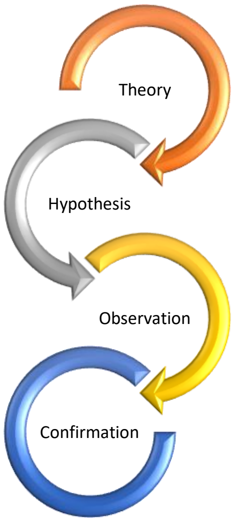


Figure 4.5: Deductive Reasoning Steps (Trochim and Donnelly, 2001)

4.4.2 Inductive Approach

An inductive approach contains perceptions that promote the development of a hypothesis. In the inductive approach, observations are regularly contemplated inside the setting of the phenomenon (Bryman, 2015; Kothari, 2004; Patton, 2005; Rice and Ezzy, 1999; Rosenthal and Rosnow, 1991; Teddlie and Tashakkori, 2009). The inductive approach is frequently used in subjectivist ontology and is often referred to as a 'base-up' approach in that it goes from the particular to the general. Trochim and Donnelly (2001) suggest that inductive reasoning starts with moving from particular observations to broader generalisations and theories. Therefore, the process begins with particular observations and measures, from which the researcher starts to notice patterns and regularities, formulates some cautious hypotheses that can be explored, and finally emerges with some general conclusions or theories (Bryman, 2015; Kothari, 2004; Patton, 2005; Rice and Ezzy, 1999; Rosenthal and Rosnow, 1991; Teddlie and Tashakkori, 2009). Figure 4.6 illustrates the steps inductive reasoning takes.

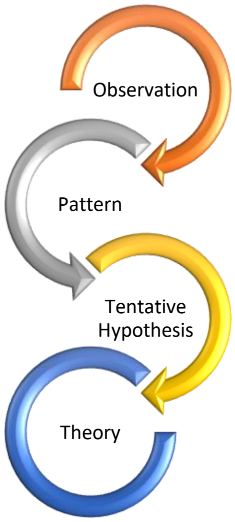


Figure 4.6: Inductive Reasoning Steps (Trochim and Donnelly, 2001)

Inductive reasoning is therefore more open-ended and exploratory, especially during the early stages, while deductive reasoning is narrower and is generally used to test or confirm hypotheses. Most research, however, involves both inductive and deductive reasoning throughout the research process (Bryman, 2015; Kothari, 2004; Patton, 2005; Rice and Ezzy, 1999; Rosenthal and Rosnow, 1991; Teddlie and Tashakkori, 2009). The scientific norm of logical reasoning provides a two-way bridge between theory and research. In practice, this typically involves alternating between deduction and induction. For further clarification and to understand the real contrasts between the deductive and inductive types in term of research approach, Saunders (2011) suggested the following differences, as can be seen in Table 4.1.

Table 4.1: The contrasts between deductive and inductive approaches (Saunders, 2011)

Deduction emphasis on...	**Induction emphasis on...**
a) Scientific principles b) Moving theory to data c) The need to clarify causal connections between variables d) The gathering of quantitative data e) The use of controls to make sure the validity of data f) The operationalisation of concepts to make sure transparency of definition g) A highly structured approach h) Researcher independence of what is being researched i) The need to choose samples of satisfactory size in order to generalise conclusions	a) Gaining an understanding of the meanings humans attach to events b) A deep understanding of the research context c) The gathering of qualitative data d) A more flexible structure to permit changes of research emphasis as the research progress e) A realisation that the research is part of the research process f) Less worry about the need to generalise

4.4.3 Abduction Approach

van Hoek et al. (2005) argue that the abductive approach stems from the insight that the greatest advances in science neither followed the pattern of pure deduction nor pure induction. Thus, mixing inductive and deductive research may lead to a greater and more significant result. In addition, the abductive process can be creative, intuitive, and even revolutionary. According to Haig (2005), there are different streams of abductive research that coexist in modern science. Abductive reasoning has entered various and different disciplines, each of which has developed the approach in their own way. Moreover, the disciplines that are adopting abductive reasoning (mixing induction and deduction) range from learning, linguistics, logic, neural networks, artificial intelligence, computer science, and so forth (A. Dubois and Gadde, 2002; Feilzer, 2010; Haig, 2005; van Hoek et al., 2005). In other words, abductive reasoning is a successful way of researching; however, the outcome is more satisfactory if a purely inductive or deductive approach were implemented (Bryman, 2015; Teddlie and Tashakkori, 2009).

This study implemented an abductive research approach, where inductive reasoning will help (i.e. including researcher) to develop a deep understanding about the client roles in the BIM implementation process and BIM maturity and benefits awareness inside the organisation. This starts by understanding the respondents' views which will help to establish the theory that explains client roles in the BIM implementation process. Deductive reasoning will facilitate establishing, testing, and confirming the relationship between BIM maturity competencies and BIM uses benefits as the theory (the relationship) has been established first and confirmation sought. The abductive approach consolidates qualitative and quantitative paradigms and allows for an investigation from both inductive and deductive perspectives (Gill and Johnson, 2010; Jogulu and Pansiri, 2011).

4.5 Research Choice

The choices outlined in the research onion include the mono method, the mixed method, and the multi-method (Saunders et al., 2011). As the names of these approaches suggest, the mono-method involves using one research approach for the study. The mixed-method requires the use of two or more methods of research and usually refers to the use of both a qualitative and quantitative methodology. In the multi-method, a wider selection of methods is used (Bryman, 2015; Creswell, 2013; Saunders et al., 2011). The main difference between the mixed and the multi-method is that the mixed-method involves a combined methodology that creates a single dataset (Flick, 2015). The multi-method approach is where the research is divided into separate segments, each producing a specific dataset; each is then analysed using techniques derived from quantitative or qualitative methodologies (Feilzer, 2010).

Quantitative research is frequently utilised as an equivalent word for an objectivist philosophy, which mainly focuses on finding theoretical evidence to confirm any proposed theories. Conversely, qualitative research is often used as synonyms for any subjectivist philosophy which mainly depends on non-numerical data to confirm any proposed theories (Bryman, 2015; Creswell, 2013; Saunders et al., 2011). To add more clarification, each type of research choice will be discussed in the forthcoming sections.

4.5.1 Quantitative Study

Creswell et al. (2007) describe a quantitative study as, *'… an inquiry into a social or human problem, based on testing a theory composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether predictive generalisations of the theory hold true.'* Newman and Benz (1998) contend that, generally, quantitative methods were predominantly used in social research and, only recently have qualitative methods been progressively considered in social research. The quantitative approach is key to a positivist school of thought, which is a critical part of the investigation of the physical sciences, such as physics, chemistry and mathematics. Quantitative research is mainly connected with experiments, survey research strategies, archival research, and case studies (Saunders, 2011).

4.5.2 Qualitative Study

Fellows and Liu (2015) define qualitative research as, *'…an exploration of the subject is undertaken without prior formulations – the object is to gain understanding and collect information and data such that theories will emerge.'* Qualitative studies rely upon the researcher being a fundamental part of the information gathering, in a genuine setting, and deciphering the outcomes in an enumerative way (M. Saini and Shlonsky, 2012). Qualitative research tends to concentrate on a single subject or unit, or a case is that is central and examined via phenomenological perception (Newman and Benz, 1998). A qualitative study is linked with a variety of strategies, and whilst these share epistemological roots and normal characteristics, each strategy has a particular stress and scope as well as a specific arrangement of procedures. A range of the strategies utilised with qualitative research include action research, case study research, ethnography, grounded theory and narrative research. At the same time, some of these strategies can be utilised in quantitative research, such as case study strategy, or in a multiple methods research design, as will be discussed in next section (Saunders, 2011). Bryman (2015) identifies the contrasts between qualitative and quantitative research, as presented in Table 4.2.

Table 4.2: Differences between qualitative and quantitative research (Bryman, 2015)

Quantitative study	Qualitative study
Numbers	Words
Point of view of researcher	Point of view of participant
Researcher is distant	Researcher is close
Theory Tested	Theory Emergent
Static	Process
Structured	Unstructured
Generalisation	Contextual Understanding
Hard Reliable Data	Rich Deep Data
Macro	Micro
Behaviour	Meaning
Artificial Setting	Natural Setting

Creswell (2013) suggests that mixing qualitative and quantitative methods leads to a process of 'triangulation' in order to search for convergence amongst the results. In addition, Denzin and Lincoln (2005) describe the concept of 'methodological triangulation' as the grouping of multiple methods to study a phenomenon. Figure 4.7 represents the options available for research.

4.5.3 Triangulation approach

There is a widely accepted view within the research community that research, both quantitative and qualitative, is the best thought of as complementary and should, therefore, be mixed in studies of many kinds (Amaratunga et al., 2002). Das (1983) states that '*qualitative and quantitative methodologies are not antithetic or divergent*'; however, even in instances where they apparently diverge, the underlying unity may become visible on deeper penetration where the situational contingencies and objectives of the researcher would seem to play a decisive role in the design and execution of the study. This stress has developed from the growing attention on 'triangulation' in research (Yin, 2013). Triangulation is a combination of methodologies in the study of the same phenomenon with the aim of improving the validity of measurement. (Amaratunga et al., 2002). Triangulation has been classified into two main categories which are mono methods and multiple methods (Saunders, 2011) (Figure 4.7).

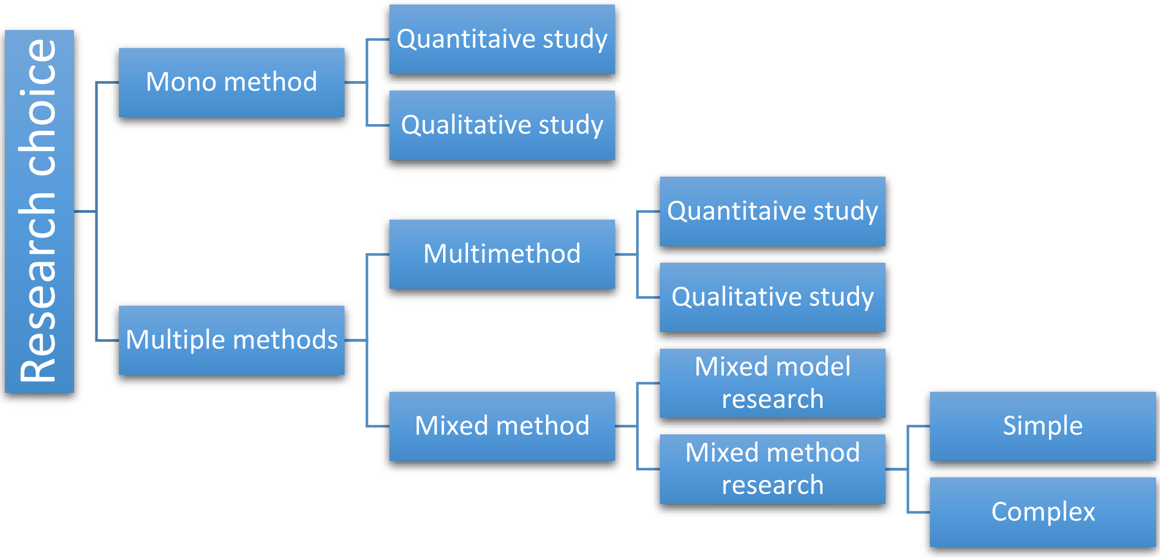


Figure 4.7: Research choice (Saunders, 2011)

Mono-method research is when either quantitative or qualitative research choice rather than a combination of both. This may be due to the demands of the philosophy and strategies employed. It could also be used to research an opposing view to existing mono-method research (Bryman, 2015; Creswell, 2013; Saunders et al., 2011).

Multiple methods are thus separated into multi-method and mixed methods research, as shown in Figure 4.7. In multi-method research more than one philosophical paradigm will be used, but this approach is limited to either subjectivism or objectivism (Bryman, 2015; Creswell, 2013; Saunders et al., 2011). In multi-method quantitative studies, the researcher develops their hypothesis based on objectivism, which is validated by implementing different types of quantitative methods (for example, a questionnaire and structured observation) with associated statistical analysis procedures (Bryman, 2015; Creswell, 2013; Saunders et al., 2011). For multi-method qualitative designs, the researcher adopts a subjectivist philosophical paradigm to establish their proposed ideas, which will be validated by implementing different types of qualitative methods (for example, in-depth interviews and diary accounts) with associated analysis procedures (Teddie and Tashakkori, 2009).

In mixed method research, both quantitative and qualitative research is combined within the research design. This means the researcher could start with an objectivist philosophy and follow this with subjectivist philosophy, or vice versa (Collis and Hussey, 2009; Kothari, 2004; Patton, 2005; Rice and Ezzy, 1999; Teddlie and Tashakkori, 2009). Alternatively, the researcher could choose to use quantitative techniques to analyse qualitative data (for example, comparing statistically the frequency of occurrence of different concepts in in-depth interview transcripts between different groups) or vice versa; this is known as a mixed method complex design (Bryman, 2015; Creswell, 2013; Saunders et al., 2011). Table 4.3 summarises the main differences between multi and mixed methods. It can be seen from the table that mixed method research is more specific in that it includes the mixing of qualitative and quantitative data, methods, methodologies, and/or paradigms in a research study or set of related studies. It could thus be argued that mixed methods research is a special case of multi-method research (Collis and Hussey, 2009; Kothari, 2004; Patton, 2005; Rice and Ezzy, 1999; Teddlie and Tashakkori, 2009). In addition, the main advantages of mixed methods are provide strengths that offset the weaknesses of both quantitative and qualitative research, provide a more complete and comprehensive understanding of the research problem than either quantitative or qualitative approaches alone, and help to explain findings or how causal processes work (Bryman, 2015; Creswell, 2013; Saunders et al., 2011).

Table 4.3: The main differences between multi and mixed method

Multi-Method	Mixed Method
Multiple methods usually tend to fall within the same paradigmatic influence. Each method could answer different sub-questions. The goals of multiple methods are usually: • Outcome triangulation—seeing social phenomena in its multiple dimensions • Data triangulation—use of two or more methods which are exhaustive and rigorous in themselves, leading to several forms of data in studying the same phenomenon.	Mixed methods could employ research strategies from different paradigms, whereby the goals are just not convergence or comparison of data, but: • Corroboration through convergence of findings, • Elaboration, by providing richness and detail, and • Initiation, by prompting new interpretations and suggesting areas of further exploration through recasting the entire research question.

When deciding what type of mixed methods design to use, it is important to take into account the overall purpose of the research (e.g., exploration or generalization), the specific research questions, and the strengths and weaknesses of each design. The four major mixed methods designs are identified below and compared in terms of their purposes, strengths and weaknesses (Table 4.4) (Bryman, 2015; Creswell, 2013; Saunders et al., 2011).

Table 4.4: Mixed method types comaprison

NO	Mixed method types	Purpose	Strenghts	Weakness
1	Sequential explanatory design	This design involves the collection and analysis of quantitative data followed by the collection and analysis of qualitative data.	• Easy to implement. • The design is easy to describe and the results easy to report.	• Requires a substantial length of time to complete all data collection.
2	Sequential exploratory design	In this design, qualitative data collection and analysis is followed by quantitative data collection and analysis.	• Easy to implement. • The design is easy to describe and the results easy to report.	• Requires a substantial length of time to complete all data collection.
3	Concurrent triangulation	In this design only one data collection phase is used, during which quantitative and qualitative data collection and analysis are conducted separately yet concurrently. The findings are integrated during the interpretation phase of the study. Usually, equal priority is given to both types of research.	• Provides well-validated and substantiated findings. • Compared to sequential designs, data collection takes less time.	• Requires great effort and expertise to adequately use two separate methods at the same time. • It can be difficult to compare the results. • Given that data collection is conducted concurrently, results of one method (e.g.,

				interview) cannot be integrated in the other method (e.g., survey).
4	Concurrent nested	In this design only one data collection phase is used, during which a predominant method (quantitative or qualitative) nests or embeds the other less priority method (qualitative or quantitative, respectively).	• Two types of data are collected simultaneously, reducing time and resources (e.g., number of participants). • Provides a study with the advantages of both quantitative and qualitative data.	• The data needs to be transformed in some way so that both types of data can be integrated during the analysis, which can be difficult. • Inequality between different methods may result in unequal evidence.

This study will implement mixed methods sequential exploratory design, because the qualitiative method need to explore BIM implementation in UK constrion client organisations and also to validate the prorposed BIM maturuty comaptencies. Quantitative method will used the validate BIM maturity comaptencies list to validate the relationship between BIM maturity and BIM uses benefits objectively. Revisiting the differences between qualitative and quantitative approaches regarding this research, as discussed by Bryman (2015), this is presented in Table 4.5.

Table 4.5: Qualitative and quantitative strategies used in directing this research

Mixed method approach for BIM maturity-benefits relationship assessment framework.	
Qualitative Approach: Conceptual Framework Development	Quantitative Approach: Conceptual Framework Validation
Words: Textual data will be collected using semi-structured interviews with BIM expert in the client organisation. **The point of view of participant:** BIM expert will be asked about their opinion regarding BIM from a client perspective, BIM maturity, and BIM benefit. The interviewer will try to understand personal points of view from the participants regarding BIM implementation experience inside the organisation. **The researcher is close:** The researcher will conduct face-to-face interviews. **Theory Emergent:** Conceptual framework will be developed using the results from interview data and literature. **Process:** Data will be qualitatively coded to understand the underlying relationships. **Unstructured:** Semi-structured interview data, by its very nature, is somewhat loosely structured. A set of interview questions will be prepared for the purpose of this research but participants will be allowed relative latitude to answer each question as they see fit. Where appropriate, the interviewer will seek further clarification from the participants.	**Numbers:** Survey data will be collected and analysed using descriptive statistical methods and advance statistical analysis like correlation and regression. **The point of view of the researcher:** The conceptual framework will be formulated from BIM expert inside client organisation and the survey participants will be asked to assess their current BIM maturity and current BIM benefits assurance. **The researcher is distant:** Since this will be an anonymous Internet survey, the researcher will have no contact with individual responders. **Theory Tested:** The conceptual framework represents a theoretical construct that was validated by the survey. **Static:** The data represented in the results of the survey represent the perceptions of participants at that point in time. **Structured:** All participants will be given the same specific questions that they are asked to answer and will be given a limited choice of responses to most questions, consistent with ranked scale surveys. **Generalisation:** Descriptive statistics and inferential analysis will be used to interpret the central tendencies of the survey data.

Contextual Understanding: Every attempt will be made by the researcher to understand the context in which the participants gave a particular response. **Rich Deep Data:** Each interview will be conducted in approximately an hours' duration or less, giving the researcher the opportunity to gather elaborate information about BIM implementation, maturity, and benefits. **Micro:** Researcher will ask the participants about BIM competencies that help them to implement BIM. **Meaning:** By evaluating responses to individual questions as well as responses to the overall questionnaire, the researcher was able to better understand the participants' point of view. **Natural Setting:** Each interview will be conducted at a location of the participant's choosing, allowing them to pick a location that is most convenient for them.	**Hard Reliable Data:** Numerical data will be used from the results of the survey to interpret the meaning. **Macro:** The data gathered will represent the opinions of client BIM professionals at various levels within the industry and can be considered to represent a snapshot view of their opinions in regards to the proposed framework. **Behaviour:** The data collected in the survey will be a quantifiable measure to categorise the opinions of the participants and will represent their current BIM maturity and BIM benefits assurance level. **Artificial Setting:** The survey will be conducted over the Internet, which is a rather impersonal way of collecting data and represents a stark contrast to the interview format. The survey will be conducted anonymously; hence, the researcher will not have any personal contact with the survey participants with regards to the survey instrument.

4.6 Research strategy

Peeling away the methodological choices reveals the next layer of the onion, namely its strategy(ies). This layer emphasises that researchers can use one or more strategies within their research design as they plan how to go about answering a research question(s). Saunders et al. (2011) list the following research strategies; experiment, survey, case study, action research, grounded theory, ethnography and archival research. It is important to note that, although in some cases researchers associate particular research strategies with particular research philosophies, the boundaries between them are often permeable; ethnography, for example, is associated with both realism and interpretivism. Conversely, whilst both the experiment and the survey research strategies are normally associated with positivism, realist and pragmatist researchers also use them. Similarly, whilst a case study, perhaps of an individual organisation, is often associated with interpretivism, case studies are also used in positivistic research. (Saunders et al., 2011). Figure 4.8 shows the relationship between research philosophy and research strategy (Sexton, 2007). For further clarification, Table 4.6 provides some justifications for selecting particular research strategies; each of these strategies will be explained in the following sub-sections.

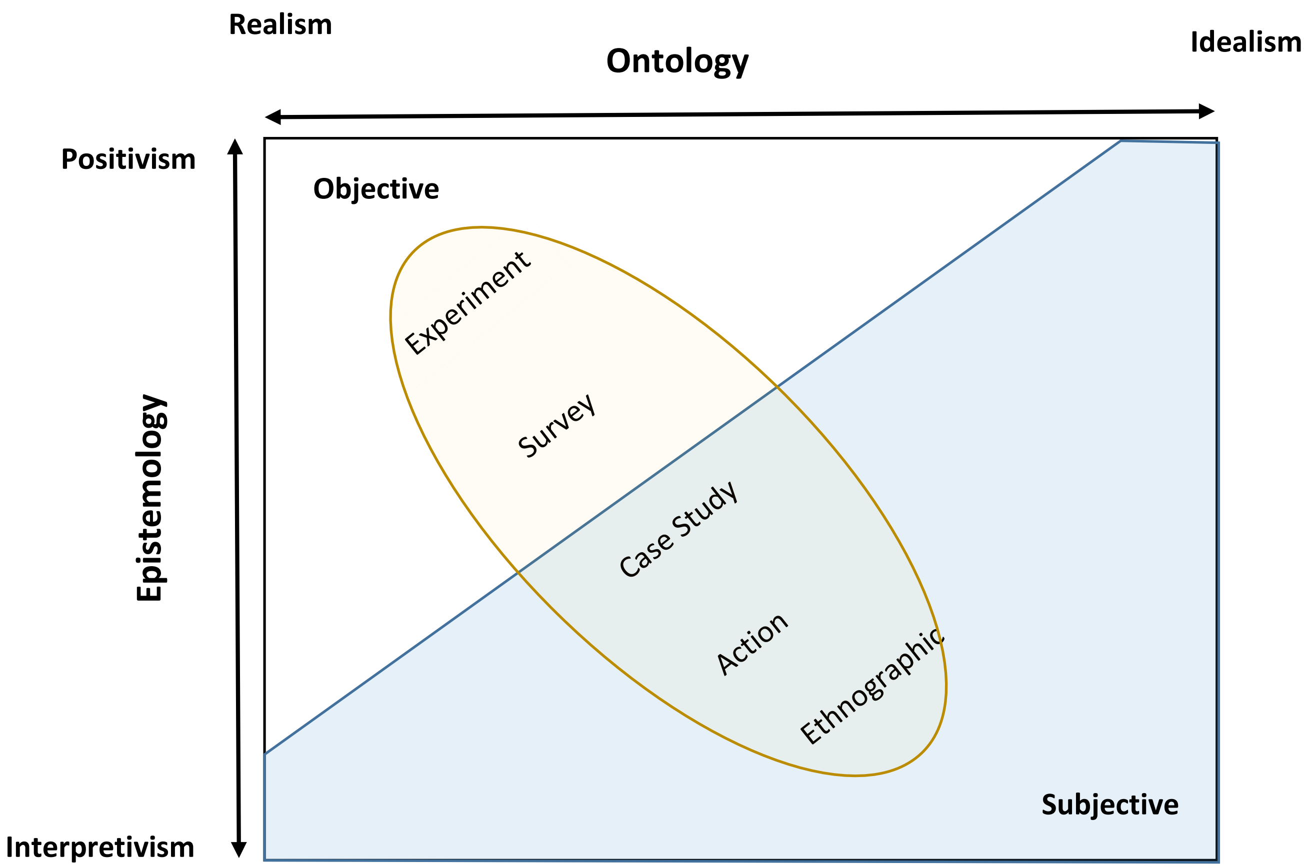


Figure 4.8: Dimension of Research Philosophy (Sexton, 2007)

Table 4.6: Justification of selecting research method (Yin, 2009)

METHOD	Form of Research Question	Requires Control of Behavioural Events	Focuses on contemporary Events
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival Analysis	Who, what, where, how many, how much	no	Yes/no
History	How, why?	No	No
Case study	How, why?	No	yes

4.6.1 Experiment

An 'experiment' is frequently considered the most demanding strategy to employ due to the search to reduce different explanations of outcomes (Trochim and Donnelly, 2001). A well-designed experimental study indicates the creation of an artificial environment within which events and elements that go normally together are controlled separately (Birley and Moreland, 2014). This is achieved by assigning an experimental group for exposure to a specific treatment, or by casually assigning the treatment to a control group and a non-control group (Creswell et al., 2007). The experimental method of research is frequently related with quantitative studies and is often employed in a positivist research context (Cooper et al., 2003; Occupytheory, 2014). Chapin (1917) states that, '*The experimental method has contributed in large measure to the striking achievements of modern science. This method allows us to analyse our relations of cause and effect more rapidly and clearly than by any other method*.' The disadvantages of experimental research include personal biases, unreliable samples, artificial results, results that can only be applied to one situation and may be hard to replicate, and lastly, difficulty in measuring human response. Furthermore, results may not be generalised to real-life situations. This research can be time consuming and expensive, and there may be several areas where experiments cannot be utilised due to ethical and practical considerations (Cooper et al., 2003; Occupytheory, 2014). This method was not considered appropriate due to its underlying aim of testing the application of a new thing in a new setting; such an aim is not required for this study that does not seeks to empirically test but rather to explore the relationship between BIM maturity competencies and BIM uses benefits.

4.6.2 Survey

A 'survey' is a strategy to generalise outcomes grounded by data resulting from sampling populations (Creswell, 2013; Saunders et al., 2011). A survey is a non-experimental inquiry that occurs in natural systems (Boudreau et al., 2001), and a survey strategy consists of the self-completion of a questionnaire or a structured interview, which is utilised to gather data that can elicit patterns of connections between variables (Bryman, 2015). In using a survey strategy, the researcher usually seeks to discover some pattern that can be generalised to the overall relevant community (Creswell, 2013; Saunders et al., 2011). This strategy relies fundamentally on quantitative data and quantitative analysis methods when looking for answers to its research questions, thus, the survey is suitable for a positivist paradigm (Oates, 2005). Sampling is an important issue in survey research, and sampling techniques can be categorised into two groups: probabilistic (random, systematic, stratified, and cluster) or non-probabilistic (purposive, snowball, self-selection, and convenience) (Oates, 2005). The advantages and disadvantages of this research strategy are presented in Table 4.7.

Table 4.7: The advantages and disadvantages of a survey (Creswell, 2013; Saunders et al., 2011)

Survey as research strategy	
Advantages	Disadvantages
1. High Representativeness 2. Low Costs 3. Convenient Data Gathering 4. Good Statistical Significance 5. Little or No Observer Subjectivity 6. Precise Results	1. Inflexible Design 2. Not Ideal for Controversial Issues 3. Possible Inappropriateness of Questions

However, further details about surveys, including sampling and procedures will be presented later in this chapter, as it is one of the selected methods for this study. A survey has been chosen for this study due to its suitability in finding the statistical relationship between BIM maturity competencies and BIM uses benefits; it also helps to achieve one of the aims of this research, namely to reach a wide number of respondents.

4.6.3 Action Research

The term ‘action research’ involves the researcher and a client working in a partnership to identify and solve a problem (Bryman, 2015). Action research came to prevalence in the 1980s & 1990s, and is often adopted by individuals who need to enhance their understanding of practice within an organisation; it also keeps in mind the end goal of improving dealings with others in a social context (McNiff and Whitehead, 2011). This type of research strategy is popular in areas such as business management, and includes people within the organisation in the identification of problems and suitable solutions; as such, it tends to avoid proposing solutions to predefined problems (Bryman, 2015). While action research is typically associated with an interpretivist stance, it can also be undertaken with a positivist or critical study paradigm (McNiff and Whitehead, 2011; Oates, 2005). The disadvantages of this strategy may include the following (Cooper et al., 2003; methodology, 2015):

1. Difficulties in distinguishing between action and research, and ensuring the application of both.
2. Delays in the completion of action research studies can be due to a wide range of reasons and are not rare occurrences.
3. There can be a lack of repeatability and rigour.

It is important to make clear the distinction between action research and consulting. Specifically, action research is greater than consulting in that it includes both action and research, whereas the business activities of consulting are limited to action without the research. This research method was not considered applicable for this study due to the nature of the problem, which aims to identify the relationship between BIM maturity and benefits and to seek generalisations; this would not be achievable if the researcher focuses on one client organisation. Therefore, this research will explore different types of organisation rather than just one client organisation.

4.6.4 Grounded Theory

The term 'Grounded Theory' was first presented by Glaser & Strauss in 1967 (Glaser and Strauss, 2009). Grounded theory includes the progress of theory and utilises qualitative data to improve the theory (Bryman, 2015). The development of theory using data is the main theme and as such, data collecting and data analysis take place concurrently (Oktay, 2012). Information is persistently assembled and broken down to refine the theory until 'saturation' occurs wherein no new topics arise from the information (Oktay, 2012). One of the main disadvantages of Grounded Theory is that it fails to recognise the embeddedness of the researcher and thus obscures the researcher's considerable agency in data construction and interpretation (Bryant and Charmaz, 2007). In addition, a grounded theory strategy tends to produce large amounts of data and is often difficult to manage. Therefore, this research strategy was not selected due to the nature of the problem whereby the theory has already been established through the literature. Instead, this research seeks to validate the relationship between BIM maturity competencies and BIM uses benefits via quaitative and quantitative research methods.

4.6.5 Ethnographic Research

In ‘Ethnographic research’, the researcher is included for a specific period in the social life of those being examined, and makes conclusions from the observation of these participants (Bryman, 2015). Ethnographic research is qualitative in nature and tends to gather together approaches; for example, observation, informal interviews and informal correspondence, such as e-mail and letters (Szewczak and Snodgrass, 2003). It is worth pointing out that some researchers have explained ethnography as a data collection instrument rather than a research design (S. Wilkinson, 2011). This research does not intend to study the behavioural patterns or physiologies of participants, as in the case of ethnographical studies, so this method was not considered appropriate.

4.6.6 Archival Research

‘Archival research’ implies that the researcher utilises information from existing archival records, which the researcher had no part in gathering (White and McBurney, 2012). Bryman (2015) defines this research as ‘unobtrusive’ in nature as the researcher is not personally involved in observing the interactions or events being examined. The use of government-collected information, such as census data, is an example of archival research. This type of research strategy is helpful with the type of hypotheses where it is impossible to ethically assign participants to groups; it is also helpful when researching trends within a population. However, a drawback of this type of research strategy is that the researcher has no control over how the data was collected and what type of controls for extraneous variables were put in place (Creswell, 2013; Saunders et al., 2011; Ventresca and Mohr, 2002) . Therefore, this research strategy was not considered appropriate due to the nature of this problem, which aims to discover the relationship between BIM maturity and benefits.

4.6.7 Case Study

Yin (2009) defines a case study strategy as, ‘*…an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident*’. A case can be a single person, subject, group or organisation (Runeson and Höst, 2009), and case study research may incorporate the examination of a single or multiple cases that can be classified as ‘descriptive’, ‘explanatory’ or ‘exploratory’ in nature. A descriptive case study is utilised to refer to a phenomenon or processes, whereas an explanatory case study is usually theory driven and may be utilised to develop a hypothesis in a large research project (Fellows and Liu, 2015). An exploratory case study is typically used to test the hypothesis to come up with logical conclusions (Yin, 2009). In addition to the philosophical stance, the research questions in a study influences the selection of a research approach. Yin (2003) argues that 'how' and 'why' questions are favoured in explanatory studies, and 'what' questions are suitable for exploratory types of research. Therefore, case studies can provide more insight for this particular study; firstly, by exploring, and secondly, by explaining the phenomenon under investigation. Bello (2003) proposes that there are several motivations to conduct a case study, and these include:

1. The investigation of an inquiry, program, population, issue or concern in order to decide on suitable research questions to encourage future research.
2. The clarification of linkages between causes and effects.
3. The description of a real-life context in which an intervention has occurred.
4. The description of the intervention itself.
5. The investigation of those circumstances in which the intervention being assessed has no reasonable arrangement of results.

Moreover, Bello (2003) believes that case studies have turned into a primary source of valuable information to researchers. There are a diversity of benefits that can be gained from implementing a case study approach, particularly in contrast with other methodologies (Saunders, 2011). One such benefit is that the information delivered is frequently more concrete and contextual, specifically due to the indepth analysis it proposes of the case under examination (Saunders, 2011). As this study aims to find the current BIM competencies in UK construction clients and to investigate their BIM experiences, a case study has been selected as one of research strategies. The following characteristics are noted as key influences in the selection of a case study research strategy for this study:

1. Facilitates an in-depth study to identify the links between client roles and BIM maturity competencies that mainly depend on the critical review of the literature and interviews;
2. Allows for multiple sources of evidence to be used which helps to increase the validity of the collected data; for example, interview and documents have been used in order to check the final assumption such as the list of the BIM competencies and their relationship with BIM clients' roles.
3. Does not control/manipulate the environment under examination (as in the case of experiments) but rather aims to allow participants to express their understanding regarding BIM, maturity, and benefits;

4. Does not interfere with the attitudes, perceptions or procedures of the environment (as in the case of action research) which will provide confident environment to express their views.
5. Analyses a contemporary event which will help the researcher to concluded new themes and results.
6. The research questions posed favour case studies due to mainly relating to understanding how BIM has been implemented in the client organisation in terms of competencies and why the client organisation decided to implement BIM.

Having chosen a case study as the research strategy, the next section explains the compromise made between the use of single and multiple case studies.

4.6.7.1 *Case Study Selection Criteria*

As outlined by (Yin, 2009), case studies can be mostly classified as multiple or single, and then, depending on the number of units of analysis, embedded (more than one unit of analysis) or holistic (one unit of analysis). Thus, as shown in Figure 4.9 (U. Kulatunga, 2008a), four types of case study designs exist which include:

1. Single holistic case study.
2. Multiple holistic case studies.
3. Single embedded case study.
4. Multiple embedded case studies.

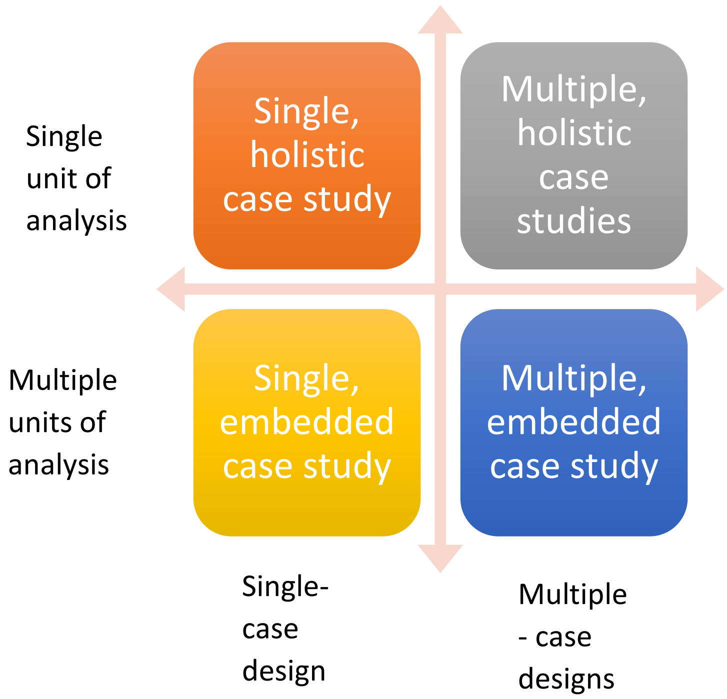


Figure 4.9: Types of case studies based on the number and units (U. Kulatunga, 2008a)

On the one hand, a single case is frequently utilised to present a critical, extreme or unique case. On the other hand, a single case might be chosen because it is typical or provides a chance to observe and analyse a phenomenon that few have considered. A case study strategy can also incorporate multiple cases. The rationale for using multiple cases could include the need for replication across cases. Cases will be selected on the basis that similar outcomes are predicted from each (Saunders, 2011). Yin (2009) states that choosing between a single and multiple case studies does not necessarily relate to the production of more evidence. Although a multiple case study is likely to produce more evidence, the purpose of each approach is different. While this study aims to find the BIM competencies for different types of clients, a multiple cases study can be the best approach in allowing the researcher to identify and compare BIM competencies for different types of clients.

According to AlSehaimi et al. (2012), there is no agreement over a definitive number of cases needed for an investigation when engaging in a multiple case study approach. According to Yin (2013), the selection of cases should be directed by the replication of logic. Each case should be considered as an experiment in itself, and following cases will either check or refute previous findings. A careful but rigorous selection of cases is crucial to ensure that the researcher obtains sufficient data to produce appropriate conclusions for the study. The number of case studies investigated by the researcher will depend on the similarity between the results, although the researcher needs at least two studies for each type of client in order to produce solid conclusions. For this study, the selection of cases is based on the aim and objectives of the research and the research context. It is simplified as the following:

a) The type of organisation is a client organisation (public, private, and mix client).

b) The organisation must currently be implementing BIM within the business process.

c) Different levels of organisational experience in BIM, which allow the researcher to compare BIM benefits against different levels of BIM experience.

d) The organisation must also be willing to cooperate and provide access to the researcher to acquire data.

All selected organisations' backgrounds and participants' information will be explained in detail within the findings and analysis chapter. Accordingly, this section has discussed the rationale behind the selection of multiple case studies for the study. The next section will look into the time horizon.

4.7 Time Horizon

The time horizon also forms part of the philosophical approach; it is closely related to the organisation and management of the research and focuses on keeping within any time limits. A PhD study has a limited time period and therefore all activities and stages of the research have to end within this. The researcher may resort to working on different stages of the research (literature review, building a model, sketching a framework, collecting data, etc.) at one time and this is called a cross-sectional process. However, if one stage of the research depends on the results of another, the researcher is restricted to work on one stage at a time and this is called a longitudinal process. Green et al. (1993) argue that there is a desperate need to set a time horizon for research, namely that research cannot run indefinitely. Moreover, Bell (2014) believes that inevitably there are deadlines which the research activity must fit and these must be stated clearly at the outset of the research. In addition, Bell (2014) suggests that, because of time pressures, researchers often seek quick answers from research. In other words, if researchers are aware of the time constraints then this can become an overriding factor when they plan the research design. Bryman (2012) proposes that cross-sectional research is frequently related with quantitative research but also recognises that procedures, such as semi-structured interviewing, represent a cross-sectional design that is quite common to qualitative design.

This research is being conducted as a major aspect of a PhD research thesis that must meet strict university rules for the timely gathering of data and presentation of findings. Therefore, given the time constraints and the nature of the mixed-method research, a 'cross-sectional' approach will be adopted. This research will provide a snapshot of data from interviews and the questionnaire when implementing the proposed framework for assessing a BIM maturity-benefits relationship from a client's perspective.

4.8 Research Technique

Saunders (2011) distinguishes data collection and analysis as the most vital part of the conduct of research. In connection with data gathering, some key issues identified by Saunders (2011) consist of 'sampling', 'secondary data' and 'primary data'. Four key, linked research techniques have been adopted for this study, which are; the literature review, in-depth semi-structured interviews, documents (as a secondary data), and an online questionnaire. In this section, these techniques are further expounded and discussed in the context of the current research.

4.8.1 Literature Review

According to Saunders et al. (2011), the literature review offers a portrayal and critical analysis of the present condition of knowledge in the subject area. In addition, the literature review defends any new research over criticisms of what has gone before, and explains why the research is important (Khoshgoftar and Osman, 2009). This research involves two stages of the literature review. The first stage of the review includes two purposes as follows:

a) At an early point of the research, the first stage literature review was conducted to form knowledge of the current issues in the UK construction industry and subsequently to identify the research problems and form the research aim and objectives.
b) After the aim and objectives were recognised, a more detailed literature review was conducted on the subject matter to form knowledge regarding BIM, BIM maturity methods, and BIM benefits for client organisations, concentrating on the theoretical and fundamental concepts. It was directed to develop a conceptual framework for a BIM maturity- benefits relationship for client organisations.

The second stage of the literature review explains, justifies, collects data, and validates the research findings. Therefore, the literature review was conducted and positioned after the initial conceptual framework was developed.

4.8.2 Interview

According to Yin (2009), the selection of the interview technique is based on the level of valuation the researcher could achieve in capturing data; this is significant since some of the evidence, such as company or personal records, can be confidential, and the opportunity to access such documents and opinions may be outside the control of the researcher. Therefore, interviews and direct observations obtained through the case studies are considered key data gathering techniques for this research.

The interview can be defined as an open process through which the researcher extracts data from a person or source (Kumar and Phrommathed, 2005; Naoum, 2012). Interviews could be personal (face-to-face) or via a medium (internet or telephone). The interview has a specific strength; it can yield information quickly and in great quantity. However, it also has limitations and weaknesses (Yin, 2009); for example, interviewees may be unwilling or uncomfortable in sharing information on all areas that the interviewer aims to investigate.

According to (Easterby-Smith et al., 2012), there are three types of interview, namely: 'structured', 'semi-structured' and 'unstructured'. They also emphasise that in-depth, semi-structured interviews are essential for qualitative methods. The interviews gather data regarding interviewee's experiences, knowledge, ideas and impressions (Alvesson, 2003) and offer an opportunity for the researcher to discover new meanings, and reveal new extents of a problem (Yin, 2009). According to C. Robson (2002), semi-structured interviews have programmed questions but the order of the questions can be changed depending on the interviewer's perceptions of what seems to be most suitable.

Semi-structured interviews will be conducted to understand the current role of client organisations in the implementation of BIM across the construction industry, and why they decided to implement BIM. It will also explore current BIM competencies that help such organisations lead BIM implementations, build their Employer Information Requirements (EIR), and validate the delivered information. In addition, the interviews will help the researcher to understand the current BIM maturity awareness among client organisations, including the current BIM uses, and desired benefits. In effect, the research will probe particular themes related to the client role in the BIM implementation process, thus making semi-structured interviews an appropriate technique to gather data. In circumstances when a researcher is familiar with the idea being researched and when the research emphasis is in a concentrated area, semi-structured interviews are a recommended data collection technique

(Bryman, 2012). This approach also accords with the interpretive epistemological standpoint that underpins this research (Saunders et al., 2009).

4.8.3 Secondary data (Document)

Secondary data, as documentary evidence, involves any material that gives information about the investigated phenomenon and that exists independently of the researcher's actions. It is normally produced for specific purposes other than those of the research but can be used by the researcher for cognitive purposes (Kumar and Phrommathed, 2005; Mingers, 2001; Newman and Benz, 1998). Yin (2013) asserts that, '*for case studies, the most important use of documents is to corroborate and augment evidence from other sources.*' Fellows and Liu (2015) identified a number of advantages of using documents over other research methods, namely that; (a) they are non-reactive where the information given is not subject to a possible distortion as a result of the interaction between the researcher and the respondent, as can be the case with interviews; (b) they help the researcher study the past; and (c) they are a cost-effective method as the information has already been produced (Toolkit, 2012). However, documents may have some limitations in terms of the accuracy and completeness of the data (D. L. N. s. BIM, 2011).

While an EIR represents a client's requirements, which reflects the client's BIM understanding, it can also give a good indication as to the organisation's BIM maturity level via examine client ability to ask the right question with level of details. For this study, different versions of an EIR were collected for comparing the improvement in the organisation's BIM maturity and its effects on the client's ability to ask the right questions, and thus lead to the desired benefits.

4.8.4 Questionnaires

Questionnaires are commonly used techniques in gathering survey data, often numerical, which tends to be easy to examine (Dörnyei and Taguchi, 2010). Frequently seen as an easy option, in reality, their use necessitates cautious design and pre-planning and invariably the analysis of the data they generate requires the adoption of a static approach. Their construction, administration, data entry and data analysis, together with the particularly useful static technique of factor analysis, are all considered (Knight and Ruddock, 2009). Oppenheim (1992) states that questionnaires give researchers the option of collecting objective data about people, their behaviour, attitudes and knowledge. Furthermore, piloting is essential to the success of a questionnaire; a proper pilot should be undertaken with experts and may be a two-stage process, involving firstly, the piloting of the questions and secondly, the questionnaire. However, most questionnaires are more likely to be carried out in a single stage (Knight and Ruddock, 2009).

In terms of the size of the sample, the researcher is required to consider the sampling accuracy that is acceptable. It is necessary to set up a sampling frame, that is, a list of cases that represent the responders (Knight and Ruddock, 2009). As reported by Cohen and Manion (2000), a questionnaire can be categorised as one of three types:

1. Structured: includes closed questions that supports analysis via statistical data. This is because of the generation of response frequencies.

2. Semi-structured: contains open-ended questions designed within a certain structure and sequence that permits respondents to concentrate their answers in particular required ways while responding in their own words.

3. Unstructured: includes completely open-ended questions, letting respondents write whatever they want with minimal structuring.

Structured questionnaires have been used in this research was useful as it added data to the case study interview responses to further gather information regarding the relationship between BIM maturity competencies and BIM uses benefits. in addition, the questionnaire survey technique enabled more specific information to be obtained from a larger number of respondents than the case study interviews. The questions in the questionnaire were structured to produce ordinal and nominal levels of measurement. It is important to bear in mind that the levels of measurement and the choice of measurement affect the type of data analysis that is performed. Cross tabulation, frequency distribution and bar charts are used to present survey results. This questionnaire consists of three main parts. Firstly, few questions to gather some information about participant's background related BIM implementation. Secondly, several questions have been designed mainly to evaluate the BIM maturity for the responder's organisation. Finally, several questions have been designed to evaluate the BIM benefits assurance for the responder's organisation. Both evaluations will help to determine the relationship between BIM maturity competencies and benefits assurances. It is important to bear in mind that the levels of measurement and the choice of measurement affect the type of data analysis that is performed. Cross tabulation, frequency distribution and bar charts are used to present survey results. Further explanation will be presented in chapter 7.

4.8.5 Objectives of the study and how they are addressed

Table 4.8 summarises how the objectives are addressed through the data collection methods. It can be seen from the table; different methods of investigation have been used to achieve different objectives. In addition, it can be concluded that some objectives only require one method to be achieved such as objective one. However, objective five required all four different methods to be achieved.

Table 4.8: the objectives of this study and the mode of investigation

NO	Objective	Methods of investigation				
		Literature Review	Experts' Opinions	Case Study		Questionnaire
				Interviews	Documents	
1	Identify the importance of BIM for the UK construction clients and client roles in BIM implementation process.	X				
2	Identify the possible area where BIM can be used and investiagte the corresponding benefits and requirements for each BIM uses from clients' perspective.	X	x	X		
3	Understand and critics the existing BIM maturity assessment models in order to propose a BIM organization maturity assessment model which can be used to evaluate the UK construction clients.	X	X	X	X	
4	Validating the proposed BIM maturity model and identify the relationship between client roles and the proposed BIM	X	X	x		

	maturity competencies.					
5	Establish, validate and produce a final assessment conceptual framework to explain the relationship between BIM maturity competencies and BIM uses benefits from the UK construction clients' perspective. This objective also includes explanation how the UK construction clients can use the conceptual assessment framework practically.	x	x	x	x	x

After discussing the data collection techniques, it is important to investigate data sampling in the context of the current research before explaining the data analysis techniques.

4.8.6 Data sampling

Whatever the research question(s) and objectives, a researcher needs to consider whether they need to utilise sampling (Saunders, 2011), and if so, the researcher needs to choose a sample. This is similarly significant whether the researcher is aiming to use interviews, a questionnaire, observations or some other data collection technique (Saunders, 2011). Sampling is the technique by which units from a population are chosen to contribute to the data gathering phase of the research (Saunders, 2011). Two sampling techniques exist when conducting research, and these are:

1. Probability or representative sampling
2. Non-probability or judgmental sampling

4.8.6.1 Probability Sampling

Probability sampling infers that the units from the population were selected with some level of randomness (Trochim and Donnelly, 2001). The probability or chance of selecting any unit from the population is the most equivalent to using this technique (Saunders, 2011). Probability sampling techniques are frequently utilised in survey-based research strategies when statistical implications are needed to analyse data, and therefore, the outcomes may be considered representative of the general population (Saunders, 2011). The procedure of probability sampling can be categorised into four phases:

1. **Detect a suitable sampling frame based on the research question(s) and objectives.**

   Population target for this research is UK construction clients. It is extremely difficult to detect sample frame for client's organisations inside UK for several reasons such as there is no official source can provide this information and any organisation can re-enact client role when they decide to build something. Therefore, this research will target all organisations how used BIM from client perspective without any specific sample frame.

2. **Adopt a suitable sample size.**

   As it was mentioned above, there is no definite sample frame for this research. Therefore, it is impossible to choose any sample size. However, this research will seek to invite all organisation the preformed client roles to increase the chance of generalization.

3. **Select the most suitable technique and choose the sample.**

   There are four main techniques to choose research sample. Firstly, simple random sampling, which is defined as a subset of a statistical population in which each member of the subset, has an equal probability of being chosen. Secondly, systematic sampling, which is defined as a type of probability sampling method in which sample members from a larger population are selected according to a random starting point and a fixed periodic interval. This interval, called the sampling interval, is calculated by dividing the population size by the desired sample size. Thirdly, stratified sampling, which is defined as a probability sampling technique wherein the researcher divides the entire population into different subgroups or strata, then randomly selects the final subjects proportionally from the different strata. Finally, cluster sampling, a sampling technique used when "natural" but relatively heterogeneous groupings are evident in a statistical population. It is often used in marketing research. In this technique, the total population is divided into these groups (or clusters) and a simple random sample of the groups is selected. Due to the limitation in detecting sample frame, the first two method cannot be implement. In addition, divided clients in-group depend on geographical factors will not meet research aim. Therefore, the stratified method will be implemented where the selected clients must have been using BIM so they will be able to answer the survey questions.

4. **Check that the sample is representative of the population.**

   Without sample frame, it will be impossible to check if the sample is representative of the population, which will be considered as one of this research limitation.

As this research will use a questionnaire, probability sampling will be employed in this study. Sampling properties, will be discussed in detail in Chapter 7 (questionnaire data analysis).

4.8.6.2 Non-probability sampling

Non-probability sampling techniques are used when the research aim and objectives require another form of sample selection (Saunders et al., 2009). Saunders et al. (2009) indicates that there are four main methods for sample selections . Firstly, purposive sampling is utilised when the sample is selected with a particular purpose in mind. Secondly, convenience samples (haphazard) where sample is selected from elements of a population that are easily accessible. Thirdly, volunteer which contain two main categories, Snowball sampling (friend of friend….etc.) and self-selection. Finally, Quota sample which where sample will be divided into groups based on certain factors such as sex .In the context of this research, Multiple methods have been implemented, start with purposive sampling was used to select a client organisation in the first phase of the research then snowball sampling. For this research, the views of BIM experts inside client organisations will be used in the creation of a framework for the relationship between BIM maturity and BIM benefits. Hence, BIM experts will be chosen based on their availability and willingness to participate. Data from this stage will be used in the development of the conceptual framework to explain the relationship between BIM maturity and benefits. This technique has been further classified as ‘expert sampling’ by Trochim and Donnelly (2001) and as ‘homogenous sampling’ by Saunders et al. (2009). This technique is recommended by Saunders et al. (2009) when the intention of the data gathering is to establish an in-depth understanding of issues. Fifteen BIM experts from six different types of client organisation will be contacted to participate in the interviews; this number was based on the study conducted by Guest et al. (2016) who found that data saturation occurred after twelve interviews in qualitative studies.

4.9 Data analysis

The data analysis is one of the significant parts of any research as it helps to investigate the collected data and, from this, draw conclusions (Creswell et al., 2007). According to Jorgensen (1989), data analysis starts with the, '*…breaking up, separating, or disassembling of research materials into pieces, parts, elements, or units*.' Thereafter, the researcher sorts them and looks for types, sequences, or patterns, and even combines quantitative and qualitative data in seeking evidence to address the initial propositions of the study (Yin, 2003). The aim of this process is to assemble or reconstruct the data in a meaningful way (Jorgenson, 1989). As stated by (Hartley and Hocking, 1971), data analysis helps to generate theories that are grounded in empirical evidence. As mentioned, this study gathered qualitative data from semi-structured interviews and quantitative data from a questionnaire survey. This section firstly describes the analysis techniques used for the qualitative data and secondly, that for the quantitative data.

4.9.1 Qualitative data analysis

The concentration on text rather than on numbers is a key feature of qualitative analysis. The 'text' that qualitative researchers analyse has most commonly come from an interview transcription or notes from participant observation sessions; however, the text can also refer to pictures or other images that the researcher examines (Lacey and Luff, 2001).

There are different phases to qualitative data analysis that are shared by most approaches (Lacey and Luff, 2001)

1. Documentation of the data and the process of data collection.
2. Organisation/categorisation of the data into concepts.
3. Connection of the data to display how one concept may influence another.
4. Corroboration/legitimization, by evaluating alternative explanations, disconfirming evidence and searching for negative cases.
5. Representing the account (reporting the findings).

Before the data is analysed, the researcher will transcribe all interviews. The process of transcribing allows the researcher to become familiar with the data (Riessman, 1993). The researcher will create Microsoft Word files for the interviews and will protect them by setting a password. For further protection, all these files will be saved in the researcher's portable computer to which only he has access.

The researcher will use the content analysis technique. The content analysis carried out for the interviews was used to ascertain a pattern of responses amongst the participants according to the predefined categories (Haron, 2013). The analysis of the interviews began with the intra-case analysis of each case and was followed by cross-case analysis for all organisations involved. The researcher will use the qualitative software NVIVO program for data coding, management, and analysis.

This study will implement a multiple case study design where the data is analysed case by case through objective analysis and later by cross-case analysis (Stake, 2013). Thus, interviews and documents will be analysed for each case. In following the case-by-case analysis, all codes will be used to conduct the cross-case analysis. Similar codes across all cases will be kept as well as those that are significantly different (Creswell et al., 2007). The information coding process is classified by Saunders et al. (2009) as either 'deductive or 'inductive'. These categories are closely associated with content analysis as well as thematic analysis, and one method is selected prior to starting the coding process (Bernard and Bernard, 2012; Braun et al., 2014). In using deductive coding, the codes may be pre-selected before beginning the coding process (Vaismoradi et al., 2013). Inductive coding, on the other hand, depends on the data to develop codes and is frequently related to 'Grounded Theory' (Bernard and Bernard, 2012). In qualitative studies that start with an inductive approach, data is frequently coded inductively (Vaismoradi et al., 2013). Therefore, an inductive approach will be used in the coding of the data as it corresponds with a qualitative study.

Each interview will be recorded in digital audio and will be later transcribed for analysis purposes. Care will be considered to make sure that all the recorded interviews are transcribed professionally without any bias. Each interview will be read and answers to questions from interviewees will be grouped for further analysis. Codes will be developed using the 'open coding' mechanism proposed by DeCuir-Gunby et al. (2012). Open coding is the process of labelling raw data under various headings so that further analysis may be conducted to organise, categorise, quantify and identify relationships within the codes. The codes will then be carefully examined through a content analysis as well as a thematic analysis. Data saturation observations, as well as codes/labels that directly relate to BIM maturity, benefits, and client roles, will be used to create a conceptual framework for BIM maturity-benefits relationship.

4.9.2 Quantitative data analysis

Quantitative data analysis regularly deals with statistical data analysis techniques. Some of the most commonly used techniques are chi-square analysis, correlation analysis, factor analysis, and so forth (Amaratunga et al., 2002). A quantitative data analysis plan generally consists of raw data assessment; data entry and transfer; data processing; communicating findings; data interpretation; and completing data analysis (Jennifer Mason, 1994). Saunders et al. (2009) recommend that numerical data gathered from surveys can be analysed using 'descriptive' or 'inferential' statistics. Descriptive statistics are utilised to describe the central tendency of the data as well as to define the dispersion of the data from the central tendency (Hinton et al., 2014). The central tendency itself is an examination of the values that can offer a general impression of the data (Saunders et al., 2009). Inferential statistics (advanced analysis), on the other hand, look at the data beyond the central tendency and are utilised to examine relationships, differences and trends within the numerical data. Inferential statistics allow the data to be tested for the strength and significance of the relationships between the variables (Saunders et al., 2009).

The quantitative analysis of this study is aimed at validating the conceptual framework that will be created from the results of the qualitative analysis on the interview data and the literature. The conceptual framework is expected to be validated/modified/refined from the data gathered from the online questionnaire. Hence, descriptive and inferential statistics are proposed for interpreting the results from the online questionnaire. This is due to the following reasons:

1. Descriptive analysis will be used to summarise a given data set in terms of average, mean, median, and standard deviations, which can either be a representation of the entire population or a sample of it.
2. The inferential analysis will also be used to measure the strengths of association between two variables, which will be achieved through the correlation technique. For this study, the two variables are the BIM maturity competencies and BIM uses benefits.

In addition, the level of measurement can influence the type of analysis used. There are four levels of measurement (Sapsford and Jupp, 2006):

- Nominal: is hardly a measurement in that it refers to quality more than quantity. A nominal level of measurement is simply a matter of distinguishing by name, e.g., 1 = male, 2 = female. Even though the numbers 1 and 2 are used, they do not denote quantity.

- Ordinal: refers to the order in measurement. An ordinal scale indicates direction and provides nominal information. Low/medium/high, or faster/slower are examples of ordinal levels of measurement.
- Interval: Interval scales provide information about the order and indicate equal intervals. From the previous example, if the distance between 1 and 2 were the same as that between 7 and 8 on a 10-point rating scale, then this would indicate an interval scale.
- Ratio (scale): in addition to possessing the qualities of nominal, ordinal, and interval scales, a ratio scale has an absolute zero (a point where none of the quality being measured exists). Using a ratio scale permits comparisons, such as being twice as high, or one-half as much.

While the research aim to find the relationship between maturity competencies and BIM uses benefits which classified as ordinal scaled, therefore, Spearman's correlation coefficient and Kendal rank have the ability to measures the strength of association between two ranked variables, which represented in this study by maturity levels and benefits assurance levels. There are difficulties associated with using Spearman's test with data from either very small samples which less than 7 or large samples which large 60, therefore spearman correlation will be used for all BIM uses except who has less than 7 responses M. (Saunders et al., 2009).

a) **Kendall rank correlation** is a nonparametric test that measures the strength of dependence between two variables. If we consider two samples, a and b, where each sample size is n, we know that the total number of pairings with a b is n(n-1)/2. The following formula is used to calculate the value of Kendall rank correlation:

Kendall rank correlation= $\frac{nc-nd}{\frac{1}{2}n(n-1)}$

Where:

Nc= number of concordant

Nd= Number of discordant

b) **Spearman correlation**: Spearman rank correlation is a nonparametric test that is used to measure the degree of association between two variables. It was developed by Spearman; thus it is called the Spearman rank correlation. Spearman rank correlation test does not assume any assumptions about the distribution of the data and is the appropriate correlation analysis when the variables are measured on a scale that is at least ordinal. The formula used to calculate Spearman's correlation coefficient is shown below:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

Where:

di = Difference in paired ranks, n= Number of responders

checking if this ρ value is significant, a Spearman's Rank significance table or graph must be used as shown in Figure 4.10.

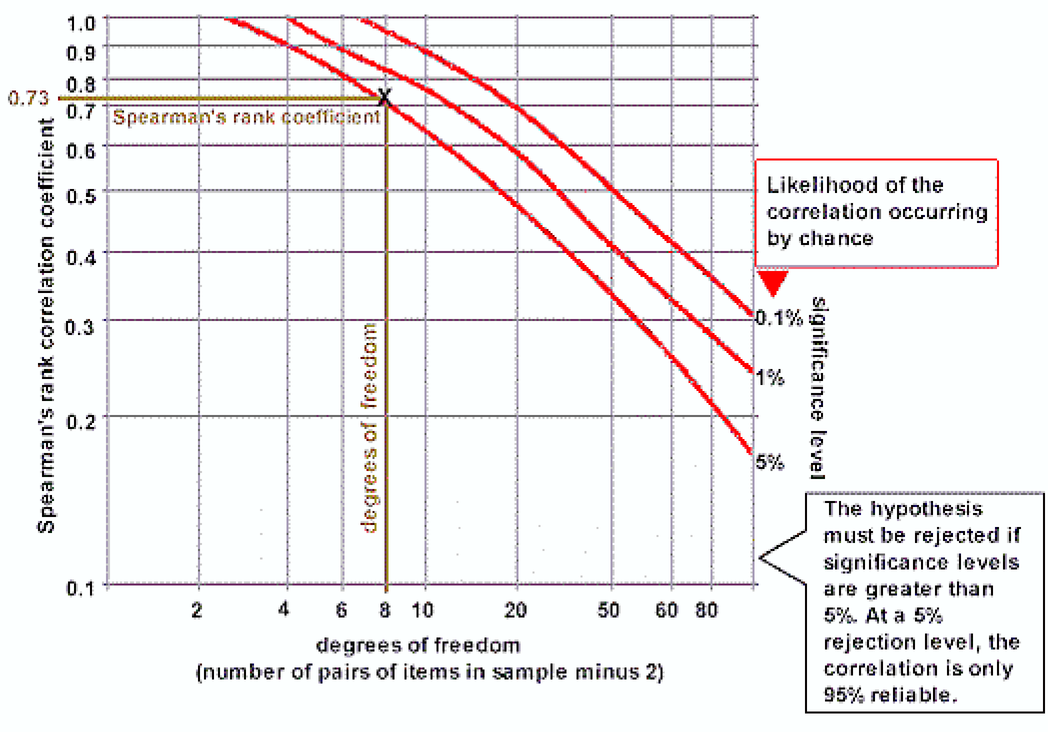


Figure 4.10: The significance of the Spearman's rank correlation coefficient and degree of freedom

The correlation analysis will be carried out on each BIM uses to find the relationship between BIM maturity competencies and BIM uses benefits.

4.10 Validity and Reliability

For any given problem, validity is one of the concepts used to determine how good a research answer is (M. L. Miller and Kirk, 1986). Yin (2013) identified two aspects of validity: internal and external. Internal validity represents whether or not what has been identified as the cause actually produces what has been interpreted as the `effect' or `response' and checks whether the right cause-and-effect relationships have been established. External validity refers to the extent to which any research findings can be generalised beyond the immediate research sample. It is worth noting that there is a different perspective on validity when viewed within the context of qualitative and quantitative research (M. L. Miller and Kirk, 1986). Several strategies are recommended by M. Saini and Shlonsky (2012) to ensure the validity of the research, and this includes 'triangulation'. Triangulation is the procedure of collecting data from multiple sources to improve data consistency (Saunders et al., 2009). Qualitative research identifies the presence or absence of a given feature in a given problem or situation, as opposed to quantitative research which measures the degree of presence of the feature itself. In this research, the literature review, interviews with BIM experts from the client organisation, documents, and the survey of BIM experts from the client perspective will be used in providing multiple data sources in formulating the framework for the relationship between BIM maturity and benefits. These are all acceptable forms of data in mixed-method research, and thereby increase the accuracy of this study.

Consistency can be confirmed from the results of the literature and the fact that the conceptual framework will represent the outcomes of the questions posed to BIM experts in client organisations; these will be gathered from face-to-face interviews. Conducting an online questionnaire in the quantitative phase of this study will validate/refine the results from the interview data in the qualitative phase of the study. On the other hand, reliability, according to Carmines and Zeller (1979), shows that the researcher's approach is consistent across different cases and projects and concentrates on the errors and bias of the study. The aim of reliability is to minimise the errors and biases in a study. The object is to ensure that, if a later investigator followed exactly the same procedures, the same findings and conclusions would result (Amaratunga et al., 2002). M. Saini and Shlonsky (2012) recognise that there is no agreement within the research community regarding this issue, but nevertheless, recommend three things to ensure reliability in qualitative research:

- Use of quotes and examples to support themes
- Consistency of themes and quotes
- Transparency of the research process

This research will utilise quotes and examples to highlight the themes emerging from the interview data. The interview data symbolise a qualitative approach to the study, whereas, the survey results represent a quantitative approach. This means that a mixed-method approach will be used in this study. By using the mixed method approach, it will allow the survey results to complement and uphold the findings of the results from the interviews and literature as conducted in the creation of the proposed framework.

4.11 Research methodological process

This chapter discussed and justified the research methodology adopted to achieve the aim and objectives of the study. Accordingly, by summarising the steps used for the study, this section presents the research methodological process (Figure 4.10). The framework consists of three main phases as follows:

1. **Phase one**

   This phase starts with a critical review of literature regarding the various issues associated with this research. A wide-ranging literature review was conducted prior to establishing the aim of this research. This represents the first data input (Input 1) in this research, namely that collected via the literature review. The role of a client organisation in the BIM implementation process, BIM benefits, and BIM maturity models were examined. This literature review leads to formulating the research aim and objectives, and the research methodology required to achieve them; this is considered the first process step. Also, this phase includes the development of the initial conceptual framework that explains the relationship between the BIM maturity competencies and BIM uses benefits from the client perspective; this is considered the second process step.

2. **Phase two**

   This phase involves the first step in the framework validation process. It starts with the data input which includes all of the qualitative data that will be collected via the case studies. In addition, this phase includes the qualitative data analysis and discussion, which is considered a process step. This phase will aim to validate the proposed list of critical success BIM competencies and establish the relationship between client roles in the BIM implementation process with the maturity competencies.

3. **Phase three**

The final phase includes a questionnaire survey of BIM professionals in the UK construction sector. In this phase, the survey represents the input data step and signifies the quantitative part of this study that aims to find the statistical relationship between BIM maturity competencies and BIM uses benefits. In addition, this phase includes the quantitative data analysis and discussion, which is considered a process step. The phase also includes the development of the final version of the conceptual framework, which is considered an output step.

Figure 4.11 Research methodological process

4.12 Summary

This chapter explored the research methodology, justifying the choice of strategy and method adopted. These issues included the; research philosophy, research approach, research strategy, research choices, data collection techniques, testing/validation/evaluation, and so forth. In addition, it highlights the differentiation between research methodology and method. This chapter presented the methods adopted to ensure the validity and reliability of the research process. Both the methodology and the research strategy were outlined and appropriately justified in line with the literature. After selecting the appropriate research methodology, the reliability of the proposed framework will firstly be examined through a pilot study before embarking on collecting the target data. The next step is to formulate the initial conceptual framework, which will be explained in detail in the next chapter.

Chapter 5: Maturity-benefits relationship assessment framework

5.1 Introduction

Following the research methodology, this chapter discusses the steps taken to develop the proposed conceptual BIM maturity-benefits assessment framework. This chapter is structured into three main sections. The first will identify the importance of developing a conceptual framework in order to meet the research aim and objectives. The second section will discuss the key factors that have been defined within the literature in order to formulate a draft assessment framework that explains the relationship between BIM maturity competencies and BIM uses benefits. Finally, the chapter will provide a discussion on the opinions of two experts regarding the proposed framework, and produce the initial conceptual framework.

5.2 Importance of developing a framework

The research methodology emphasised the importance of conceptualising the phenomenon under investigation, or pre-establishing an initial theory prior to starting the data collection and analysis. In conceptualising the phenomenon, the main theories pertaining to the study, how they are organised, and the circumstances within which the theories and interrelationships are said to be true can be highlighted (Yin, 2003). When research aims to explain a particular planned or current relationship, the approach could be principally defined by two key concepts; namely, the framework and the model (Gartner, 1985; Greene et al., 1989). The framework provides the overall structure of the research, while the model explores the specific methodology (Gartner, 1985; Greene et al., 1989). A framework is used in research to give an overall picture of the possible courses of action, or to bring a preferred approach to a thought or idea (Yin, 2003). Eisenhardt (1991) introduces three main types of framework, namely 'theoretical', 'practical' and 'conceptual'. Eisenhart (1991) recommends that a 'practical framework' directs the research in *'what works in the experience or exercise of doing something by those directly involved in it.'* Miles and Huberman (1994) defined a conceptual framework as a visual or written product, one that, 'explains, either graphically or in narrative form, the main things to be studied the key factors, concepts, or variables and the presumed relationships among them.' More explicitly, a conceptual framework places emphasis on presenting the connectivity between all aspects of research. The interconnectedness, dependency and the structure concerning the problem, purpose, literature, methodology, data collection, analysis, resources, and functions are pictured using the framework of the research. A theoretical framework has been defined by Imenda (2014) as, '*refer[ing] to the theory that a researcher chooses to guide them in their research. Thus, a theoretical* *framework is the application of a theory or a set of concepts drawn from one and the same theory, to offer an explanation of an event, or shed some light on a particular phenomenon or research problem*.'

In comparison, a model typically involves a deliberate simplification of a phenomenon or a specific aspect of a phenomenon. Models can be described as theories with a more narrowly defined scope of explanation; a model is descriptive, whereas a theory is explanatory as well as descriptive (Nilsen, 2015). In a more abstract way, it can be understood as a theoretical construct that represents something using the set of variable quantities and the logical and quantitative relationships among them. In scientific research, these are crucial concepts and allow for investigation and reasoning regarding the phenomena described by the model. The model may idealise the situation within the given framework, by making assumptions to simplify, or remove the error included by natural variations within the system.

For this research, the conceptual framework has been adopted to represent the relationship between BIM maturity competencies and BIM uses benefits. It is based on the following:

1. The ability of the conceptual framework will move beyond descriptions of 'what' to explanations of 'why' and 'how', and this will provide an answer as to why clients need BIM maturity and how they can connect BIM maturity with their business.
2. The conceptual framework will focus on the relationship between the variables, and, for this research, the main aim is to find the relationship between BIM maturity competencies and BIM uses benefits.
3. Regarding a validated existing theory that may guide this research in that there is no defined relationship between BIM maturity competencies and BIM uses benefits in the previous research. Therefore, the conceptual framework will help to validate the proposed relationship.
4. It is impractical to describe the relationship between BIM maturity competencies and BIM benefits in a quantitative way only due to the subjective relationship between them. Therefore, conceptual framework provides the ability to understand the relationships far beyond the theoretical side.

For these reasons, the conceptual framework represents the most appropriate type of framework to explain the relationship between BIM maturity competencies and BIM uses benefits.

Accordingly, Figure 5.1 illustrates how the constituent parts (namely, the main concepts, their interrelationships, and the presence of a boundary) derived from theory were combined with expert opinion to develop the conceptual framework relating to this study.

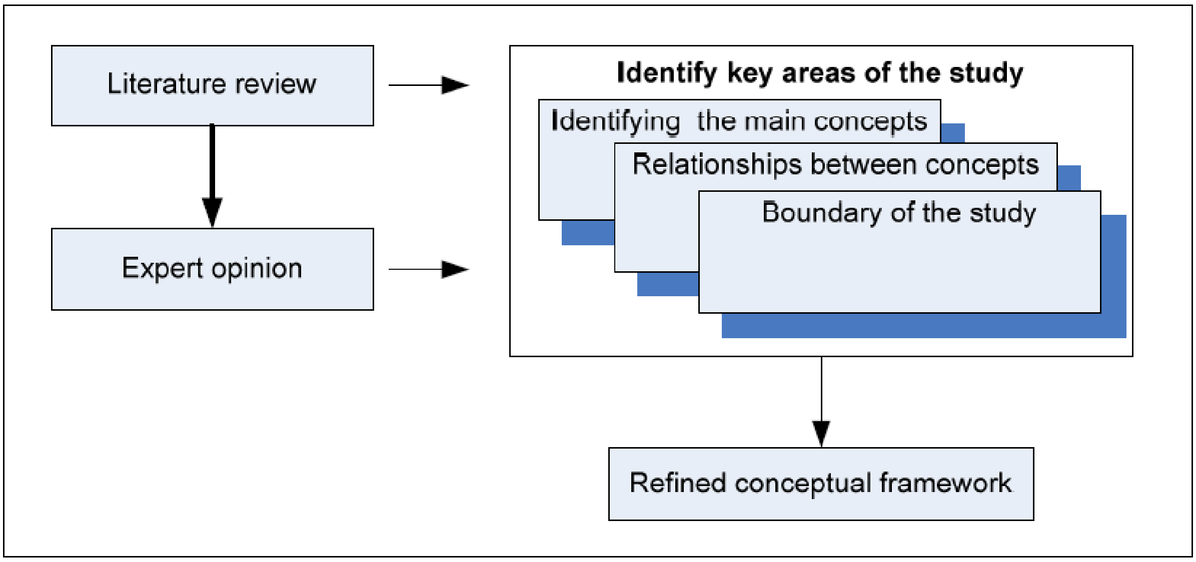


Figure 5.1 Development of the framework (U. Kulatunga, 2008b)

5.3 Initial l framework development steps

The development of the proposed conceptual framework consists of three main steps as follows:

1. Identifying BIM uses benefits and requirements (Literature)
2. Developing a proposed BIM maturity model (Literature)
3. Establish the initial relationship between BIM uses benefits and BIM maturity competencies by linking the identified BIM uses requirements with the BIM maturity competencies via understating the requirements and expect what are the competency (ies) can help to provide these requirements.

These steps are demtonstrated in Figure 5.2, and each step will be explained in further detail in the following sections.

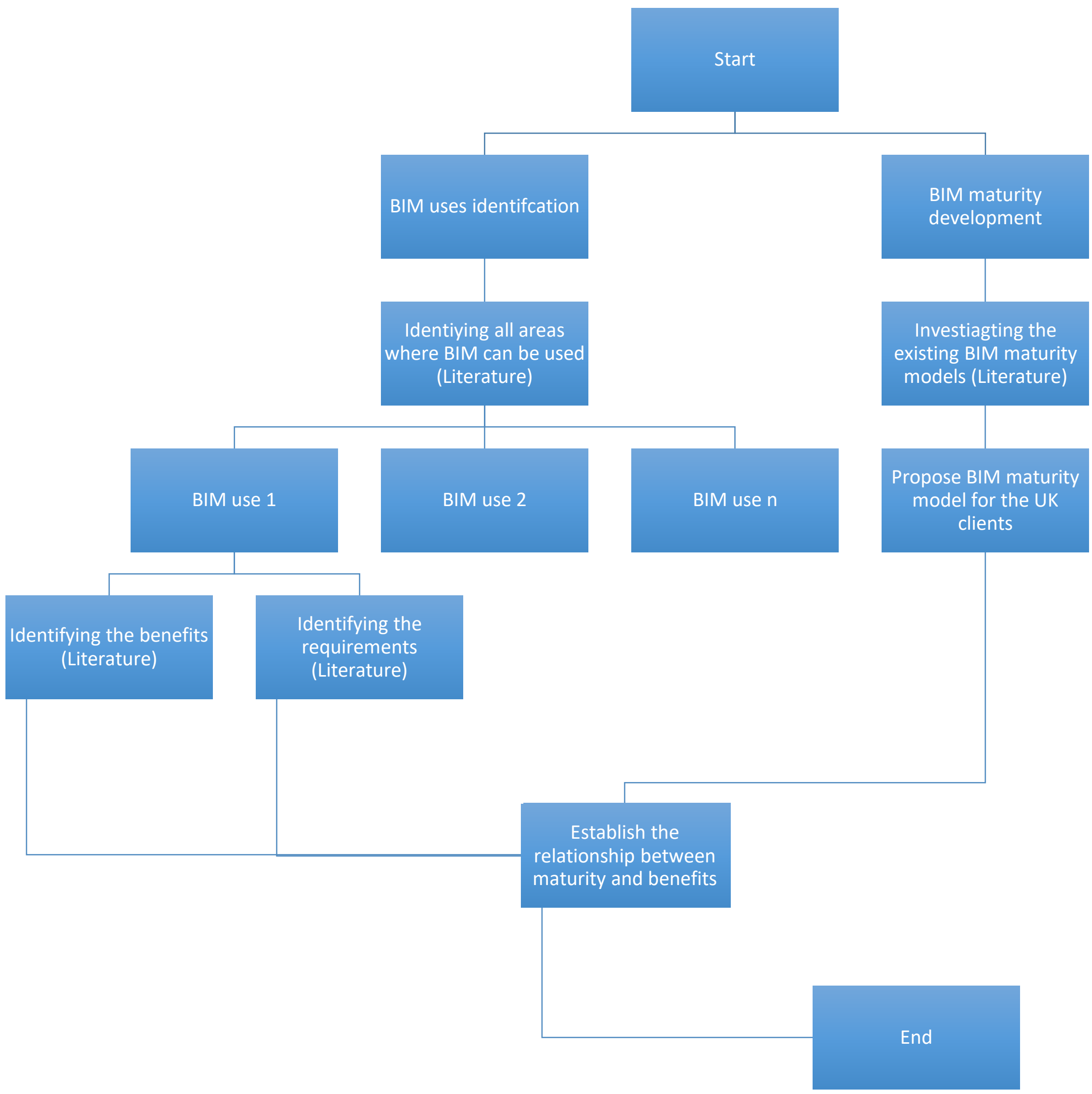


Figure 5.2: The draft initial BIM maturity-benefits framework development steps

5.3.1 BIM uses benefits and requirements (Step 1)

Haron (2013) states that the benefits of BIM support the clients' full understanding regarding the BIM implementation process; it does this by helping organisations address their action plan for BIM implementation in order to meet their needs. With BIM-based processes, clients can potentially realise a greater return on their investments as a result of the improved integrated design, construction, and operation process, which in turn, increases the value of project information in each phase and allows for greater efficiency within the project team.

Simultaneously, clients can reap dividends in a project's quality and cost, and the future operation of the asset (Eastman, 2011). Due to the considerable impact that BIM can potentially have on traditional construction project problems, like cost overrun, schedule delays, and quality issues (Jackson 2002; Eastman 2011), the client is in a position to benefit most from its use.

Selecting areas where BIM should be used in order to achieve the desired benefits represents a challenging task for the client organisation. The task requires knowledge regarding each BIM use and an understanding of the client requirements in order to use BIM in certain areas. The BIM uses benefits and requirements have been identified through the literature review and discussed in Chapter 2. The client's ability to provide the essential requirements in order to implement BIM is directly affected by the existence of BIM competencies inside the client's organisation, and the degree of excellence in BIM that clients have already developed (Ashworth et al., 2016b; Wing et al., 2015). This can be considered as the key element in order to establish the proposed relationship between BIM maturity competencies and BIM uses benefits because understanding these requirements will help to identify which BIM maturity competency (ies) can support client to provide these requirements. Therefore, before establishing the proposed relationship it is important to identify the BIM maturity competencies.

5.3.2 BIM maturity competencies (Step 2)

As discussed in Chapter 3, the terms competency and maturity have been used previously to manage and assess different types of innovation in the construction industry, and these terms can be used to assess the implementation of BIM across the UK construction industry. In addition, several models have been used to assess different types of BIM user such client, designer, and contractor organisations to evaluate the BIM implementation developments. However, it was determined that only a few models can be used to assess client organisations in particular. From the critical review of the literature presented in Chapter 3, it was concluded that the Succar (2009) and CIC (2012) models have the potential to assess client organisations in the UK. Based on these models, 19 competencies have been selected to represent a client's proficiency in their BIM implementation (Table 5.1), which were defined and discussed in Chapter 3.

Table 5.1: The essential client BIM competencies defined from the literature

No	Competency	Description
1	Organisation Mission	A mission is a fundamental purpose for the existence of an organisation. Goals are specific aims that the organisation wishes to accomplish.
2	BIM Vision	A vision is a picture of what an organisation is striving to become. Objectives are specific tasks or steps that when accomplished move the organisation toward their goals.
3	BIM Champion	A BIM Champion is a person who is technically skilled and motivated to guide an organisation to improve their processes by pushing adoption, managing resistance to change, and ensuring the implementation of BIM.
4	Data Sharing	This competence defines the client ability to share a different type of information among their stakeholders.
5	Management Support	To what level does management support the BIM planning process.
6	BIM Committee	The BIM Planning Committee is responsible for developing the BIM strategy of the organisation.
7	Standards	BIM Standards define all project delivery, legal issues, and risk mitigation.
8	Organisation Hierarchy	An arrangement of personnel and groups into functional groups within the organisation.
9	Training	The training is to teach so as to make fit, qualified, or proficient in a specific task or process.
10	Education	Education is to formally instruct about a subject.
11	Role and responsibilities	Roles are the primary function assumed by a person within the organisation and responsibilities are the tasks or obligations that one is required to do as part of that role.
12	Change readiness	The willingness and stated preparedness of an organisation to integrate BIM.
13	BIM Skills	BIM skills that client should pay attention to in order to best utilise it.
14	Software	The programs and other operating information used by a computer to implement BIM.
15	Hardware	Physical interconnections and devices required to store and execute (or run) BIM software.
16	Physical space	Functional areas within a facility used to properly implement BIM within the organisation.
17	Network	Solutions, deliverables and security/ access control.
18	BIM Execution Plan	This document lays out how BIM will be implemented on the project as a result of the decision of the group.
19	Quality Assurance system	This system issued to inspect the model system by system noting any omissions, mistakes, or areas for improvement. Also, comparing and benchmarking BIM deliverables.

5.3.3 The relationship between BIM maturity and BIM uses benefits (Step 3)

Gomes et al. (2013) claims that, by integrating both benefits and maturity model assessment approaches, it will be possible to increase the effectiveness of strategic projects and improve the confidence of business sponsors that their investment in projects will return business benefits. A higher level of maturity is achieved when client organisations assess their capabilities and benchmark their performance against standards and competitors Graham et al. (2014). Knowing beforehand the impact that process maturity has on the organisation's performance is essential when focusing on the elimination of internal resistance to change, whilst taking advantage of the favourable factors that positively influence organisational maturity (Urban, 2015).

The real benefit of BIM cannot, therefore, be realised at a low level of maturity or at the 'lonely BIM' stage due to the lack of coordination and collaboration with other BIM users (Sackey et al., 2013). While this research seeks to identify the relationship between BIM benefits and maturity, there are two key challenges that need to be addressed to establish this relationship, namely; how to connect BIM maturity competencies with BIM uses benefits, and how to address BIM maturity improvement effects on BIM benefits achievement.

5.3.3.1 Connecting BIM maturity competencies with BIM uses benefits.

The connection is proposed by finding the relationship between BIM uses requirements and the BIM maturity competencies; both were identified through literature review. At this stage of the framework development, this relationship is established by understanding the requirements and identifying which competency(ies) can help a client to provide these requirements. For instance, one of the common requirements that clients need to meet when using BIM in some areas is to use staff with the ability to demonstrate both BIM and walk through models to validate their outcomes. It is proposed that meeting this requirement will have a significant connection with some maturity competencies, such as BIM skills, training, and technology competencies. Furthermore, improving these competencies will help the client to provide the aforementioned requirements. Based on this proposition, all BIM uses requirements have been connected with the related BIM maturity competencies.

With regard to this proposed connection, the BIM uses have relationships with particular BIM maturity competencies. Consequently, improving these competencies will increase a client's chance of achieving the desired benefit of using BIM in a particular area. For instance, Table 5.2 shows the proposed connection between the requirements and maturity competencies for using BIM in existing condition modelling. In addition, it reveals the relationship between maturity competencies and BIM uses benefits as a result of the proposed connection. The same procedure will be followed to establish the relationship between all BIM uses benefits and BIM maturity competencies .

Table 5.2: The relationship for the Existing Condition Modelling BIM use

No	BIM Uses	BIM Uses Requirements	BIM Maturity Competencies	BIM Uses Benefits
1	Existing condition modelling	1. Staff are able to manipulate, navigate, and review a 3D model. 2. Familiarity with Building Information Model authoring tools. 3. Familiarity with 3D laser scanning tools. 4. Familiarity with conventional surveying tools and equipment. 5. Ability to determine what is the optimum level of detail that may add 'value' to the project. 6. Ability to select the appropriate software to create the site linked BIM model.	1. BIM skills 2. Training 3. Standards 4. BIM champion 5. BIM Vision 6. Software 7. Hardware 8. Quality assurance system	1. Increase the efficiency and accuracy of existing conditions, documentation and representation. 2. Help in future modelling and 3D design coordination. 3. Provide an accurate representation and visualisation of work that has been put into place. 4. Real-time quantity verification for accounting cost estimation purposes. 5. Disaster Planning. 6. Time Saving Utility Design.

5.3.3.2 Effects of BIM maturity development on BIM uses benefits achievement

Identifying the level maturity development effects on the achievement of BIM uses benefits requires the classification of BIM benefits into levels that reflect their maturity development without such classification it will difficult to evaluate the relationship. As explained in Chapter 3, maturity levels have been classified into five main levels, i.e. initial, defined, managed, integrated, and optimised. The following aims to determine suitable benefit classification criteria that reflect the level of maturity development.

(Bradley, 2010) states that benefit classification, according to a variety of criteria, will increase understanding of the nature of the benefits, aid analysis, and improve communication.

Therefore, different types of benefit classification methods have been presented that have been adopted by various client organisations. Table 5.3 summarises these classification methods with a brief description for each. In addition, each will be evaluated to check its suitability to classify BIM benefits for this research. It can be seen that the different types of classification can be based on stakeholder, category, business type, sigma type, and changing type. This research aims to identify the relationship between benefits and maturity; therefore, each type will be evaluated to determine its suitability for use in this research.

Table 5.3: Benefit classification summary (Bradley, 2010)

No	Classification Name	Description
1	By stakeholder	One widely used approach classifies benefits and dis-benefits according to the stakeholder, who will feel or experience their impacts. As this research just focuses on the client organisation, this type of classification is not applicable.
2	By category	Categorising benefits into groups, which are relatively independent of one another, can be useful for aiding benefit identification, facilitating the analysis of a large number of benefits, and consolidating them. This type of benefits classification seems beyond the aim and objectives of this study.
3	By business impact	Classifying benefits by business impact is helpful when checking strategy alignment and balance, and when comparing the relative significance of benefits. This type of benefits classification seems beyond the aim and objectives of this study.
4	By Sigma Value type	Classifying benefits into three main levels, logical, expected, and definite, according to beneficial knowledge and experiences. Connecting benefits with knowledge and experience, and reflecting the capability of the organisation could be useful in identifying the relationship between BIM maturity competencies and BIM benefits.
5	By changing Type	Classifying benefits depends on the required change, such as, for example, doing new things, stopping doing existing things, and doing existing things a bit better. This type of benefits classification seems beyond the aim and objectives of this study.

As mentioned previously, this research seeks a benefit classification that could reflect maturity development. Therefore, classifying benefits according to a SIGMA value type which is able Connecting benefits with knowledge and experience, and reflecting the capability of the organisation seems to be the most suitable method to achieve the research aim to find the relationship between BIM maturity competencies and BIM uses benefits. This type of classification has three levels, which describe the level of benefits assurance in terms of users' knowledge and experiences, as explained below:

1. **Definite Benefits**: the benefit has an accurately predictable base on a high level of competence and experience; this benefit is unlikely to be affected by external changes.
2. **Expected Benefits**: the benefit can be predicted based on trends or experience elsewhere. The degree of confidence is less as this benefit could be affected by external changes; sometimes a probability rating may be attached to the value.
3. **Logical Benefits:** logical benefits are appropriate for certain applications, but there are no data or experiences on which to base a realistic prediction. This should be used as a measure to monitor improvements.

This research will adopt the above benefit classification to explain the relationship between BIM benefits assurance and maturity development levels. Therefore, in order to express the relationship between maturity and benefits, the traditional maturity levels have been amended to include benefit levels. For example, the traditional Initial maturity level means that organisations have limited level of competencies development which mean in benefits level that client organisations don have unable to predict BIM benefits which may be limited to design stage only. Improving client organisations maturity will improve their ability to predict benefits which was expressed in the new proposed maturity labels. These suggested labels are defined as follows:

1. **Not exist**: BIM competency does not exist in the client organisation in any format. For example, if a BIM champion, as one of BIM competencies, is located in the 'not exist' level, there is no role called BIM champion in the client organisation.
2. **Expected Design Benefits, Logical Construction Benefits, Logical In-Use Benefits:** Any competency located on this level will help the client to realise benefits from BIM, but only during the design stage and without any ability to extend their expectations to the construction and in-use stages. This level reflects a limited maturity level in terms of BIM competencies.
3. **Definite Design Benefits, Expected Construction Benefits, Logical In-Use Benefits:** Reflects good improvement(s) in BIM maturity competencies whereby the client has developed enough knowledge to accurately expect benefits from BIM during the design stage, and which can extend to the construction stage. However, a client

organisation at this level still has limited ability to expect any benefits from BIM during the in-use stage.

4. **Definite Design Benefits, Definite Construction Benefits, Expected In-Use Benefits:** Reflects a very good improvement(s) in BIM maturity competencies whereby the client has enough knowledge and experience to accurately expect benefits from BIM in the stages of design and construction, which can also extend to the in-use stage.
5. **Definite Design Benefits, Definite Construction Benefits, Definite In-Use Benefits:** A high level of BIM competencies that reflects deep BIM knowledge and wide BIM experiences, and supports the client organisation to accurately expect benefits from BIM at any stage through the asset life cycle.

By successfully addressing the two main challenges, which are the connection between BIM maturity competencies and BIM uses benefits and the effects of maturity development on the benefits assurance, the relationship between BIM maturity competencies and BIM uses benefits are able to be established. Figure 5.3 depicts the conceptual framework that has been developed from the findings from the literature review. The core of the framework represents the assessment relationship between BIM maturity competencies and BIM uses benefits. From the Figure, it can be seen that this relationship starts by identifying the area where BIM can be used to produce certain benefits, then by defining the requirements that clients need to provide to use BIM effectively, then by establishing the connection between requirements and competencies which consequently lead to a relationship between BIM maturity competencies and the corresponding benefits.

Thereafter, the conceptual framework was drafted by incorporating the aforementioned key areas, which was followed by two expert interviews being carried out to further refine it. The opinions of the experts regarding the subject area under consideration for this study and on the drafted conceptual framework are discussed below.

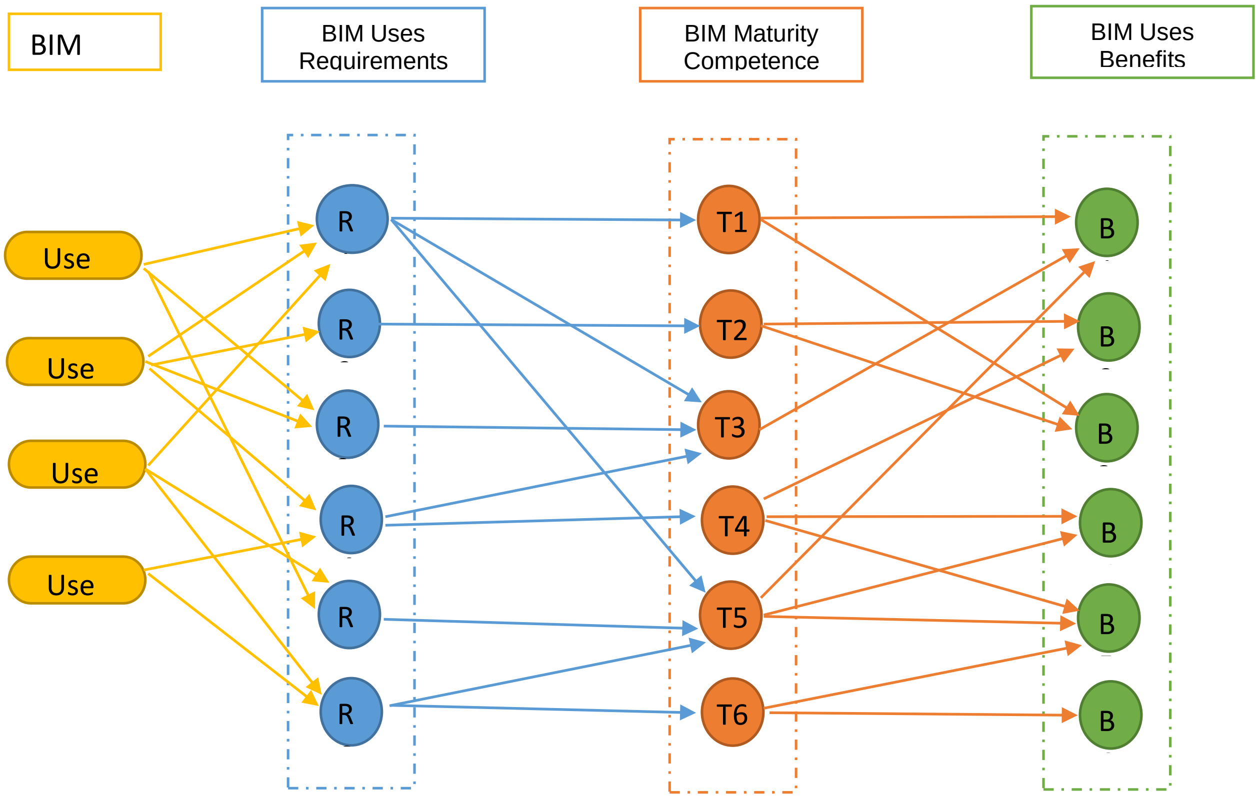


Figure 5.3: The initial framework for the research

5.4 Pilot study (Experts' opinions)

Pilot studies assist in the development of research before carrying out the full study, but they can be concentrated more specifically on certain research concerns and theories. Similar concerns arise for both illustrative quantitative study pilots as those for qualitative research, namely that, '*many features of their design could not be determined without prior exploratory research*' (Richard et al., 2009). In addition, they argued that no design is so perfect that it cannot be improved by a prior, small-scale exploratory study; thus, pilot studies are usually worth the time and effort. Furthermore, a pilot study must be carried out if any feature of the research design needs clarification (Yin, 2003). This section discusses the data that was gathered from the client organisation, called organisation P. It starts by providing the background of the organisation, which is followed by the feedback on the initial conceptual framework.

5.4.1 Organisation P background

Organisation P. is a national government body responsible for most aspects of the transport system; in particular, it is accountable for implementing the transport strategy and for managing transport services. Organisation P. defined BIM as, '*a process involving the* *collaborative production, use and management of digital representations of the physical and functional characteristics of a facility / asset.'* In addition, it considered that the resulting information models, when fully coordinated, support decision-making about a facility or asset throughout its lifecycle from the earliest conceptual stages, through to design and construction, operation and maintenance, and eventually decommissioning and demolition. Information Modelling & Management (IM&M) is a term used by organisation P. to describe what the industry has invented BIM for, and has used it to focus on not only the production and utilisation but also, more importantly, on the management of data and information. The list of the interviewees and their backgrounds are presented in Table 5.4.

Table 5.4: Pilot study interviewees for organisation P

Name	Background	Area of Expertise	Current role	Experience(years)
CP1	Civil Engineering	Design and Development Management	BIM consultant	18
CP2	Computer Networks Technology	Information system management	BIM consultant	11

5.4.2 Initial conceptual framework feedback

This section discusses feedback from organisation P. on the conceptual framework. The framework was sent firstly via e-mail to the participants with a brief description that highlighted its importance and purpose. Two weeks later, the two participants met at their organisation's head office to discuss their comments, and this discussion was mainly divided into three sessions. The first discussed the proposed maturity model and lasted for one hour. The second session focused on the benefits assurance matrix and the link between benefits and maturity; this took a further hour.

5.4.2.1 Proposed maturity model

Several comments were made by participants, CP1 and CP2, on the proposed maturity model; firstly, there is a significant change between level one (Not Exist) and level two (Expected Design Benefits, Logical Construction Benefits, Logical In-Use Benefits), which could be reduced by adding an additional maturity development step. Both participants suggested that the missing level could be, 'improving maturity for a certain purpose as necessary', which is traditionally called an ad-hoc, or initial, level. Secondly, both participants suggested that the current labels/titles of the maturity levels are inapplicable due to several reasons, as follows:

1. The proposed labels/titles of the maturity levels suggest that a client must have a certain maturity level in order to begin to gain benefits from the in-use stage. However, this does not really reflect the actual client's situation where they can achieve some benefits during the in-use stage, even at a low-level maturity.
2. To understand the proposed labels/titles of the maturity levels, the client must have considerable knowledge about BIM, which is currently missing among UK construction clients. Therefore, the proposed labels/titles will add unnecessary confusion amongst clients about the BIM maturity model.

Both interviewees, therefore, suggested retaining the traditional BIM maturity level labels/titles, such as those adopted by the project management maturity model, which have been used for a long time across the UK construction industry. The proposed maturity level titles were accordingly changed to new titles in line with the traditional maturity models, which are well known by the UK client organisations. The comparison between the labels/titles is presented in Table 5.5.

Table 5.5: A comparison between the initial and final maturity levels' titles

Maturity levels	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Initial Description	None	Not exist	Expected Design Benefits Logical Constructio n Benefits Logical In-Use Benefits	Definite Design Benefits Expected Constructio n Benefits Logical In-Use Benefits	Definite Design Benefits Definite Construction Benefits Expected In-Use Benefits	Definite Design Benefits Definite Construction Benefits Definite In-Use Benefits
Final Description	Not exist	Initial	Defined	Managed	Integrated	Defined

The participants also suggested replacing and adding new competencies that may affect the implementation of BIM within the client organisation. They agreed to replace the BIM Execution Plan (BEP) with the Organisation Information Requirements (OIR). This was because the BEP is provided by project stakeholders and reflects the need to respond to a client's requirements, while the OIR is the main competency that the client must have in order to facilitate the implementation of BIM. In addition, both participants agreed to add 'Validation Process' as one of the main competencies that the client must have in order to verify the information that comes from the stakeholders, and ensure that it meets the client's BIM requirements. The final representation of the BIM maturity competencies and their definition against each maturity level is presented in Appendix C.

5.4.2.2 The benefit assurance levels

Furthermore, both participants also suggested that the assurance labels needed amending to reflect the changes proposed for the maturity levels. The main reason behind for this was to use these proposed levels to assess the client organisations for benefits assurance whilst aligning with the maturity assessment. This would help to validate the proposed relationship between maturity competencies and BIM uses benefits via a correlation analysis because both assessment results will be range from 1 to 5. As the BIM maturity assessment results show competency developments in terms of levels one to five, the benefits assurance level should similarly span from one to five in order to statically validate the relationship. In addition, this new classification would give more flexibility to identify the actual level of benefits assurance if the participants found himself between logical and expected level. Based on this rationale, both participants suggested adding intermediate levels between the main levels such level 2 and 4. Therefore, five levels have been proposed to reflect the BIM benefits assurance levels and their alignment with the maturity levels (Table 5.6). These five levels of benefits assurance reflect the client's ability to predict the desired benefits of BIM, which depend mainly on the knowledge and experiences of the client organisation. This knowledge and experience could be represented by the development of BIM maturity competencies.

Table 5.6: The final benefits assurance levels' definitions

Final levels	Logical 1	2	Expected 3	4	Definite 5
Description	Logical benefit for certain applications, but there are no data or experience on which to base a realistic prediction. It should be measured to monitor the improvement.	There is an improvement in the ability to predict benefits due to the improvement in knowledge and experiences. However, there is still difficulty in maintaining this ability which is usually fluctuating.	The benefit that can be predicted are based on trends or experience elsewhere. The degree of confidence is less as this benefit could be affected by external changes; sometimes a probability rating may be attached to the value.	Significant improvement in the ability to predict benefits. However, some limitation in knowledge and experiences prevent the prediction from reaching a high level of accuracy.	The benefit has an accurately predictable base on a high level of competence and experience; this benefit is unlikely to be affected by external changes.

5.5 Proposed conceptual maturity-benefits relationship assessment framework

As outlined previously, in response to the feedback elicited from the pilot study, several amendments were made to the main elements of the initial conceptual framework such as maturity competencies, maturity levels and benefits assurance level. These main changes were in the maturity and benefits assurance level descriptions. The proposed conceptual framework contains the following four main elements and the connections between them (Figure 5.4) whereby (as discussed above) the relationships start with BIM uses and end with BIM benefits:

1. ***BIM uses*****:** 21 areas were identified through a critical review of the literature regarding where BIM can be used to realise benefits to the client organisation.
2. ***BIM uses requirements*****:** the essential requirements that the client organisation must provide in order to use BIM in certain areas. All these requirements and their connection with BIM uses; identified through the literature.
3. ***BIM maturity competencies*****:** 19 competencies have been acknowledged via the literature and experts' opinions, along with five maturity levels, which start with initial and move through identified, managed, and integrated, to finally optimised. The connection between BIM uses requirements and BIM maturity competencies have been established based on requirements details and which competency(ies) can support clients in providing such requirements. For instance, some requirements have one connection with certain competencies, such as the connection between the 'providing BIM software' requirement and the 'software' competency. Other requirements have a connection with more than one BIM maturity competency, such as the connection between the 'staff ability to use BIM model' with the 'BIM skills', 'training', 'education', and 'technology' competencies. All the proposed BIM maturity competencies will be validated by qualitative data collection and analysis which will be presented in Chapter 6.
4. ***BIM maturity competencies relationship with BIM uses benefits*****:** The proposed connections between BIM uses benefits and BIM maturity competencies have been identified using the connection between requirements and competencies. For instance, using BIM in the '*Cost Estimate*' area required BIM vision, role and responsibilities, and data sharing; the corresponding benefits from using BIM in cost estimate have a direct connection with the same competencies. These connections will be validated quantitative data collection and analysis which will be presented in Chapter seven within the final explanation.

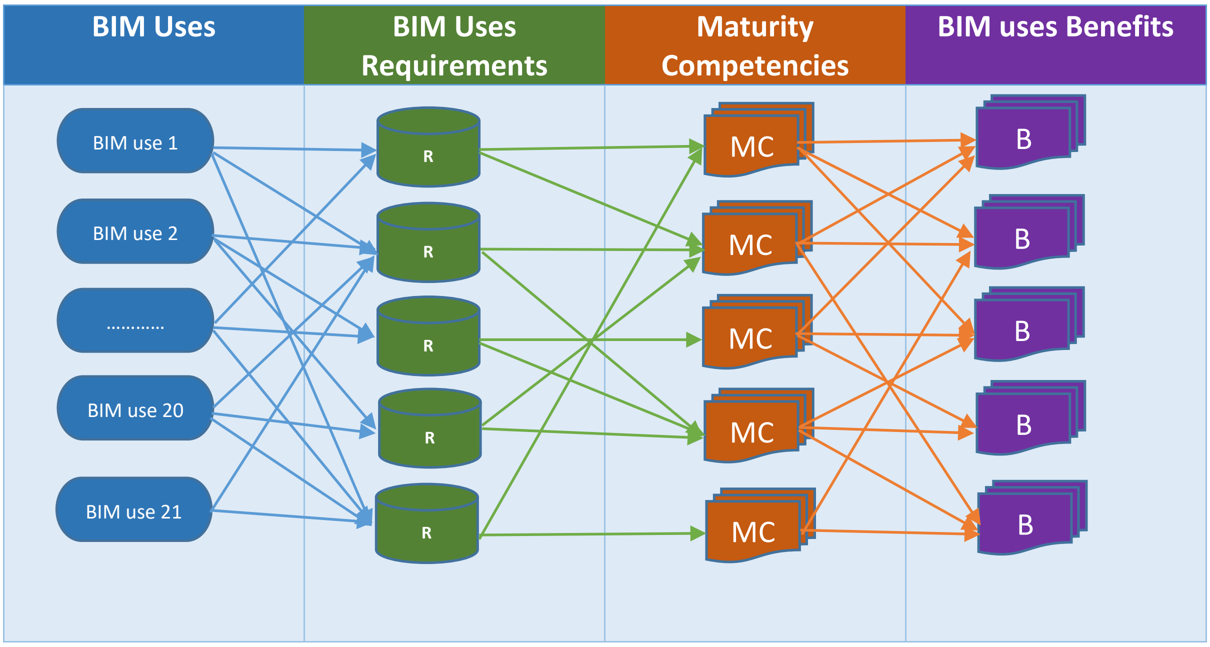


Figure 5.4: BIM maturity-benefits relationship assessment framework

5.6 Summary

This chapter discussed the development of the proposed conceptual maturity-benefits relationship assessment framework by identifying the main concepts, their relationships and the boundary of the subject area under consideration. The components of the conceptual framework were elicited from a critical review of the literature and were further supported and defined by expert opinion. The proposed conceptual framework illustrated the relationship between BIM maturity competencies and BIM uses benefits. Furthermore, this framework denotes the main areas, such as BIM maturity, BIM benefits, and the relationship between them, which will be empirically investigated during the case studies for deeper understanding and validation. Having developed the proposed conceptual framework, the next chapter presents the first part of the validation process via qualitative data collection and analysis.

Chapter 6: Qualitative Data Analysis

6.1 Introduction

The previous chapter presented the development of a conceptual framework to explain the relationship between BIM maturity competencies and BIM uses benefits. This chapter discusses the process of validating the conceptual framework, which this is based on qualitative data analysis. The objectives of the qualitative analysis are validating that the importance of BIM benefits to client organisations as one of the motivational factors to implement BIM, identify the required BIM competencies that UK construction clients need enable them to fulfil their role of developing their EIR, validating the BIM model outcomes, and leading a BIM implementation process and compared it with the proposed list of competencies, Establish the level of BIM maturity awareness among UK construction clients, and Explore the maturity-benefits relationship among UK clients and investigate the relationship between the current maturity levels of client organisations with the levels of BIM benefits assurance.

6.2 Data collection procedure

The framework proposed for this research aims to enable client organisations to implement BIM effectively by clarifying the relationship between BIM maturity competencies and BIM uses benefits. The initial conceptual framework for this research was developed based on the findings from the critical review of literature and the opinions of two experts (presented in the previous chapter). As discussed in Chapter 4, the first step of the validation for this conceptual framework was conducted via semi-structure interviews with six case studies reflecting different types of client organisations. 15 BIM experts have participated from these case study client organisations to elicit information related to BIM implementation in their organisations. Before outlining the interview questions, these questions must reflect the following factors:

1. Ensure that the questions are understandable to the interviewees, and have a clear, unambiguous meaning.
2. Ensure that the questions will gather all the necessary data required to validate the proposed framework.
3. Ensure that the questions are sequenced in order to elicit the right information.
4. Ensure to avoid leading questions.

The final interview questions, and their aims, are represented in Table 6.1. The questions sequence starts with why the client has implemented BIM, and then moves to gather information about client roles, ending with some questions related to BIM maturity and benefits.

Table 6.1: The final interview questions with explaining each question's aim

NO	Question	Aim
1	Why does your organisation decide to implement BIM?	To investigate the current motivation factors that help the client to implement BIM and whether these factors vary with particular client types.
2	Do you think clients have to lead BIM implementation process?	To explore the degree of client role understanding among UK clients.
3	What do you think the client leadership criteria is?	To investigate the client leadership criteria and whether these criteria vary with different client types.
4	In term of competencies, what do you think of your organisation as a client the required competencies that support you to develop a strong EIR?	To identify the required BIM competencies that help the client to develop their EIR and whether these competencies vary with different client types.
5	In-term on competencies what do you think the required competencies that your organisation as a client must have to be able to validate the information that comes from your supply chain?	To identify the required BIM competencies that help the client to validate the outcomes and whether these competencies vary with differing client types.
6	Did you have ever use BIM maturity model to assess your organisation?	To explore current BIM maturity understanding and check if any model has been used and for what reason.
7	Did you think there is a relationship between BIM maturity and BIM EIR? How?	To investigate BIM maturity-EIR relationship awareness among client organisations.
8	Did you think there is a relationship between BIM maturity and BIM benefits? How?	To investigate the BIM maturity-benefits relationship awareness among client organisations. Also, to check whether the benefits motivate the client to improve their maturity in BIM or determine if they have different view.
9	What is your organisation current BIM uses? Why you choose use BIM in this particular area?	To explore current BIM uses and the criteria that client follows to select BIM uses.
10	What are the benefits your organisation looking for to achieve via using BIM?	To compare the desired benefits with BIM uses.
11	Please can answer our proposed BIM maturity evaluation model?	To test the model and check if it really represents the current BIM implementation situation within client organisations
12	Is it possible to have different versions of your EIR?	To use the EIR as the second source of data to improve validation process quality. Also, to investigate the effects of the maturity results on the EIR quality.

6.3 Data analysis procedure

This section provides a general view regarding the data analysis procedure of the explanatory stage and is based on the data collected through semi-structured interviews and the EIR documents; the latter are treated as secondary data. The NVIVO 11 program has been used to facilitate the analysis procedure and techniques, which have been discussed in detail in Chapter 4. Figure 6.1 presents the coding structure that has been implemented to collect and analyse verbatim transcripts from the interviews. Figure 6.2 shows the qualitative data analysis procedure, which starts with collecting and analysing data for each case study and is followed by a cross-sectional analysis into the five main areas; this will be discussed in detail later in this chapter.

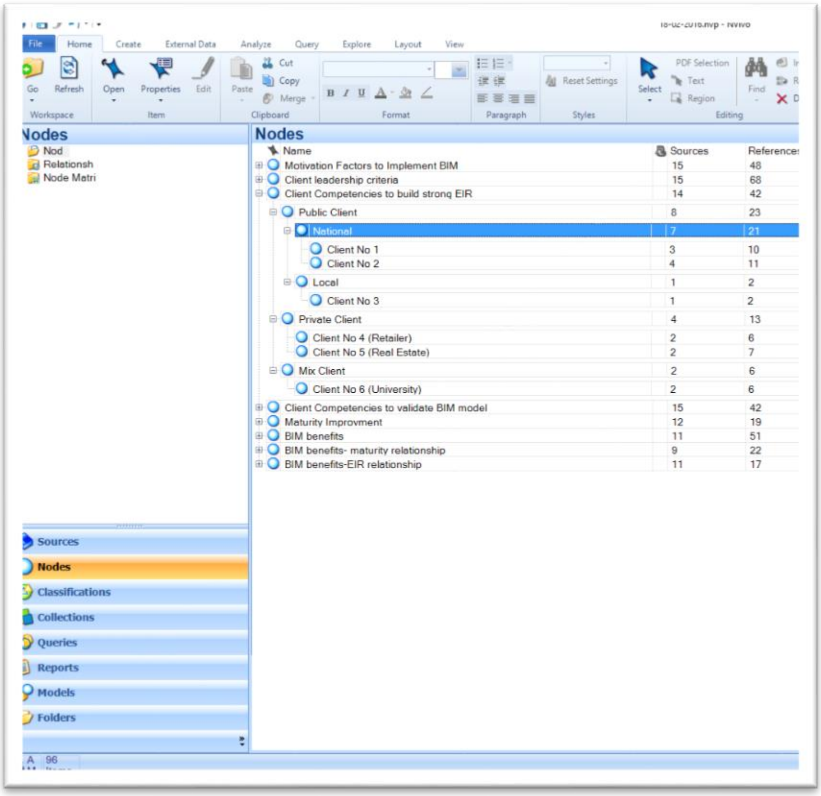


Figure 6.1: Themes structure from NVIVO program

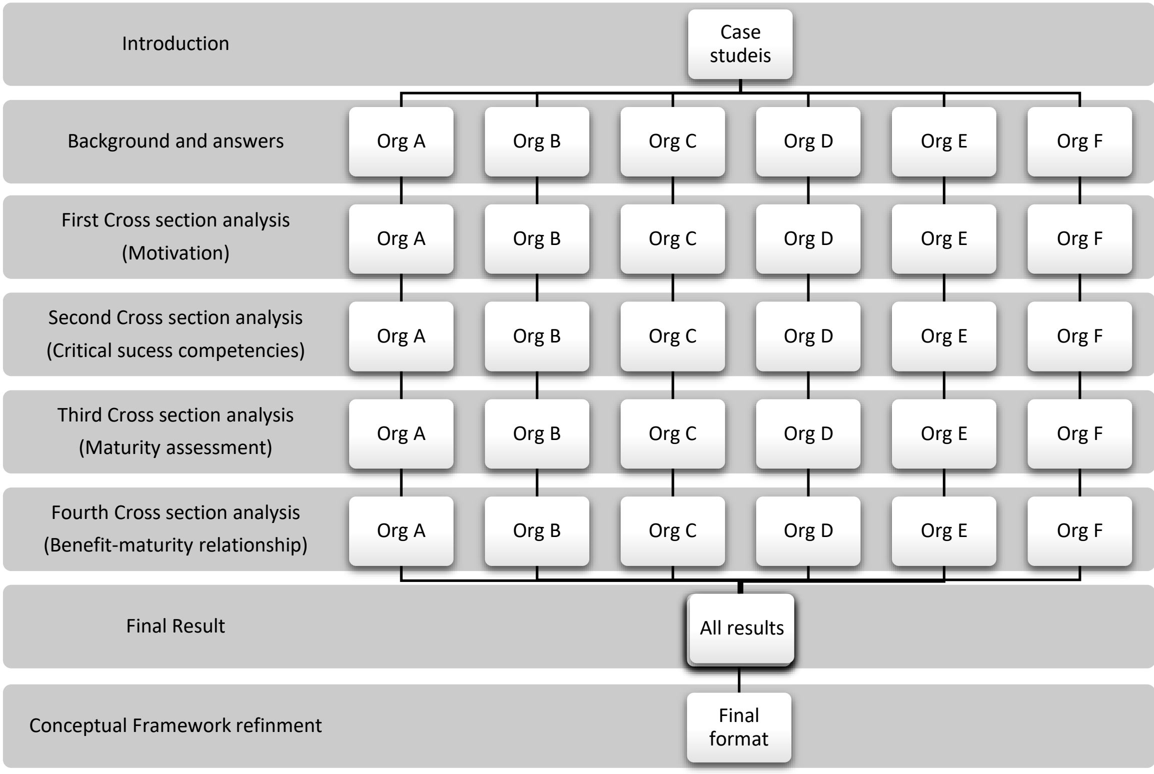


Figure 6.2: Qualitative analysis procedure

In each of the case studies, the first part discusses the background and current level of BIM implementation in order to understand its context. The second part focuses on the identification and discussion of the main elements of BIM implementation within the client organisation. These were identified in the literature review, and are as follows:

a) Motivation Factors:

   Identifying the main motivation factors that attract a client organisation to implement BIM. Understanding these factors will help the researcher to explore current client understanding regarding BIM implementation and the corresponding benefits.

b) Critical competencies for BIM implementation within the client organisation to lead the BIM implementation process, develop their BIM requirements, and validate the BIM model outcomes. Identifying these competencies will help the researcher to validate the proposed ones, which have been identified from the literature.

c) BIM maturity.

Explore current client understanding and usage regarding different types of BIM maturity assessment methods. In addition, assess client organisation against the proposed BIM maturity model to establish an understating of the BIM implementation levels inside the organisation in terms of their weaknesses and strengths.

d) BIM uses and benefits.

Explore the current client's BIM uses and the desired benefits of BIM. In addition, the current BIM benefits assurance level by using the proposed level to understand the current BIM benefit within the organisation will be assessed. From the maturity and benefits assessments, the research will be able to explore the relationship between these elements for the client organisation.

In the third and final part of the case studies, the EIR documents will be investigated in terms of the developments in the ability to display clients' needs and make sure it will be met. In addition, each document will be examined in detail to determine the weaknesses and strengths and to compare them with the maturity assessment results. This will help to validate the connection between clients' maturity development and their ability to express their needs through the EIR

A cross-sectional analysis was conducted between case studies at four levels, as described below (Figure 6.3):

1. A motivation cross analysis has been conducted to investigate the importance of benefits as a motivation factor for client organisations to implement BIM. The results will help to validate that BIM benefits are crucial for all client organisations.
2. A cross analysis has been conducted on the critical success competencies; this aims to investigate the different types of BIM competencies that are required by client organisations in order to develop their requirements, validate BIM models, and lead a BIM implementation process. This also enabled the researcher to compare the BIM competencies identified from the literature with those proposed by the interviewees.

3. The third cross analysis explored the awareness and usage of BIM maturity models among the client organisations.

4. The final cross analysis investigated the BIM maturity-benefits relationship among UK construction clients.

After completing the qualitative data analysis, the refinement of the conceptual framework is presented which was enabled through a series of semi-structured interviews.

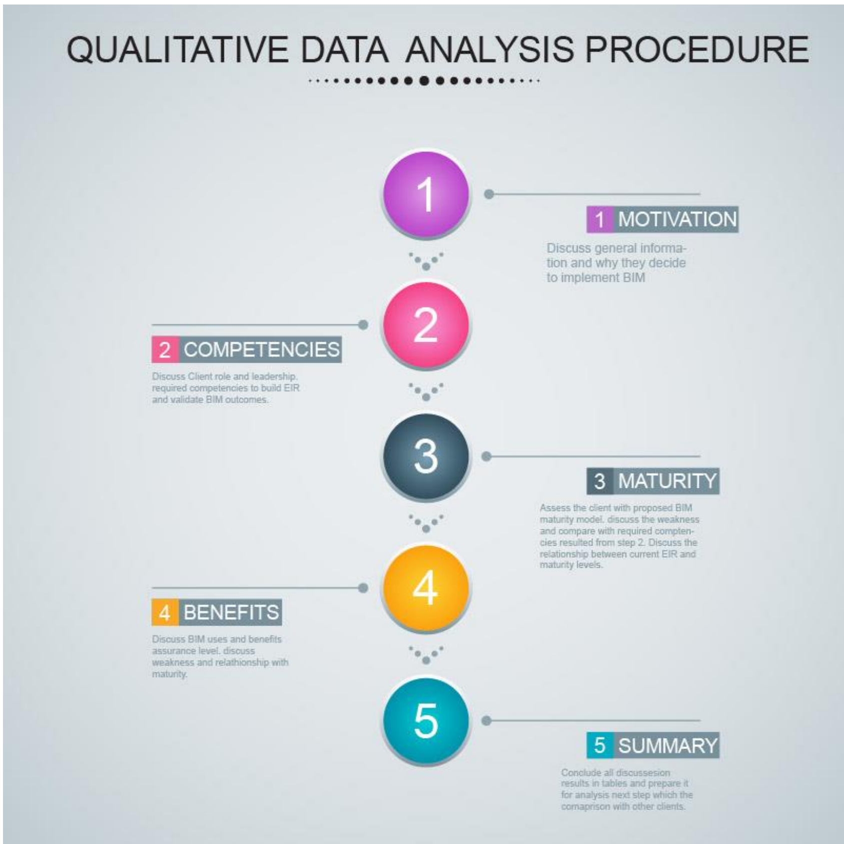


Figure 6.3: BIM implementation main elements for the client organisation

6.4 Case study findings for client organisation A

This section discusses the data that was collected from client organisation A. It starts by providing the background of the organisation, which is followed by a presentation of the data collected via interviews and documents. These data were analysed and discussed in detail according to the category to which they belong.

6.4.1 Client organisation A: Background

Client organisation A is a public government client, which is mandated to follow the Government Construction Strategy to implement BIM Level 2 by 2016. Within organisation A, the BIM process has introduced information for a library of standard components and associated COBie data that will be used on future projects. It has simplified and informed the decision-making process, and provided a single central resource for essential data for use throughout the entire asset lifecycle. The data and model outcomes will be used to produce an optimal asset performance, which will enable the organisation to explore and closely monitor their asset usage, for example, how the systems are operating, and when and why they need maintaining. Organisation A considered that the real value of implementing BIM is in modelling for better user outcomes with the ability to feed these data back to inform future projects. The list of the interviewees and their backgrounds is presented in Table 6.2 below. The interviewees have different levels of experience and work in different roles; this improves the interviews' data richness in term of range of information and level of detail.

Table 6.2: Interviewees for organisation A

Name	Background	Area of Expertise	Current role	Experience(years)
CS1-1	Environmental Engineer	Principal Project Sponsor	BIM champion	30
CS1-2	Project Management	Facility management	Technical Standards	16
CS1-3	Architectural Technology	Building Construction Technology	BIM Support Officer	13

6.4.2 Data analysis and findings

In this section, the responses to the questions were combined to reflect the themes and codes emerging from the data analysis about each particular issue. The titles for the following subsections under which the results of the interviews are analysed and discussed are as follows; the main motivation factors, the critical success competencies, BIM maturity, and BIM benefits.

6.4.2.1 The main motivation of using BIM

Interviewees CS1-1, CS1-2 and CS1-3 concur that organisation A has been using BIM in their projects since 2011 and that the main driver is the UK Government mandate for the adoption of Level 2 BIM on all centrally public procured projects by 2016. This organisation barely knew the meaning of BIM and its impact on their projects and did not have any idea how to apply it within the organisation. However, when they started to use BIM on their projects, they realised that this type of approach has the potential to produce significant benefits throughout all life cycle stages of their projects. As CS1-2 comments:

"[…] *ultimately, it comes from a government mandate, we were pushed by the government to be BIM level 2 by 2016 [...]. So, following this strategy we started to implement BIM without knowing the potential of it. But, when we started to define and understand BIM for us, we found huge benefits can help us* […]. CS1-2"

It can be concluded that client organisation A prioritised their motivation factor as the Government BIM mandate; this was the main reason to implement BIM in the first place which is understandable as organisation A's business falls within the public sector, which is guided by UK Government Strategy. Moreover, they added BIM benefits as the second motivation factor, which they realised after using BIM; this motivated them to implement it in other projects. Considering BIM benefits as one of the motivation factors can reflect a good level of BIM understanding within organisation A because they are not just following the Government mandate but they realise that BIM can improve their business significantly.

6.4.2.2 Critical success competencies for BIM implementation

Under the main theme of critical success competencies for BIM implementation, three sub-themes emerged, which were: client BIM leadership, developing BIM employer information requirements, and data validation:

1- **Client BIM leadership**

All interviewees believe that the client needs to lead the BIM implementation process and this is based on two main reasons. The first is that the client has the required authority to push their supply chain to implement BIM in their processes, which will optimise the BIM benefits for the client (as well as for the supply chain). In addition, the client develops the requirements in the early stages of the project and will receive the outcomes at the end of project completion; therefore, the client has to lead this process. Indeed, CS1-3 comments that:

"If the client does not define the BIM process so the individual players will not be in-line and they will find it hard to collaborate with each other. Also, they will do self BIM which will not add value to the industry. CS1-3"

While each interviewee identified several criteria to evaluate a client's ability to lead BIM implementation processes, such as BIM knowledge, AIR, data sharing methods, and standards, the most frequently cited criterion was that clients have to know what type of information they need, when they need it, and in what format. In addition, they identified several competencies that support a client with leading a BIM implementation process, such as asset information requirements, data sharing methods, and standards. This view was explained by CS1-3:

"They need to explain when and where they need information, at what stage of the project they need to exchange the information and in what format and what that information is. […]. The client needs to ask questions themselves first for what they are doing and why they are doing it." [CS1-3]

2. Developing BIM employer information requirements

All interviewees stated that the EIR is important to document and has a strong relationship with the benefits of BIM. In addition, all interviewees discussed different types of competencies that may help clients develop their EIR. These competencies include data security, data sharing, standards, BIM vision, training, and physical space. This was outlined by CS1-3:

"Generally, we apply British standards but we use our standards in the issue related to data protection and security issues. We established a good office to manage BIM implementation in our project. In addition, we trained our staff on new BIM British standards." [CS1-3]

It can be concluded that organisation A improving their BIM understanding via training and produce a secure environment where data can be structured and shared will support them to produce an EIR that can reflect their need effectively. In addition, a good BIM vision can also provide a significant support for any required changes.

3. Data validation

Client organisation A uses external technical assessors to validate the information received from their supply chain. They understood that they are now in the middle of a learning process and do not currently have all the requirements to validate this information. Nevertheless, they already know what they want to improve in the validation process; this suggests that they have a good BIM vision but still need improvements in other competencies, such as management support and standards. All interviewees proposed several competencies that may support the client to validate the BIM model outcomes, such as BIM skills, data sharing, data protection, BIM champion, BIM technology, and validation processes. Indeed, CS1-3 argues:

"You need technical competencies. You need to develop software in order to validate the in- coming data because some of the COBIE received has millions of lines. So you

need to automate the data validation process and that required investment in the right technology and process and understanding. Also, you need to have people with BIM skills and BIM standards. CS1-3"

From the analysis, several competencies were identified that a client must have in order to develop their EIR; validate the BIM outcomes and ensure that they are capable of leading the BIM implementation process throughout the project life cycle. Table 6.3 represents these competencies for organisation A.

Table 6.3: Critical success competencies for organisation A

Client role	Required Competencies
Develop EIR	• Standards • Data Protection and security • Physical space • Training • Data Sharing method • BIM Vision
Validate BIM model outcomes	• BIM Skills • Data sharing method • Standards • BIM technology • Data protection • Information manager • Validation Process
Client leadership	• Asset information requirements • Data Sharing • Standards

Organisation A identified different competencies regarding each role. Developing their EIR needs BIM vision to guide BIM uses in the project lifecycle and to guide questions in the EIR in order to reflect the organisational needs. This response suggests that organisation A has a good understanding about BIM and the effect of BIM vision on their requirements. In addition, they add standards, training, data sharing, physical space, and data protection as the essential competencies that the client must have to develop their EIR. Selecting these competencies also means that this organisation has a good level of BIM understanding because if the client wants to start to develop their EIR they need standards to follow and data sharing to ensure the team are fully involved in this process. Also, training is an essential competency that helps staff to become familiar with a new process, such as BIM because it will increase the level of knowledge and understanding among the organisation. However, organisation A also added new competencies to enable them to validate the BIM model outcomes. These include BIM skills, BIM technology, BIM validation, and a BIM champion. This indicates that organisation A has a good understanding of the validation process and what they need in order to validate the information from their supply chain because they aware that these competencies will help them to go through BIM model and check the outcome information.

For client leadership, organisation A added organisation information requirement as a new competency that enables them to lead the BIM implementation process. Selecting one new competency suggests there is a lack of understanding about BIM leadership within the organisation, and this may be because organisation A is in the early stages of their BIM implementation. In addition, it is found that organisation A selects the same competencies for different roles, such as standards and data sharing methods. This suggests that they believe that being more mature in these competencies will enable them to move from just developing their EIR to validating the information. Furthermore, greater maturity in these competencies will enable them to lead the BIM implementation process. This emphasises the importance of the maturity level for these competencies and its effects on client abilities in BIM.

6.4.2.3 BIM maturity

Under the main theme of BIM maturity, the following four sub-themes were elicited: the EIR-maturity relationship, maturity improvement, maturity assessment, and the maturity level:

1. **EIR-maturity relationship**

   The interviewees understand that their BIM requirements evolved with their organisation's maturity development. This seems obvious when comparing the first version of the BIM requirements with current versions because there are significant improvements in the current EIR which reflects the improvements in the BIM maturity competencies; CS1-2 comments that:

"Our understanding has developed since we started to implements BIM in our processes. So we can now develop our requirements with enough detail to make sure that we will get our desired benefits. CS1-2"

It can be concluded that organisation A understands that improving their BIM maturity will help them to improve their EIR. However, the absence of a BIM maturity model could present a barrier to them in managing BIM as an organisational change, in that they may lack a formal guide them to plan and implement improvements in terms of BIM uses effectiveness.

2. **The maturity improvement**

   The interviewees believe that they need: to improve their maturity to fully understand BIM; to improve their ability to ask the right questions from their supply chain; and to improve their ability to validate the received information. Therefore, it can be concluded that the interviewees understand the importance of maturity and they seek to improve it. CS1-1 argues:

   "We need to improve our maturity so we can lead the implementation process and are able to make sure that our supply chain will create a BIM model for our purpose only. In addition, improving our maturity will help us to speak a common language with our stakeholders." [CS1-1]

   It can be seen that organisation A emphasises that maturity improvements will help them fulfil their roles as clients in developing the requirements and validating the deliverables. Therefore, developing such a BIM maturity assessment model has significant importance to client organisations.

3. **Maturity assessment**

   All interviewees believe that they do not assess their organisation against any maturity assessment model. The main reason is that they are only aware of the UK wage BIM maturity model that is essentially used to assess project BIM maturity but not that of an organisation. The absence of such a model could encourage the organisation to focus only on the project, rather than the organisation, as illustrated by CS1-1:

   "We are the pilot for the government to gain BIM level 2 by 2016. In addition, we have a review now by a BIM task group on our process and how we meet the Level 2 BIM." [CS1-1]

4. **The maturity level**

   All interviewees indicated that they do not assess their organisation against any organisational maturity model and, in addition, they do not have any particular level of maturity that they are aiming to reach. They only perceive Level 2 BIM as the target for their project to achieve, as CS1-2 states:

“We have to follow the government mandate to reach BIM Level 2 by 2016.” [CS1-2]

Thus, organisation A has not heard of the term organisation BIM maturity and instead focuses on BIM level 2 assessment to evaluate their work progress and future improvements. The absence of such a maturity model could prevent a client organisation from improving the competencies that will enable them to fulfil their role as a client organisation.

Organisation A has been assessed against the proposed BIM maturity model and the results are presented in Table 6.4. In general, for most competencies, they are between level 3 and 4, which indicate a good level of maturity; however, the OIR, organisation hierarchy, and physical space are the exceptions, which are at a low level of maturity. The red competencies in the assessment table refer to those that organisation A could not recognise as success factors in the BIM implementation process.

The absence of an organisation maturity model could hinder organisation A from managing improvements in their competencies; it could also impede them from exploring other competencies that may affect their BIM implementation. For these reasons, it can be suggested that improving maturity for some competencies and not for others is guided by personal views and limited BIM experiences. Therefore, providing an organisational BIM maturity model may help the client organisation explore other competencies that they have not considered but that may affect their BIM implementation. This could also help the client to monitor their BIM maturity development and invest in the right competencies rather than waste time and cost in developing competencies that may not further improve their BIM results.

Table 6.4: Organisation A maturity assessment results

Maturity Elements	Not Exist	Level 1	Level 2	Level 3	Level 4	Level 5
Organisation Mission						
BIM Vision						
BIM Champion						
Management Support						
Data Sharing						
Standards						
Organisation Hierarchy						
BIM Committee						
Training						
Education						
Role and responsibilities						
Change readiness						
BIM Skills						
OIR						
Validation Process						
Quality assurance system						
Software						
Hardware						
Physical space						
Network						

6.4.2.4 BIM benefits

Four sub-themes are identified under BIM benefits, and these are: the benefits-EIR relationship, the benefits-maturity relationship, benefits assurance, and desired benefits:

1. **The benefits-EIR relationship**

All interviewees believe that there is a strong relationship between the EIR and the desired benefits. This relationship comes from defining client requirements in the proper way to ensure that the supply chain understands and delivers what the client wants. As CS2-1 states:

"[…] EIR essentially and BIM British standards are helping the client to gather his benefits." [CS1-1]

Believing that the EIR is essential to achieve the desired BIM benefits came as a result of developing both good BIM knowledge, and understanding of the organisation. This suggests that improving knowledge and understanding, or in other words BIM maturity, will help the client to identify the critical success factors that support them to gather the benefits through the EIR.

2. **The benefits-maturity relationship**

Most interviewees believe, in theory, in the relationship between BIM maturity competencies and BIM uses benefits, but they do not have sufficient evidence to prove it, as they tend not to fully implement BIM across the whole project lifecycle. However, the interviewees understand that, without sufficient maturity, it will not be possible for them to realise and optimise the benefits of BIM. This could indicate that client organisation A is still in the early stages of BIM implementation, without enough case studies to compare and evaluate their improvements against BIM benefits achievements. This highlighted the potential importance of the BIM maturity assessment model to a client organisation in that it could help them to make improvements that will support them to achieve the desired benefits of BIM. This was illustrated by CS1-3:

"Yes, you need to improve your systems to realise your asset. If we look project by project we will not get any benefits, but if we look to it at how we will manage data information and understand the standards this will increase your knowledge which allows you to get benefits. We understand that we need to improve our BIM maturity to improve BIM benefits." [CS1-3]

3. **Benefits assurance**

The interviewees understand that they are on a learning curve but that they are in a good position now which helps them to predict some BIM benefits and increase benefits assurance, as stated by CS1-1:

"However, we are not seeing the benefits yet because we are on learning curves now. Nevertheless, we are now in a good position we know what we want which definitely will increase the benefits assurance" [CS1-1]

Due to the improvements in BIM knowledge that the organisation A has achieved through their BIM implementation journey, they are seeing significant improvements in their ability to predict what the expected benefits when using BIM in some certain areas.

4. The desired benefits

All interviewees discussed different types of benefit, such as reduced cost and time, improved quality, better design coordination and improved asset management. Identifying these types of benefits can be considered a reflection of good BIM understanding within the organisation A, especially if the benefits relate to the operation and maintenance stage, such as improved asset management. This was outlined by CS1-1:

"Improve Quality, improve Asset Management and reduce cost and time." [CS1-1]

A benefits assessment has been carried out on organisation A in order to compare the current benefits assurance level with the maturity assessment results (Table 6.5). It can be concluded that organisation A currently suffers from an inability to predict some BIM uses benefits, which mainly places their assurance level between 1 and 2. As illustrated, organisation A shows limited improvement in some competencies, which indicate that this lack of improvement has a direct effect on organisation A's prediction of some BIM uses benefits. In the same context, a good improvement in some maturity competencies enhances organisation A's ability to predict other BIM uses benefits. This may give a positive impression of the relationship between BIM maturity competencies and BIM uses benefits.

Table 6.5 Benefits assessment results for organisation A

Current BIM uses	Benefit	Level 1 (Logical)	Level 2	Level 3 (Expected)	Level 4	Level 5(Definite)
Design Review	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
Record Modelling	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
Asset maintenance scheduling	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
Asset system analysis	Benefit 1					
	Benefit 2					
	Benefit 3					
Asset management	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					

6.4.2.5 Document analysis

As emphasised previously, the EIR is an important document that can reflect the client's BIM understanding and signify much more about their BIM maturity. This document includes several items that can reflect the client's maturity; for example, current client standards, collaboration extents, software and hardware specifications, role and responsibilities, data drop specifications, the Level of Detail (LOD), and so forth.

Two versions of the EIR have been collected from organisation A. The first represents their BIM requirements at the early stage of their BIM implementation and the second, their current BIM requirements. Before analysing these documents, it will be useful to display the current BIM uses in organisation A to explore the purpose and extent to which BIM has been used within the project lifecycle stages (Table 6.6), and investigate the relationship between their current BIM uses and the client requirements. Organisation A is using BIM at different stages with more used for the in-use stages; this reflects a good level of BIM knowledge and understanding because they realise that the BIM can produce significant benefits in operation and maintenance stage for client organisation.

Table 6.6: BIM uses in organisation A

No	BIM use	Stage
1	Design review	Design stage
2	Record modelling	Hand over stage
3	Asset management	In-use stage
4	Maintenance scheduling	In-use stage
5	Asset system analysis	In-use stage

Early stage BIM requirements

This document represents the first BIM requirements sent to all the supply chains. The document contained ten sections and each section deals with a different aspect; this is presented in Table 6.7. Organisation A focuses on just ten areas where the requirements are mostly generic and not as detailed as required. This lack of detail could reflect a basic understanding of BIM within the organisation because they are unable to be specific in the information they request which mean they leave it to their supply chain to decide. The organisation used this format as it is based on the British Standards and does not contain any changes to reflect their needs. This could be due to a lack of BIM knowledge and understanding within organisation A.

Table 6.7: The early stage BIM requirements sections details

No	BIM requirements	Description
1	Standards	What is the BIM standard to be used for the project?
2	Software Platforms	BIM and other software platforms to be utilised.
3	Stakeholders Roles & Responsibilities	Identifies project leadership and additional team members / stakeholders and their roles and responsibilities.
4	Project Deliverables/BIM Models/Project Characteristics	Defines the project deliverable and the format in which it is delivered and exchanged.
5	Stage 6 Change Process	Defines exchange of data for TA change order checking.
6	Coordinates	Defines the common coordinate system for all BIM data.
7	Planning the Work & Data Segregation	Addressing such issues as work set and linked file organisation to enable multi-discipline, multi-user access and project phasing as well as ownership of project BIM data.
8	Security	Specific organisation security issues are defined here.
9	Level of Detail	Defines the level of detail for the models and objects for each stage of the project.
10	H&S/CDM(M)	The designer shall indicate any residual Risk(s) as an attribute of the particular element/component/area within the BIM model(s).

Current BIM requirements

There are significant improvements in the current version of the BIM requirements, which reflects the development of the organisation's understanding and BIM maturity. The requirements start with a clear definition of the projects and the project delivery process. These two components reflect the organisation's BIM vision and answer the main questions, namely; why is BIM being used on this project, when should be used, where and what are the expected benefits from using it. The rest of the BIM requirements explain the deliverables for each stage of the project lifecycle and list some of the questions that need to be answered by the supply chain at the end of each stage; this leads to the production of a BIM model that can meet clients' needs. These detailed requirements reflect significant improvements in the organisation’s maturity due to their ability to express their needs in greater depth and with richer detail. However, the requirements asked that all information must be received with identical specifications for BIM Level 2; this was due to the client’s commitment to meeting the UK BIM strategy target, but meant they did not evaluate whether the deliverable would be beneficial to them.

All information is required in the COBIE-2012 format, which highlights some weaknesses in the organisation in that it is just focusing on delivering projects to the Level 2 BIM format without considering the desired benefits for the organisation. The absence of clear organisation information requirements, as presented in the maturity assessment results, will limit the client requirements to just project needs, rather than considering the organisation as a whole. A low level in organisation BIM skills can also be seen in the requirements, as it depends on an external Technical Assessor (TA). Depending on an external TA could be beneficial at this stage of a BIM implementation, but the organisation should develop and embed these skills in-house where the organisation’s mission can be reflected in their BIM vision. Their training and education competencies are at a good level of maturity, which reflects the organisation’s plan to improve the BIM skills of their employees.

6.5 Case study findings for client organisation B

This section discusses the data that was collected from client organisation B. It starts by providing the background of the organisation, which is followed by the data collected from the interviews and documents. These will be analysed and discussed in detail according to the relevant category.

6.5.1 Client organisation B background

Client organisation B is also a public government client, which is following the UK Government Strategy to implement BIM Level 2 by 2016. Organisation B’s workforce receives substantial amounts of information that come from projects across the UK. BIM technology and process is used to reform this information and make it usable in future projects. BIM features help the organisation to reduce the efforts needed to initiate each project and create a useful information template that can be used in all projects. In addition, the organisation seeks to reduce cost and time, and increase quality through the use of BIM in their projects. The list of interviewees and their backgrounds has been presented in Table 6.8. It can be seen from the Table that the interviewees have different levels of experience and work in different roles; as before, this can help to improve the interviews' data richness in terms of information and level of detail.

Table 6.8 List of the interviewees for organisation B

Name	Background	Area of Expertise	Current role	Experience(years)
CS2-1	Project Management	Environment awareness	BIM and GSL Programme Manager	24
CS2-2	Industrial Engineer	Maintenance Manager	Regional MEICA Engineer	20
CS2-3	Environmental Conservation	Climate Change and Sustainable Development,	Senior Project Manager	17
CS2-4	Water management	Environment awareness	Flood and Coastal Risk Management Advisor	15

6.5.2 Data analysis and findings

In this section, the responses to the questions were combined to reflect the themes and codes emerging from the data analysis about each particular issue. The sub-heading titles are; the main motivation factors, the critical success competencies, BIM maturity, and BIM benefits and under these sections the results of the interviews are analysed and discussed.

6.5.2.1 The main motivation of using BIM

All the interviewees from organisation B provided the same answers; namely that there are two motivations to implement BIM in their projects. Firstly, they are a Government client, and as such are following the UK Government mandate for the adoption of Level 2 BIM on all centrally public procured projects by 2016. Secondly, they are using BIM because they are aware that BIM can produce a wide range of benefits throughout the project life cycle.

Furthermore, due to the organisation's history of using IT in construction projects, they predict that BIM, through supporting information management, can produce benefits for their project before they even start using it. As CS2-4 comments:

> *"Couple of reasons, the first one is to meet the government strategy to be BIM level 2 by 2016 and the second reason is we recognised the wide BIM benefits on the project lifecycle management, [...]CS2-4"*

Client organisation B ranked their motivation factors and the first motivation that pushes them to implement BIM in their project is the Government BIM mandate. As a national

Government public client they have to follow government strategy, and in particular the BIM mandate. However, BIM benefits are a secondary motivation to expand BIM implementation inside their organisation and encourage staff use. The same situation in organisation A can be seen here where considering BIM benefits as one of the motivation factors can reflect good level of BIM understanding among organisation A

6.5.2.2 Critical success competencies for BIM implementation

Under this main theme are three sub themes, namely client BIM leadership, developing BIM Employer Information Requirements (EIR), and data validation:

1. **Client BIM leadership**

   The interviewees believe that the client needs to lead the BIM implementation process for two reasons. The first is that the client can normalise the business process with his supply chain and unify the requirements form, which leads to reduced efforts and time and cost savings. The second reason is that, within the organisation, leadership will help the client optimise their BIM benefits. In addition, one of the Interviewees believe that, while the client sends the requirements, they must lead this process to ensure that the supply chain meets these requirements and delivers the desired benefits. This was demonstrated by CS2-3:

   "The client needs to lead the implementation process because as we are sending the requirements it is better to be led by ourselves than one of the supply chain. Also, we are the only person who can say what we need and explain how we need it. CS2-3"

   Each interviewee proposed several criteria to evaluate a client's ability to lead a BIM implementation process. However, the most frequently cited criteria are that the client has to know how to implement BIM in the structured activities for commercial and operational business inside the organisation. Also, they have to understand BIM and the required standards needed for use in their projects. In addition, the responders highlight that the client needs certain competencies that will enable them to lead BIM implementation processes, such as BIM skills, BIM technology, asset information requirements, data sharing, standards, and quality assurance system. This was indicated by CS2-3:

   "[…] needs to understand the BIM in the first place. Also, he needs a clear structure of how BIM can work in the organisation. We need to understand what we want to achieve

in the project by using BIM in it. Also, we need a clear understanding of BIM maturity levels and the available standards like Cobie. CS2-3"

2. Developing BIM Employer Information Requirements (EIR)

All interviewees believe that the EIR is an important documents and without a good EIR it is impossible to achieve the desired BIM benefits. The interviewees proposed several competencies that may help a client organisation to develop an EIR, which leads to the desired benefits. These competencies are standards, data sharing, BIM skills, and BIM vision. As suggested by CS2-1 and CS2-4:

"[…] The EIR must reflect the entire organisation requirements, not just a certain project. CS2-1"

"[…] Need BIM competence and clear BIM vision and BIM understanding. Also, you need technical expertise to support the process. Also, we can you the available standards which will help you to develop your own requirements. CS2-4"

3. Data validation

The interviewees understand that the clients need to know the expected deliverables so they will be able to compare and validate them. In addition, they believe that they need to set up common data environments that may enable them to automate the validation process. Furthermore, they understand that they need the right competencies, including BIM skills, standards, data sharing, BIM technology, data protection, validation process, BIM champion, and role and responsibilities, in order to be able to validate such information. As confirmed by CS2-2:

"You need to keep reviewing your requirements with your stakeholders throughout all project life cycle stages. They client needs to keep an open dialogue with his stakeholders to reduce the changes. Also, the client staff must have some BIM competencies like tools standards so they need to be familiar with what they will receive from their stakeholders. CS2-2"

According to the interviewees' answers, a number of BIM competencies have been identified which reflect the abilities that a client must have to develop their EIR as the first step in a BIM implementation process. Moreover, they differentiated the competencies that enable the client to validate the BIM outcomes and those that make the client capable of leading a BIM implementation process throughout the project lifecycle. Table 6.9 represents these competencies for organisation B.

Table 6.9 Critical success competencies for organisation B

Client role	Required Competencies
Develop EIR	• Standards • Data Sharing method • BIM Vision • BIM skills
Validate BIM model outcomes	• BIM Skills • Data sharing method • Standards • BIM technology • Data protection • Role and responsibilities • BIM champion • Validation Process
Client leadership	• BIM Skills • BIM technology • Asset information requirements • Data Sharing • Standards • Quality assurance

From Table 6.9, organisation B selects several competencies; some are particular to certain roles while others are appropriate for all client roles. Organisation B observed that developing an EIR needs BIM vision to direct BIM uses in a project lifecycle and to support the development of questions in an EIR that reflect an organisation's objectives. In addition, interviewees added standards, BIM skills, and data sharing as required competencies that a client must have to develop a BIM EIR. Selecting these competencies reflects good BIM understanding within organisation B because standards and BIM skills will be useful to request the information format and data sharing also crucial to share the information and increase the level of client requirements understanding among client supply chain.

From the same table, it can be concluded that organisation B added new competencies that focus on ability to validate BIM model outcomes. These competencies include a BIM champion, BIM technology, BIM validation, role and responsibilities, and data protection. These additions emphasise that organisation B has a good awareness of the validation process and what is needed to validate the information that comes from their supply chain.

For client leadership, organisation B adds organisation information requirements and a quality assurance system as further competencies that enable them to lead a BIM implementation process. Selecting these two new competencies means that there is considerable awareness of BIM leadership understanding inside the organisation. In addition, it can be seen that organisation B selects same competencies for different roles, such as standards, data sharing methods, and BIM skills, which means that they believe that to be more mature in these competencies it is necessary to move from just developing an EIR to validating the information. In addition, greater maturity in these competencies will enable them to lead a BIM implementation process. This emphasises the importance of the maturity level for these competencies and its impacts on client abilities in BIM.

6.5.2.3 BIM maturity

Under the theme of BIM maturity, the following four sub-themes were elicited, namely: the EIR-maturity relationship, maturity improvement, maturity assessment, and the maturity level:

1. **The EIR-maturity relationship**

   The interviewees understand that their BIM requirements must be unified across the organisation and reflect the client's understanding of their needs including what, when, and where they will be using the received data. It can be concluded that organisation B understand that improving their BIM maturity will help them to improve their EIR. However, the absence of such a model could hinder the management of BIM as a substantial organisational change and impact on their ability to effectively plan and implement improvements in terms of BIM uses effectiveness. This was indicated by CS2-1:

   "The client needs to fully understand what are his requirements and how he wants the data we will be providing to him. Also, he needs to know what the end uses of the

system are and how he will reuse the stored data. Again he needs to know exactly what he wants so he will be able to set good enough requirements. CS2-1"

2. **The maturity improvement**

The interviewees understand that they need to improve their organisational BIM maturity to understand the technological changes and be able to choose the best for their system. Also, they indicate that improving maturity will reduce the gap between the client and their supply chain so they can speak the same language. These responses helped the researcher to conclude that the interviewees understand the importance of maturity and that they seek to improve it. As CS2-1, CS2-2, and CS2-3 commented:

"I think the client needs to improve his maturity because of the changes in the technologies so the client can understand and choose what is best for them. CS2-1"

"The client needs to improve his maturity so he can speak the same language with his stakeholders and be able to send the right requirements to them. CS2-2"

"Good maturity will help you to fully understand the expectations from using BIM in your project, for example, the benefits of using 4D or 5D models. CS2-3"

It can be seen that organisation B perceives that maturity improvements will help them reduce the knowledge and understanding gap within their supply chain. Therefore, developing such a BIM maturity assessment model has significance to client organisations.

3. **Maturity assessment**

As explained in the first case study, it can be recognised that the same responses for this sub-theme appear here. All Interviewees agreed that they do not evaluate their organisation by any maturity assessment model. The main reason is that they cannot identify any model except the UK wage BIM maturity model that is essentially used to assess project BIM maturity and not that of an organisation. As previously indicated, the absence of such a model will encourage the organisation to focus only on the project rather than on the organisation. This was demonstrated by CS2-1:

"I am not aware of any BIM maturity models. Only we use the triangular maturity models to assess our maturity. CS2-1"

4. **The maturity level**

As all Interviewees do not assess their organisation against any organisational maturity model, they do not have any particular level that they are aiming to reach. They only included BIM Level 2 as the target for their project to achieve due to the Government's mandate. This was indicated by CS2-3:

"I think we are mandated to achieve BIM level 2. We need to prepare ourselves as an organisation before we start to develop a project with BIM level 2 otherwise we will not get all the benefits from it. We are now using cobie and 1192-2-3 standards in developing our requirements. CS2-3"

According to the interviewees, organisation B appears not to have heard of the term organisation BIM maturity and instead just focuses on the BIM level 2 assessment to evaluate their work progress and future improvements. The absence of a maturity model could prevent such an organisation from improving the competencies that will enable them to fulfill their role as a client.

Organisation B has been assessed against the proposed BIM maturity model, and Table 6.10 shows the maturity assessment results. In general, for most of the competencies, they are between level 2 and 3, which can be said to be a moderate maturity level. The exception to this is the software, and hardware where they are at a low maturity level. As with organisation A, the red competencies in the assessment table refer to the competencies that this organisation could not recognise as success factors in the BIM implementation process.

The absence of an organisation maturity model prevents client B from managing improvements in their competencies' maturity. In addition, it prevents them from exploring other competencies that may affect their BIM implementation. For these reasons, it can be suggested that improving maturity for some competencies and not for others is guided by personal views and limited BIM experience. Therefore, providing such a model could help the client organisation explore other competencies that they have not considered and that may affect their BIM implementation. It could also help the client monitor their BIM maturity development and invest in the right competencies rather than waste time and cost in developing areas that may not improve their BIM results.

Table 6.10: Organisation B maturity assessment results

Maturity Elements	Not Exist	Level 1	Level 2	Level 3	Level 4	Level 5
Organisation Mission						
BIM Vision						
BIM Champion						
Data Sharing						
Management Support						
BIM Committee						
Standards						
Organisation Hierarchy						
Training						
Education						
Role and responsibilities						
Change readiness						
BIM skills						
OIR						
Validation Process						
Quality assurance system						
Software						
Hardware						
Physical space						
Network						

6.5.2.4 BIM benefits

Four sub-themes are identified under the main BIM benefits theme, which are: the benefits-EIR relationship, the benefits-maturity relationship, benefits assurance, and the desired benefits:

1. **The benefits-EIR relationship**

   The interviewees understand this relationship but they also believe it must extend to include all the scope of the work components. In addition, they believe that a clear EIR will make working with the supply chain easier and cause fewer problems; this, in turn, will lead to optimised BIM benefits, as CS2-2 argues:

   "[..], we are always chasing our supply chain for information but when you have clear requirements you will definitely get what you want. CS2-2"

   Recognising that there is a relationship between EIR and the desired benefits of BIM reflects sound BIM knowledge and a good understanding of the organisation. This emphasises that improving knowledge and understanding, or BIM maturity, will help the client to identify the critical success factors that support them in gathering the benefits as EIR.

2. **Benefits-maturity relationship**

   The interviewees understand that improving their maturity will help with reusing data, which can generate significant cost and time benefits. In addition, it can help them to ask the right questions from their supply chain, which can also result in achieving benefits. Such views suggest that client organisation B has an understanding of the benefits maturity relationship. However, the absence of such a relationship within their organisation potentially prevents them from following a clear, planned guide for improvement that would help them increase their BIM benefits. As indicated by CS2-3:

   "[…] I think that. Improving your maturity will help you to set up your requirements at an early stage of the project which definitely will lead you to meet your objectives. CS2-3"

3. **Benefits assurance**

The interviewees understand that improving BIM maturity in the organisation will increase their BIM benefits assurance which emphasise the importance of BIM maturity model in increasing client chance to achieve the desired benefits of BIM, as CS2-2 argues:

"We understand that we need to improve our BIM maturity to improve BIM benefits assurance. CS2-2"

4. **The desired benefits**

The interviewees proposed different types of benefits but insisted on the data use repeatability, and on cost and time reduction, reduced risks, improved efficiency and improved information accessibility. It can be concluded that organisation B desired benefits reflect that currently they are not giving considerable attention to BIM benefits in operation and maintenance stage which again results due to lack of BIM knowledge and understanding. As CS2-1 comments:

"Cost reduction, time reduction, fewer changes, reduced all types of risks, developability, and improving assurance which reducing the time for checking and monitoring. CS2-1"

A benefits assessment has been carried out on organisation B in order to compare the current benefits assurance level with the maturity assessment results (Table 6.11). Organisation B potentially lacks the ability to predict some BIM uses benefits, which places their assurance level between 1 and 2. As illustrated, organisation B shows limited improvement in certain competencies, which indicates that this lack of improvement has a direct effect on the ability to predict some BIM uses benefits. In the same context, an improvement in some maturity competencies could also enhance organisation B's ability to predict other BIM uses benefits. This may give also a positive impression of the relationship between BIM maturity competencies and BIM uses benefits.

Table 6.11: Benefits assessment results for organisation B

Current BIM uses	Benefit	Level 1 (Logical)	Level 2	Level 3 (Expected)	Level 4	Level 5(Definite)
Design Review	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
Clash detection	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
CONSTRUCTION SYSTEM DESIGN (VIRTUAL MOCK-UP)	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
3D CONTROL AND PLANNING (DIGITAL LAYOUT)	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
Record Modelling	Benefit 1					
	Benefit 2					
	Benefit 3					

	Benefit 4					
Asset Management	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					

6.5.2.5 Document analysis

Organisation B has developed two versions of their EIR; the first represents BIM requirements in the initial stages of BIM implementation in the organisation, whereas the second represents the current BIM requirements, which have been used in their 2014 projects. Before investigating these documents, it would be beneficial to display the current BIM uses in organisation B in order to explore; firstly, for what purpose BIM has been used and secondly, to what extent in terms of project lifecycle stages (Table 6.12). Finally, this will be useful in investigating the relationship between current BIM uses and client requirements. It can be seen from the table that organisation B is using BIM at different stages with more used in the construction stage; this suggests a limited level of BIM knowledge and understanding within the organisation.

Table 6.12: BIM uses in organisation B

No	BIM use	Stage
1	Design review	Design stage
2	Clash detection	Design-Construction stage
3	Construction system design	Construction stage
4	3D control and planning	Construction stage
5	Record modelling	Hand over stage
6	Asset management	In-use stage

Early stage BIM requirements

The first version of the EIR is formatted in an Excel sheet, which is divided into columns and rows. The columns represent the project's lifecycle stages, while rows contain the project deliverables. Each deliverable is assigned to a certain stage and with a specific level of detail (LOD). The deliverables are divided into eleven main categories, namely: site condition, design, environmental, construction, project management, commercial and financial products, procurements products, economic viability, approvals, asset management, health safety, modelling, and commissioning and performance evaluation. This document indicates poor BIM understanding within the organisation as the client depends on the supply chain to decide what to provide. The absence of requirements suggests that the client is unable to formulate any questions, which may add unnecessary risk to the project. At this stage of BIM implementation, it could be understood that the client prefers to choose the attitude of 'wait and see' where the supply chain is fragmented and provides unplanned deliverables.

Current BIM requirements

The last version of the EIR used by organisation B is the standard EIR template. The use of a standards template reflects considerable improvement in BIM understanding by the organisation and they are in a stronger position now to take a lead in their projects. In addition, it can be seen that the organisation has already made some amendments across the template, which also suggests that the organisation is starting to know what they want and to choose what is appropriate for their projects. This improvement can also be seen at the maturity level where the organisation has reached a good level in their BIM vision, BIM skills, Organisation Information Requirement (OIR), and Validation process. The organisation depends on their staff in the validation process, and their particular BIM skills. The weakness within organisation B can be found within their EIR, which focuses on delivering the project at BIM level 2 only. There is an absence of data drop detail requirements, which could explain the low level of quality assurance system in the maturity assessment.

6.6 Case study findings for client organisation C

This section discusses the data that was collected from client organisation C. It starts by providing the background of the organisation, which is followed by the data that was collected via interviews and documents. These will be analysed and discussed in detail according to the relevant categories.

6.6.1 Client organisation C background

Client organisation C is a public, government client, classified as a local public client. Organisation C considered using BIM as far back as 2006 on the 'Developing Schools for the Future' projects, and BIM has been used on a number of capital projects to improve stakeholder engagement and design development. Furthermore, BIM was considered at the start of their town hall project; however, it was not included in the contractual documentation. To date, organisation C has been using BIM on a number of projects over the past two years. It is clear that significant benefits in terms of reduced cost and good quality have already been realised. Their ambition now as an organisation is to use the model to make their building management process more efficient and provide a better service to their customers.

The list of the interviewees and their backgrounds is represented in Table 6.13. It can be seen from the Table that the interviewees have different levels of experience and work in different roles; this can improve the interviews' data richness in terms of the range of information and level of detail provided.

Table 6.13 List of the interviewees for organisation C

Name	Background	Area of Expertise	Current role	Experience(years)
CS3-1	Building surveyor	Principal project coordinator	Capital programme manager	30
CS3-2	Project Management	Property management system	Project control officer	15

6.6.2 Data analysis and findings

In this section, the responses to the questions in related issues were combined to reflect the themes and codes emerging from the data analysis about each particular issue. The following sub-section titles are; the main motivation factors, the critical success competencies, BIM maturity, and BIM benefits. Under these sections the results of the interviews were analysed and discussed.

6.6.2.1 The main motivation of using BIM

According to CS3-1 and CS3-2, organisation C started using BIM because of their design architect firm who convinced them to use it by explaining the expected benefits. Currently, they are not using BIM in all their projects but have confidence about how BIM can improve their projects and generate benefits for their organisation. They emphasised that they started to implement BIM because of the benefits, and not because of the Government mandate. However, they still looking to achieve BIM level 2 by 2016. As both interviewees comment:

"[…] The first project we used BIM on it, the idea comes from the architect which advise us to use BIM in our project. That is the beginning of our journey in 2010 [...]. We have good success in the first project which can prove the concept of using BIM and asset information and can translate to people who working in operation and maintenance phase of projects […]. CS3-1"

"[…] only the BIM value and benefits represent our bases to implement BIM in our project [...]. we still following government BIM mandate to be BIM level 2 by 2016 […]. CS3-2"

Although organisation C is a local public client, they implemented BIM because of their supply chain advice, which first introduced BIM to them, and not due to the Government mandate. Moreover, BIM benefits later on, have motivated them to continue to use and expand their BIM implementation across their organisation. However, the Government mandate is still a motivation factor as they strive to achieve BIM level 2.

6.6.2.2 Critical success competencies for BIM implementation

Under this theme there are three sub themes, which are Client BIM leadership, EIR, and data validation:

1. **Client BIM leadership**

   Both CS3-1 and CS3-2 believe that the client needs to lead the BIM implementation process because, if the client wants to use BIM information in the maintenance and operation phase, they have to lead the supply chain by providing this type of information. This was demonstrated by CS3-1:

"If you want to use that information in operation and maintenance phases you need to ask for it in the first place. So clients have lead this implementation process or they will or get what they want. CS3-1"

The criteria identified by interviewees as important for client leadership included; BIM understanding, BIM skills, EIR, management support, and technical criteria that include software and hardware capabilities. In addition, the two interviewees insisted that the client has to develop a flexible EIR that can be amended throughout the project lifecycle and kept updated. This was indicated by CS3-2 and CS3-1:

"clients need to understand what information they need and when and for what purpose in which format. Also, clients need to know what the EIR mean and explain to their supply chain in simple language […]. In addition, you need the vision to know where to use BIM and to what extent also standards, BIM skills […]. We need a flexibility in EIR because if you put your requirement now and your project have six years to develop after two years you will be out of date. CS3-2"

"Also, you need a technical part so you can manage your model. That is the challenges we are facing right now we need people with good knowledge. You need management support from your project management team, also your captured data must be structured in a way that makes them beneficial to end users. […] new roles will be good to fill the gaps between the current management systems which have used in the organisation. CS3-1"

2. **Employer Information Requirements (EIR)**

   Both interviewees agreed that the BIM EIR is an important document which formulates the relationship between the client and their supply chain. In addition, they emphasised that the client must have BIM knowledge for, and collaboration with, the operation and maintenance teams. Indeed, CS3-2 argues:

   "We need inform clients. […] you got to engaged with your operational teams, engineers and discuss with them how this information need to be presented and how it need to be structured […]. CS3-2"

3. **Data validation**

   Client organisation C uses external technical assessors to validate the received information from their supply chain; this is due to limited in-house resources. Both interviewees said that they need good collaboration with their supply chain to validate the information and confirmed they are using COBIe to share the information across project stakeholders. This was indicated by CS3-2 and CS3-1:

   "We are a local authority which led by the government. We don't have enough in-house capabilities so we have always brought in consultant support to help us to validate the information coming from the stakeholders. […] we usually set up a workshop with our supply chain to discuss the incoming information. We have themes to discuss like information security and maintenance information. CS3-1"

   "We used COBIe to collect and share the information with the main and subcontractors. […] In hand over stage we did a quality check to make sure that the information there and structured in the right way. CS3-2"

According to the participants' answers, a number of competencies were identified which reflect those that a client must have to develop the EIR, to validate the BIM outcomes and those that enable the client to lead a BIM implementation process throughout the project lifecycle. Table 6.14 represents these competencies for organisation C.

Table 6.14: Critical success competencies for organisation C

Client role	Required Competencies
Develop EIR	• Standards • Data Sharing method • BIM Vision • BIM skills
Validate BIM model outcomes	• BIM Skills • Data sharing method • Standards • Data protection • Network • BIM champion
Client leadership	• BIM Skills • BIM technology • Management support. • Asset information requirements • Data Sharing • Standards • BIM Vision

From Table 6.14 it can be seen that organisation C selects different competencies for different roles. Organisation C trusts that developing an EIR requires BIM vision to guide BIM uses in the project lifecycle and to guide questions in an EIR to reflect organisational needs. In addition, the interviewees added standards, BIM skills, and data sharing as required competencies that the client must have to develop their EIR. Selecting these competencies also suggests that organisation C has a good level of BIM understanding because, if a client wants to start to develop their EIR, they need standards to follow and data sharing to ensure all the team are involved in this process. Also, BIM skills will help the client to understand the expectations of the BIM model.

For the same table, it can be concluded that organisation C has added new competencies to enable them to validate BIM model outcomes. This indicates their understanding that, validating BIM model outcomes requires more competencies than those provided in just developing the EIR. These competencies include a BIM champion, data protection, and networks; this suggests that organisation C has a good understanding of the validation process and what they need to validate the information that comes from their supply chain.

For client leadership, organisation C adds organisation information requirements, management support, and BIM technology as new competencies that will enable them to lead a BIM implementation process. Selecting these new competencies means there is good BIM leadership awareness inside the organisation; this comes from the indication that organisation C is in a good position to start to lead the BIM implementation process with their supply chain. In addition, it can be seen that organisation C selects the same competencies for different roles, such as standards and data sharing methods, and BIM skills, that means they believe achieving greater maturity in these competencies will enable the organisation to move from just developing an EIR to validating the information. Thus becoming more mature in these competencies will enable them to lead a BIM implementation process. This emphasises the importance of maturity level for these competencies and its effects on a client's ability in BIM.

6.6.2.3 BIM maturity

Under the main theme of BIM maturity, the following four sub-themes were elicited, which are: the EIR-maturity relationship, maturity improvement, maturity assessment, and maturity level:

1. **EIR-maturity relationship**

   The interviewees observe that improving their maturity will improve their BIM understanding, which will support them in developing their EIR. This was demonstrated by CS3-2:

   "we look forward to improving our BIM maturity because we think it will improve our BIM understanding which will help us to develop our requirements and choose right information at the right time […]. CS3-2"

   It can be deduced that organisation C understands that improving their BIM maturity will help them to improve their EIR. However, the absence of an organisation maturity model may leave a significant barrier in managing BIM as a substantial change and in guiding them to plan and implement improvements in terms of BIM uses effectiveness.

2. **The maturity improvement**

   The interviewees believe that they need to improve their maturity to improve their BIM understanding and BIM knowledge. As CS3-2 comments:

"we look forward to improving our BIM maturity because we think it will improve our BIM understanding which will help us to develop our requirements and choose right information at the right time […]. CS3-2"

It can be understood that organisation C emphasises that maturity improvement will help them improve their knowledge and understanding regarding BIM implementation. Therefore, developing a BIM maturity assessment model has importance to client organisations.

3. **Maturity assessment**

   All interviewees observed that they assess their organisation against a BIM maturity assessment model, and that the Capability and Maturity Matrix (CMM) of the NCBIMs was used. In addition, they used BIM Level 2 criteria to assess their organisation's maturity. This was explained by CS3-1:

   "we used CMM to assess our BIM maturity level and we also currently focusing on BIM level 2 […]. CS3-1"

4. **The maturity level**

   Both interviewees agree that they only put BIM Level 2 as their target for their project:

   "We have to follow the government mandate to reach BIM Level 2 by 2016. CS3-2"

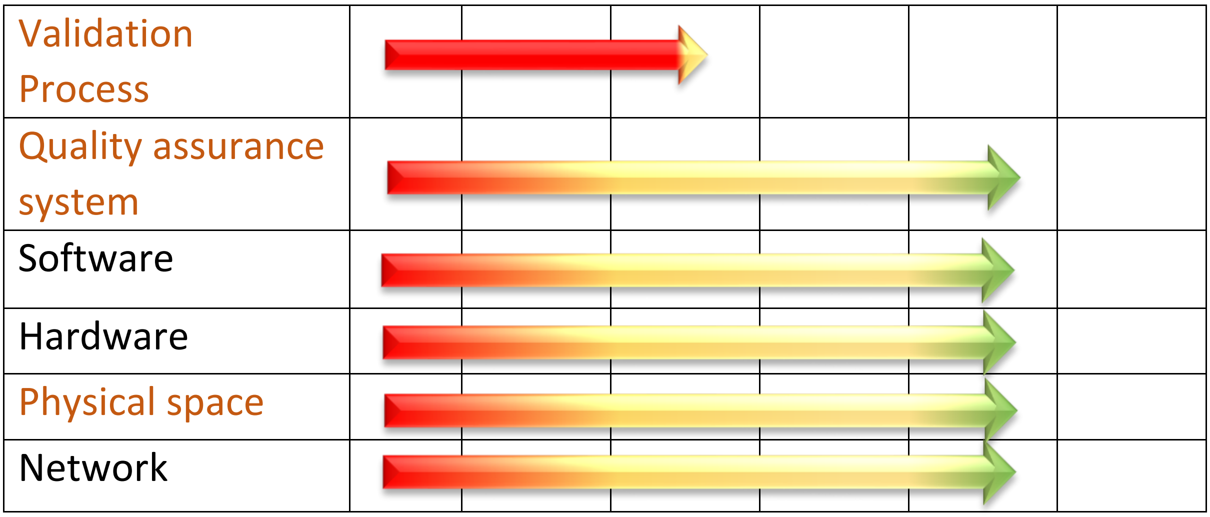
   Thus, organisation C used NBIM's model to assess their project in addition to the BIM Level 2 criteria. However, they had never heard of the term organisation BIM maturity. The absence of such a maturity model could prevent the client organisation from improving their competencies that will enable them to fulfil their role as a client organisation.

Organisation C has been assessed against the proposed BIM maturity model, and Table 6.15 shows the assessment results. Generally, organisation C achieved a good maturity level for the competencies, except for the OIR, validation process, and the BIM committee. The reason for this is that they are not aware of the importance of these competencies for their BIM implementation process. The red competencies in the table refer to those that organisation C could not recognise as success factors in the BIM implementation process.

Furthermore, the absence of an organisation maturity model could hinder organisation C in managing improvements in their competencies' maturity. It could also prevent them from exploring other competencies that may affect their BIM implementation. For these reasons, it can be seen that improving the maturity of some competencies and not for others may be guided by personal views and limited BIM experience. Therefore, providing such a model could help the client organisation explore other competencies that they have not considered and that may affect their BIM implementation. It could also help the client to monitor their BIM maturity development and invest in the right competencies rather than waste time and cost in developing those that may not enable them to improve their BIM outcomes.

Table 6.15: Organisation C maturity assessment results

Maturity Elements	Not Exist	Level 1	Level 2	Level 3	Level 4	Level 5
Organisation Mission						
BIM Vision						
BIM Champion						
Management Support						
Data Sharing						
Standards						
Organisation Hierarchy						
BIM Committee						
Training						
Education						
Role and responsibilities						
Change readiness						
BIM Skills						
OIR						



6.6.2.4 BIM benefits

Four sub-themes are identified under BIM benefits, and these are: the benefits-EIR relationship, the benefits-maturity relationship, benefits assurance, and desired benefits. These are further outlined as follows:

1. **The benefits-EIR relationship**

   All interviewees understand that the ability to ask the right question in an EIR will increase the chances of achieving the desired benefits, as CS3-1 comments:

   "[…] if you can ask the right question in your requirement this will increase your chances to get your benefits […]. CS3-1"

   Believing that there is a relationship between an EIR and the desired benefits of BIM reflects good BIM knowledge and an understanding of the organisation. This could confirm that improving knowledge and understanding or, in other words BIM maturity, can help the client to identify the critical success factors that support them to gather the benefits through an EIR.

2. **The benefits-maturity relationship**

   Both interviewees believe that there is a relationship between BIM benefits achievement and BIM maturity levels due to the improvement in BIM understanding and knowledge. This suggests that client organisation C has a clear understanding of the benefits maturity relationship; although the absence of such a relationship prevents them from following a guided improvement plan that will increase their BIM benefits achievements. Indeed, CS3-2 argues:

"definitely, there is a good relationship between improving your maturity and BIM benefits due to a huge improvement in your BIM understanding and knowledge […]. CS3-2"

3. **Benefits assurance**

The interviewees understand that they are gaining good benefits from using BIM in their projects, which also improves their confidence. This emphasis that improving client BIM knowledge and understanding is crucial to achieve the desired benefits of BIM. This was indicated by CS3-1:

"However, we are not seeing the benefits yet because we are on learning curves now. Nevertheless, we are now in a good position we know what we want which definitely will increase the benefits assurance. CS3-1"

4. The desired benefits

Both interviewees propose different types of benefits, such as cost and time savings, improved communication, better programming, and improved asset management. CS3-1 commented that:

"Improve communication, improve Asset Management, and cost and time saving. CS3-1"

A benefits assessment has been carried out on organisation C in order to compare the current benefits assurance level with the maturity assessment results (Table 6.16). Organisation C is currently impacted by the lack of ability to predict some BIM uses benefits, and that locates them at the in-use stage only, which means their assurance level is between 1 and 2. As illustrated, organisation C's maturity assessment shows improvement in some competencies that may support them in predicting the benefits related to BIM uses only in the design and construction stages. It can be concluded that the current BIM maturity improvement for organisation C is not good enough to extend their ability to predict benefits to cover in-use BIM uses. This could give a positive impression of the relationship between BIM maturity competencies and BIM uses benefits.

Table 6.16: Benefits assessment results for organisation C

Current BIM uses	Benefit	Level 1 (Logical)	Level 2	Level 3 (Expected)	Level 4	Level 5(Definite)
Phase planning	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
	Benefit 7					
Clash detection	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
Digital fabrication	Benefit 1					
	Benefit 2					
	Benefit 3					
Record modelling	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
Asset management	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					

6.6.2.5 Document analysis

Organisation C started their BIM journey by simply adding a word in their requirements without any detail; this reflects their poor understanding and knowledge about BIM at that time. Recently, their BIM requirements have been improved as they have used it in one of their big projects with support from the Government and external consultants. However, before starting to investigate these documents, it would be useful to display the current BIM uses in organisation C to explore for what purpose BIM has been used and to what extent in terms of the project lifecycle stages (as shown in the Table 6.17). It would also help to investigate the relationship between current BIM uses and the client requirements. It can be seen from the table that organisation C is using BIM at different stages with more used in the design and construction stages; this suggests a limited level of BIM knowledge and understanding.

Table 6.17: BIM uses in organisation C

No	BIM use	Stage
1	Phase planning	Design stage
2	Clash detection	Design-Construction stage
3	Digital fabrication	Construction Stage
4	Record modelling	Hand over stage
5	Asset management	In-use stage

Early stage BIM requirements

The first version of the EIR for organisation C is formatted as requesting the use of BIM in their project, but without any specification or detail. This suggests that the organisation does not have the ability to ask questions related to BIM uses due to limited BIM understanding, knowledge, and experience across the organisation. Such an approach implies that the client will allow their supply chain to lead their BIM implementation, which means that the client will receive some BIM benefits but potentially not achieve exactly what they require. Understanding this weakness will encourage organisation C to become more aware of the importance of an EIR and to try to improve it.

Current BIM requirements

The last version of the EIR used by organisation C is the standard EIR template. The use of a standard template means there are considerable improvements in their BIM understanding and knowledge and they are currently in a good position to take the lead in their projects. Through the support they gained from the Government and external consultants organisation C amended a few items in their standard EIR to ensure it reflected their actual needs. The current BIM maturity assessment results also show that organisation C achieved a very good maturity level, especially within management support, data sharing, BIM skills and technology competencies. The organisation depends on an external consultant to validate the information coming from their project stakeholders; this can be seen in the process competencies that suffer from a low level of maturity, especially in the OIR and validation process. The weakness found in organisation C's EIR is that they focus on delivering the project at BIM Level 2 only.

6.7 Case study findings for client organisation D

This section discusses the data that was collected from client organisation D. It starts by providing the background of the organisation, which is followed by the data collected via the interviews and documents, which will be analysed and discussed in detail.

6.7.1 Client organisation D background

As a private organisation, organisation D is one of the leading BIM-practising companies in the retail sector, having co-founded the 'BIM for the Retail' working group in 2010 under the Government's BIM Task Group. All stores built by them over the last four years have used BIM for all the construction information. Organisation D hosts and authors BIM models in Revit for several of their 'model' stores; these form their starting point and baseline. The models are modified by architects on a project-by-project basis in order to incorporate the specific mechanical, electrical, structure, architectural details, and even abnormalities in the ground. They have an in-house, developed BIM library of every element used in their projects, so there is no need to consult the National BIM Library or other resources. The list of the interviewees and their backgrounds are represented in Table 6.18. It can be seen from the Table that the interviewees have different levels of experience and work in different roles. This could improve the interviews' data richness in terms of the information and level of detail gathered.

Table 6.18: List of the interviewees for organisation D

Name	Background	Area of Expertise	Current role	Experience(years)
CS3-1	Architect	Construction Model Development	BIM Champion	18
CS3-2	Architect	Architectural Technologist	BIM Coordinator	15

6.7.2 Data analysis and findings

In this section, the responses to the questions were combined to reflect the themes and codes emerging from the data analysis about each particular issue. The titles for the following subsections are; the main motivation factors, the critical success competencies, BIM maturity, and BIM benefits. These contain the analysis and discussion of the results from the interviews.

6.7.2.1 The main motivation of using BIM

According to CS4-1 and CS4-2, organisation D decided to implement BIM for several reasons; firstly, offers were received from their supply chain to use BIM in their projects. Also, they saw that the market's BIM maturity had been rapidly developing, leaving them obliged to take steps in BIM implementation in order to keep pace with the market. In addition, they felt they did not have to follow the Government's BIM mandate to achieve Level 2 by 2016 because they believe that only BIM benefits could push them to implement it in their organisation. As part of a private client organisation, both interviewees agree that they need a good business case to implement any new initiative, such as BIM. In addition, the business case is not just about cost and time but needs to include several long-term considerations, such as store operation and maintenance. As CS4-1 and CS4-2 commented:

"in construction, there are consultants' contractors and they developing their capability in BIM. They told us about the BIM and this the future and we seeing a benefit by using BIM in our project. This motivate us to start using BIM in our project because if don't do it now it will be growing very fast and it will be very difficult to us to catch it later on but we feel relax and we taking our time in doing it because we don't have to meet the government mandate deadline which 2016. […]. CS4-1"

"In our organisation like us we need a business case for implementing any new thing such us BIM for example we can ask for training and new consultant and new software because will get benefits like […]. So you need a good evidence. We did that regularly and we will ask ourselves what we can do more. In Our BIM level 2 Pilot project, our consultants are speaking to all our business department and try to understand our business and using BIM to meet our needs. It is a business case for us it is not just time or cost it is a wider picture for us […]. CS4-2"

Client organisation D stated that they implemented BIM because of advice and offers received from their supply chain, which influenced their decision. Additionally, the development in the market in terms of BIM maturity motivated them to implement BIM and thus maintain their competitiveness. BIM benefits were ranked third by organisation D as a motivation factor that pushed them to implement BIM.

6.7.2.2 Critical success competencies for BIM implementation

Under this theme are three sub themes, which are: client leadership, EIR, and data validation:

1. **Client leadership**

Both interviewees agree that the client has to lead the BIM implementation process to achieve the desired benefits. However, the current situation for their organisation does not allow them to lead their supply chain. Both interviewees feel optimistic about BIM's future in their organisation and their ability to lead a BIM implementation process across their stakeholders. This was explained by CS4-1 and CS4-2:

"Yes they need to drive the process but right now the employer doesn't have the competency to do it. So, they are looking for the design team or design manager whoever to deliver the model for advice. The problem in this situation the design team don't know what to do either it will like blind leading the blind. If the client not able to lead BIM, the design will not know what to deliver so the outcome will be messy. CS4-1"

"our consultant now and contractors told look what we can do in BIM and look what we can give you in terms of benefits. They are showings us now what we can get from BIM. But also you need to make a commitment and your supply chain will come on board. Now we can say that our supply chain leading us in BIM. CS4-2"

Both interviewees identify several measures as leadership criteria, which help a client organisation to lead BIM implementations and optimise their BIM benefits. These criteria are; a BIM manager, BIM champion, BIM committee, and BIM skills, plus training, and software. In addition, one of the interviewees suggest that a client can use an external consultant to help their BIM leadership as an initial step but insists that an in-house team will expand an organisation's ability to lead a BIM implementation process. This was indicated by CS4-2 and CS4-1:

"We need BIM manager and BIM champion, BIM committee, BIM skills, Training, software […]. We now using external consultant that helping us to develop our own competence. They can make sure that the BIM model deliverables are meeting our needs. Also, they need in-house expertise because they believe in BIM and they understand our organisation culture. Also, I think it is not necessary you have the in-

house expertise to start using BIM but you can use an external consultant if they understand your business […]. CS4-1"

"an external consultant firm which helping them to set up their requirements. Furthermore, it must be a good relation between business supporter and the BIM manager to support BIM implementation in the organisation. CS4-2"

2. **Employer Information Requirements (EIR)**

   Both interviewees give the same opinion in that a BIM EIR is a crucial document that helps the client achieve their desired benefits. In addition, they highlight that the client must have good collaboration with their supply chain. As CS4-1 and CS4-2 commented:

"Our approach is we use our consultant to produce our EIR. We are not in a hurry to produce our EIR. We gave the consultant some of the things that but be in EIR. We believe that we will revisit our EIR again after six months if we did it in 80% percent now it will be good for us. We focusing on our BIM level 2 Pilot project to experience our EIR and how we can modify it. We using Standards EIR as our baseline and we did some change on it to meet our needs. CS4-1"

"EIR play a vital role because it will tell our contractor that what we will pay for and to make sure he will do it in our way. CS4-2"

3. **Data validation.**

Client organisation D uses external technical assessors to validate the information from their supply chain for two reasons; firstly, they do not have sufficiently skilled staff inside the organisation, and secondly, they believe there is no difference in outcome whether the validation process is done in or outside the organisation. In addition, they agree that they must have some sort of competence to be able to validate the BIM model outcomes. These competencies include; BIM skills, software, hardware, training, data sharing, and a quality assurance system. Indeed, CS4-2 and CS4-1 indicated that:

"[…] need test criteria and make sure we have the proper software to collect the data. We are using now external consultant as an information manager to validate the information […]. It definitely good to have these skills inside the organisation but we still believe that there is no much difference between having this competence inside or outside the organisation. CS4-2"
"we did that in a manual way like traditional way but we like to make it automated process in future and this need software, hardware, skills, training, standards, data sharing and quality assurance system. CS4-1"

According to the interviewees' answers, several measures have been identified which reflect the competencies that a client must have to develop an EIR as the first step in a BIM implementation process. Moreover, the competencies enable the client to validate the BIM outcomes and make the client capable of leading a BIM implementation process throughout the project lifecycle. Table 6.19 represents these competencies for organisation D.

Table 6.19: Critical success competencies for organisation D

Client role	Required Competencies
Develop EIR	• Standards • Data Protection and security • Data Sharing method • BIM skills • Education
Validate BIM model outcomes	• BIM Skills • Data sharing method • Standards • BIM technology • Quality assurance system • BIM champion
Client leadership	• BIM Champion • BIM committee • BIM Skills • Training • BIM technology • Management support.

In Table 6.19, it can be seen that organisation D selects different competencies for different roles. Organisation D believes that developing an EIR needs standards, data protection and security, data sharing methods, BIM skills, and education as essential competencies that a client must have to develop their EIR. Selecting these competencies also suggests that this organisation has a good level of BIM understanding because, if a client wants to develop their EIR BIM skills, the standards represent the required competencies that support them to ask the right questions in the EIR.

From the same table, it can be concluded that organisation D adds new competencies to enable them to validate the BIM model outcomes. These competencies include BIM technology, a quality assurance system, and a BIM champion, which indicates that organisation D has a good understanding of the validation process and that they need more competencies than those just required to develop an EIR.

For client leadership, organisation D adds BIM champion, management support, training, and BIM committee as new competencies that will enable them to lead a BIM implementation process. Selecting these new competencies indicates that there is a good BIM leadership awareness inside the organisation, and suggests that organisation D is in a good position to start leading the BIM implementation process with their supply chain.

In addition, it can be seen that organisation D selects the same competencies for different roles, like standards and data sharing methods, which implies they believe that developing more maturity in these competencies will enable a move from just developing an EIR to validating the information. Furthermore, it indicates that greater maturity in these competencies will enable them to lead a BIM implementation process. This emphasises the importance of maturity level for these competencies and its effect on a client's ability in BIM.

6.7.2.3 BIM maturity

Under the theme of BIM maturity, the following four sub-themes were elicited: EIR-maturity relationship, maturity improvement, maturity assessment, and maturity level:

1. **EIR-maturity relationship**

   Both interviewees observe that they need to understand BIM in order to be able to develop an independent EIR and this BIM understanding will increase as BIM maturity increases. It can thus be determined that organisation D understands that improving their BIM maturity will help them to improve their EIR. However, the absence of such a model will leave a significant barrier for them to manage BIM, which is a substantial change and requires guidance in planning and implementing improvements in term of BIM uses effectiveness. This was demonstrated by CS4-2:

   "if you want to develop independent EIR and only for your own business, you must have a good level of BIM understanding. We believe that BIM maturity can help you to get this level of understanding. CS4-2"

2. **The maturity improvement**

   The interviewees believe that they need to improve their maturity to enhance their BIM benefits. Both interviewees agree that improving an organisation's maturity will improve its ability to use BIM tools and information, which will increase any BIM benefits. This was indicated by CS4-2 and CS4-1:

"We need to improve our maturity to be able to use all information in the model in a proper way and avoid recollecting information it there why we cannot use it.CS4-1"

"to improve BIM benefits. If you understand BIM tools you will be able to get more out from them. CS4-2"

It can be seen that organisation D understands that maturity improvements will help them to achieve the desired benefits of BIM through improving their ability to use BIM tools effectively. Therefore, developing such a BIM maturity assessment model has significance for client organisations.

3. **Maturity assessment**

   Both interviewees agree that they do not assess their organisation against any BIM maturity assessment model, except for BIM Level 2; this is because they do not have prior knowledge about any BIM maturity model. Indeed, CS4-1 confirmed:

"No, we just focusing on BIM level 2 maturity. CS4-1"

4. **The maturity level.**

   CS4-2 indicates that organisation D only puts BIM Level 2 as their target for their project to achieve for the following reasons:

"We try to achieve BIM level 2 but we are not in a hurry and not following government mandate […]. CS4-2"

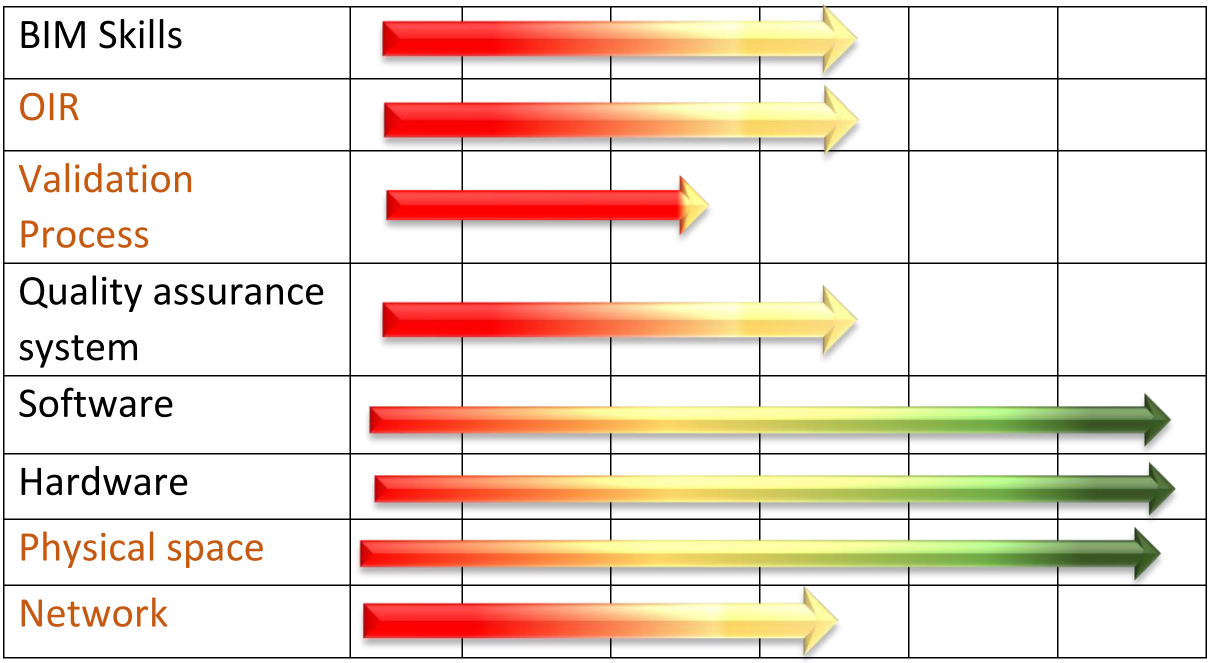
Organisation D has never heard of the term organisation BIM maturity and focuses instead on the BIM Level 2 assessment to evaluate their work progress and future improvements. The absence of such a maturity model will prevent the organisation from improving the competencies that will enable them to fulfil their role as a client organisation.

Organisation D has been assessed against the proposed BIM maturity model, and Table 6.20 shows the maturity assessment results. In general, for most competencies, the organisation is between levels 2 and 4, which can be understood as a good maturity level. However, BIM technology competencies are the exception, which have reached a high level of maturity. As before, the red competencies in the assessment table refer to the competencies that organisation D could not recognise as success factors in a BIM implementation process.

The absence of an organisation maturity model prevents client organisation D from managing their competencies' maturity improvements. In addition, it prevents them from exploring other competencies that may affect their BIM implementation. For these reasons, it can be seen that improving maturity for some competencies and not for others is influenced by personal views and limited BIM experiences. Therefore, providing such a model will help the client organisation explore other competencies which they have not previously considered and that may affect their BIM implementation. This could also help the client monitor their BIM maturity development and invest in the right competencies rather than waste time and cost in developing those that may not improve their BIM results.

Table 6.20: Organisation D maturity assessment results

Maturity Elements	Not Exist	Level 1	Level 2	Level 3	Level 4	Level 5
Organisation Mission						
BIM Vision						
BIM Champion						
Management support						
Data Sharing						
Standards						
Organisation Hierarchy						
BIM Committee						
Training						
Education						
Role and responsibilities						
Change readiness						



6.7.2.4 BIM benefits

Four sub-themes are identified under the main BIM benefits theme, which are: the benefits-EIR relationship, the benefits-maturity relationship, benefits assurance and desired benefits.

1. **The benefits-EIR relationship**

   Both interviewees believe that there is a relationship between an EIR and BIM benefits. This relationship develops through creating a good EIR and will increase BIM benefits. However, both interviewees agree that they do not have the metric to represent this relationship, as explained by CS4-1:

   "[…] I convinced that if we did our EIR in a good way all the benefits we expect to have by using BIM it will be increased. […] not sure about the metrics right now but definitely, it will increase. We start by using standards EIR as our baseline and we changed it now to meet our business. CS4-1"

   Believing that there is a relationship between an EIR and the desired benefits of BIM reflects good BIM knowledge and understanding of the organisation. This indicates that improving knowledge and understanding, or BIM maturity, will help the client to identify the critical success factors that support them to gather the benefits as an EIR.

2. **The benefits-maturity relationship**

   Both interviewees believe that improving an organisation's maturity will increase its BIM benefits by improving its ability to develop an EIR and validating the BIM model outcomes. This indicates that client organisation D has a clear understanding of the benefits maturity relationship. However, the absence of such a relationship prevents them from adopting a model of improvement that will help them to increase their BIM benefits. As CS4-2 argues:

"yes, we believe that improving your maturity will improve BIM model outcomes by asking the right question in EIR and improve our positions in BIM discussion and validation process. CS4-2"

3. **Benefits assurance**

The interviewees assume that they are gaining good benefits from using BIM in their projects. In addition, they emphasise that gathering BIM benefits is important because they need these benefits as evidence to keep using BIM in their organisation. This was demonstrated by CS4-1:

"In our situation as the private client has a clear difference from another type of client, you will not found anyone says here enough budget and enough staff to start using BIM in your project. […] we need to do that in our daily work and try to prove that BIM has good benefits for our project before we ask for any additional resources for BIM implementation. Here you need real evidence for your daily work to convince your manager that your idea is worthy to implement. Like the type of sneaking from the back door. CS4-1"

4. The desired benefits

Both interviewees propose different types of benefits, such as unified standards, common data language, object classification, clash avoidance and improved risk analysis. It can be seen that from organisation D desired benefits that they are very limited which can reflect the level of BIM knowledge and understanding among the organisation. CS4-1 commented on this:

"Unified standards, common data language, object classification*,* clash avoidance, and improve risk analysis. *CS4-1"*

A benefits assessment has been carried out on organisation D in order to compare their current benefits assurance level with the maturity assessment results (Table 6.21). Organisation D has currently reached a good level in its ability to predict current BIM uses benefits. Despite this, the maturity assessment for organisation D shows limitations in some competencies; however, this does not affect the organisation's ability to predict benefits. The main reason could be that the current level of maturity improvement is just enough for the organisation to predict benefits. This implies that the client organisation does not necessarily need to be fully mature in BIM to be able to predict their BIM benefits.

Table 6.21: Benefits assessment results for organisation D

Current BIM uses	Benefit	Level 1 (Logical)	Level 2	Level 3 (Expected)	Level 4	Level 5(Definite)
Phase planning	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
	Benefit 7					
Design review	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
Clash detection	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
Digital fabrication	Benefit 1					
	Benefit 2					
	Benefit 3					
Record modelling	Benefit 1					
	Benefit 2					
	Benefit 3					

	Benefit 4					

6.7.2.5 Documents analysis

For the past seven years, organisation D has been using BIM in silos and employees have different opinions on how to do it. Therefore, they have different versions of their EIR, which are reflective of the particular departments inside organisation. This means that they are without any single version of an EIR that can express what the organisation needs as one unit. However, they are currently trying to put everything into one format and are using an external consultant to help them develop this one format EIR to reflect their organisation's needs. They are using a standards EIR as a base and changing a few things regarding their needs. In addition, they are continuing to update it whilst undertaking a BIM Level 2 pilot project. It will be beneficial to view the current BIM uses in organisation D in order to explore for what purpose BIM has been used and to what extent in terms of the project lifecycle stages (Table 6.22). It would also be useful to investigate the relationship between current BIM uses and the client requirements. It can be seen from the Table that organisation D is using BIM at different stages with more used in the design and construction stages; this reflects a limited level of BIM knowledge and understanding within the organisation.

Table 6.22: BIM uses in organisation D

No	BIM use	Stage
1	Phase planning	Design stage
2	Design review	Design stage
3	Clash detection	Design-Construction stage
4	Digital fabrication	Construction stage
5	Record modelling	Hand over stage

Early stage BIM requirements

Organisation D has different versions of their EIR, which represents the needs of the different departments that created them. Creating different versions of an EIR occurs due to the nature of BIM implementation inside organisation D, which involves work within discrete teams. Currently, organisation D is putting a lot of effort into producing one format of their EIR that reflects the organisation's needs as one unit.

Current BIM requirements

The latest version of the EIR used by organisation D is the standard EIR template. They use a standard template as a base and include a few amendments to incorporate their needs. Trying to use a standards version of an EIR represents a considerable improvement in BIM understanding and knowledge within the organisation, and they are currently in a good position to take the lead in their projects. Currently, they are using an external consultant to support them in developing a one format EIR. However, they are looking to develop their competencies and improve their in-house BIM skills. The current BIM maturity assessment results also show that organisation D achieved very good maturity levels, especially for BIM technology. However, they still need to improve some competencies, such as a BIM champion, standards, validation process, and a quality assurance system.

6.8 Case study findings for client organisation E

This section discusses the data that was collected from organisation E, and starts by providing the background, which is then followed by a presentation of the data collected from the interviews and documents; these will be analysed and discussed according to the category to which they belong.

6.8.1 Client organisation E background

As a property development company, organisation E found that BIM was able to improve the design and construction process beyond their initial expectations. Firstly, they expected the main operational benefit of BIM to be clash detection; an application which allows computer processes to check certain rules like code regulations and any possible structural issues during the design phase. However, BIM had many more benefits for their projects; for example, it allowed organisation E to undertake construction rehearsals in a 4D timeline to identify sequencing and logistics issues and ensure the programme was as efficient as possible. BIM also allowed the company to achieve sustainability objectives by increasing off-site manufacture and reducing on-site waste. Organisation E states that, by implementing BIM, they significantly reduced the risk budget for the project. The list of interviewees and their backgrounds is presented in Table 6.23. As with the other client organisations, the interviewees have different levels of experience and work in different roles, and this could help to generate rich interview data in term of the range and level of detail.

Table 6.23: List of the interviewees for organisation E

Name	Background	Area of Expertise	Current role	Experience(years)
CS5-1	Building surveying	Project executive	BIM Champion	30
CS5-2	Architect	Design management	BIM Consultant	32

6.8.2 Data analysis and findings

In this section, the responses to the questions were combined to highlight the emerging themes and codes about each particular issue. The titles for the upcoming sub-sections are as follows; main motivation factors, critical success competencies, BIM maturity, and BIM benefits. These were the themes under which the results of the interviews were analysed and discussed.

6.8.2.1 The main motivation of using BIM

According to interviewees CS5-1 and CS5-2, there are a number motivation factors that influenced organisation E's decision to implement BIM. The first were the benefits, where they found that BIM could improve their project quality and building operations. The second factor was the Government BIM mandate that encouraged them to implement BIM. Finally, the overall market's BIM maturity also inspired them to implement it in their projects. However, both interviewees insist that they do not feel under pressure because of the Government mandate and are improving their capability just to improve the BIM benefits. CS5-1 and CS5-2 commented that:

"[…] we believe that BIM can help us to improve our building quality and operate it very well. […] As a private sector we found there is an advantage in BIM as a new procurement bridge which can make direct negotiation with main contractors where traditionally it is one of the main problems in our project. […] The maturity of the market like contractors and engineers push us to use BIM in our project. […] Also the main reason is the government mandate. CS5-1"

"We are not following the government mandate. But it affects the maturity of the sector itself. So we think we need to improve our BIM capabilities but not necessary meet BIM level 2 in all its details and standards. CS5-2"

Thus, client organisation E identifies BIM benefits as the main motivation factor that made them decide to implement BIM in their projects. Moreover, the Government mandate is also a motivation as well as the overall construction industry's BIM maturity in the UK, where all their supply chain is currently using it.

6.8.2.2 Critical success competencies for BIM implementation

Under this theme there are three sub themes, namely client leadership, EIR, and data validation:

1. **Client leadership**

   CS5-1 and CS5-2 believe that the client has to lead the BIM implementation process to maintain the pressure that will encourage the supply chain to implement BIM. In addition, they believe that client leadership will support BIM implementation across the construction industry and will speed up the implementation process. This was explained by CS5-1 and CS5-2:

"I think it is not an easy journey for people to implement BIM in their project so the client can maintain the pressure to make that happened and that can happen by leading it and ask for it in his project which makes the others have to implement it. CS5-1"

"They need to support the implementation process CS5-2"

Each interviewee identified several factors as client BIM leadership criteria. These factors are BIM skills, BIM standards, BIM vision, a BIM champion, change management, and employer information requirements,

"The client needs to understand BIM and provide all the necessary competencies like understanding BIM standards, clear BIM vision and improve staff BIM skills to make sure that BIM can make good effects on your business. […]. CS5-1"

"they need to champion it because it is change management process. So, they have to understand the principles behind it. They need to understand the challenges of change management. They need to have a good idea about the employer information requirements. CS5-2"

2. **Employer Information Requirements (EIR)**

   Both interviewees have the same opinion regarding the importance of Employer Information Requirements (EIR) in that they believe this document will help them to gather the required information to solve their projects' problems. In addition, they agreed that the client needs good BIM understanding and a certain range of competencies to develop an EIR. These competencies may include BIM standards, data sharing, a BIM champion, and an OIR. This was indicated by CS5-1 and CS5-2:

"[…] the EIR is to provide information that can help you to solve your problems in the project. […] I think we need an external help and guidance which will help us to develop our EIR. I think you need to know what you need at the end of the model. CS5-1"

"[…] So I think we need to understand the business side of the project like asset management and facility management. […] The lack is to bring capital and operation teams together. If the client wants to optimise his EIR he needs to bring the facility management team at beginning. CS5-2"

3. Data validation

Client organisation E is currently using an external consultant to validate the BIM models that are provided by their supply chain. However, both interviewees agree that having the in-house capability to validate information will optimise their BIM benefits. In addition, they agreed that they must have some competencies to be able to validate the BIM model outcomes, and that these include; BIM skills, technical expertise, standards, and data sharing. This was demonstrated by CS5-2 and CS5-1:

"[…] For our organisation we recognise that we cannot do it inside so we employ an external facilitator which have the good technical capabilities to check deliverables among data drops. CS5-2"

"if we want to do that in-house we need skills, checking platform, technical expertise, and standards, to do that but currently we don't have the ability to do that. Now we receiving a report from our consultant explain the current model situation and for example how clash detection the have and other details. CS5-1"

According to the participants' responses, some competencies have been identified as those which are critical for success, which support the client to be able to develop their EIR as the first step in the BIM implementation process. Moreover, there are competencies that enable the client to validate their BIM outcomes and those that make a client capable of leading a BIM implementation process throughout a project lifecycle. Table 6.24 represents these competencies for organisation E.

Table 6.24: Critical success competencies for organisation E

Client role	Required Competencies
Develop EIR	• Standards • Data Protection and security • Data Sharing method • BIM Vision

	• BIM skills • Organisation mission
Validate BIM model outcomes	• BIM Skills • Standards • BIM technology • Role and responsibilities • Network • BIM Champion
Client leadership	• BIM Champion • BIM Skills • BIM technology • Asset information requirements • Standards • BIM Vision • Change readiness

From Table 6.24 it can be seen that organisation E selects different competencies for different roles. Organisation E observed that developing an EIR requires BIM vision to guide BIM uses in the project lifecycle and to guide any questions in the EIR. Also, BIM skills are required to identify how BIM can be used. Furthermore, the interviewees add standards, data sharing data protection, and the organisation mission as essential competencies that a client must have to develop their EIR. In selecting these competencies, it suggests that this organisation has a good level of BIM understanding because, if a client wants to start to develop their EIR they need standards to follow and data sharing to ensure all the team are involved in this process. Also, data sharing is one of essential competencies that help staff share information and queries with their supply chain. However, the selection of organisation mission may reflect that the client includes the organisation's mission in developing an EIR, and not just particular project requirements; this can thus be considered an OIR.

From the same table, it can be seen that organisation E adds new competencies to enable them to validate BIM model outcomes. These competencies include roles and responsibilities, BIM technology, networks, and a BIM champion; these selections suggest that organisation E has a good understanding of the validation process and what they need in order to validate the information that comes from their supply chain.

For client leadership, organisation E adds organisation information requirements and change readiness as new competencies that would enable them to lead a BIM implementation process. Selecting these competencies reflects that client E has a good understanding of BIM implementation leadership. The red competencies in the assessment table refer to those that organisation E could not recognise as success factors in a BIM implementation process.

In addition, it can be seen that organisation E selects the same competencies for different roles, like standards and data sharing methods; this indicates that they believe that being more mature in these competencies will enable a client to move from just developing an EIR to validating the information. It also indicates that a greater maturity in these competencies will enable a client to lead a BIM implementation process; this emphasises the importance of the maturity level for these competencies and its effects on a client's ability in BIM.

6.8.2.3 BIM maturity

Under the theme of BIM maturity, four sub-themes were elicited, which were the EIR-maturity relationship, maturity improvement, maturity assessment, and maturity level:

1. **EIR-maturity relationship**

   Both interviewees agree that developing client maturity will help to make any requirements clear to the supply chain, which in turn will support them in accurately meeting those needs. CS5-1 argues:

   "[…] while EIR explain to the supply chain what client want at the end and it needs to be simply and let the design and contractor teams make that happened. The EIR needs to be clear about what client want at the end so as much as your maturity is good your EIR will be clear. CS5-1"

   It can be concluded that organisation E understands that improving their BIM maturity will help them to improve their EIR. However, the absence of such a model will leave a substantial barrier in managing BIM, which represents a significant change, and guiding them to plan and implement improvements in terms of BIM uses effectiveness.

2. **The maturity improvement**

   The interviewees believe that they need to improve their maturity to improve their BIM understanding. Both agree that improving client maturity can improve work efficiency and meet the client's desired quality. As demonstrated by CS5-1 and CS5-2:

   "our work going better more efficiently and at desired quality. CS5-1"

   "Increasing your maturity will help you to increase your BIM understanding which helps you to develop your EIR and use the model for operation and maintenance. CS5-2"

   It can be seen that organisation E emphasises that maturity improvements will help them to improve their knowledge and understanding regarding BIM implementation. Therefore, developing such a BIM maturity assessment model has significance for client organisations.

3. **Maturity assessment**

   Both interviewees agree that they do not assess their organisation against any BIM maturity assessment model, even BIM Level 2. This was explained by CS5-1:

   "No framed work because we are new in BIM. We are not focusing on BIM level 2. CS5-1"

   Organisation E has not heard of the term organisation BIM maturity and instead focuses on the BIM Level 2 assessment to evaluate their work progress and identify future improvements. The absence of such a maturity model could prevent the organisation from improving the competencies that will enable them to fulfil their role as a client.

4. **Maturity level**

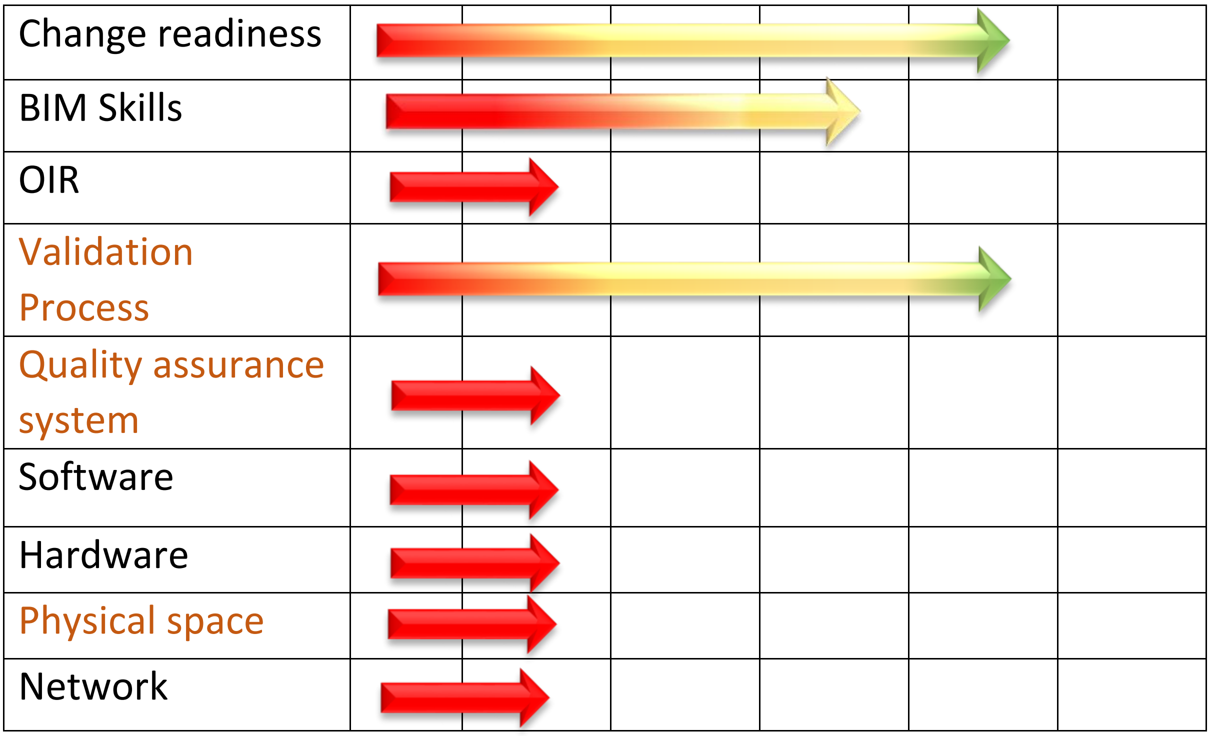
   As mentioned previously, organisation E has not heard the term organisation BIM maturity. Therefore, they have no specific level they plan to reach.

Organisation E has been assessed against the proposed BIM maturity model, and Table 6.25 shows the maturity assessment results. In general, for most competencies, they are between levels 2 and 4, which can be considered a good maturity level. The exceptions to this are the OIR, organisation hierarchy, BIM committee, quality assurance system, and BIM technology, which indicate a low maturity level. As with other client organisations, the red competencies in the assessment table refer to the competencies that organisation E could not recognise as success factors in a BIM implementation process.

The absence of an organisation maturity model can prevent client E from managing any maturity improvement in their competencies. In addition, it could prevent them from exploring other competencies that may affect their BIM implementation. For these reasons, and as previously found, it can be seen that improving maturity for some competencies and not for others may be guided by personal views and limited BIM experiences. Therefore, providing such a model will help a client organisation to explore other competencies which they have not considered and that may affect their BIM implementation. This could also help the client to monitor their BIM maturity development and invest in the right competencies rather than waste time and cost in developing those that may not enable them to improve their BIM results.

Table 6.25: Organisation E maturity assessment results

Maturity Elements	Not Exist	Level 1	Level 2	Level 3	Level 4	Level 5
Organisation Mission						
BIM Vision						
BIM Champion						
Management support						
Data Sharing						
Standards						
Organisation Hierarchy						
BIM committee						
Training						
Education						
Role and responsibilities						



6.8.2.4 BIM benefits

Four sub-themes are identified under the BIM benefits theme which are; the benefits-EIR relationship, the benefits-maturity relationship, benefits assurance, and the desired benefits:

1. **The benefits-EIR relationship**

   Both interviewees believed that there is a relationship between an EIR and BIM benefits, and that this relationship develops through creating a clear EIR, which will increase any BIM benefits. This was demonstrated by CS5-1:

   "[…] when your EIR is good enough and has the right questions it definitely leads to gather more and more benefits. CS5-1"

   Believing that there is a relationship between an EIR and the desired benefits of BIM reflects good BIM knowledge and an understanding of the organisation. This can emphasise that improving knowledge and understanding, or BIM maturity, will help the client see the critical success factors that support them in gathering the benefits as an EIR.

2. **The benefits-maturity relationship**

   Both interviewees believe that, without full BIM understanding it is impossible to achieve BIM benefits. However, improving BIM maturity will expand an organisation's

BIM knowledge and improve their BIM understanding. This potentially indicates that client organisation E has a clear understanding of the benefits maturity relationship. However, the absence of such a relationship in their organisation prevents them from using a structured approach to improvement that will lead to an increase in BIM benefits achievements. Indeed, CS5-2 argues:

"if we did not understand BIM (I mean full understand) it seems to me impossible to gain what you want from using BIM. Improving your maturity will help us to improve our BIM knowledge and understanding [...]. CS5-2"

3. **Benefits assurance**

The interviewees believe that they are currently achieving benefits from using BIM in their projects. In addition, they are now trying to benchmark their work in BIM, which will enable them to compare and analyse. This was indicated by CS5-1:

"we believe that BIM can support and develop our business. Our company spent lots of money in investing in BIM but how that can compare to long term benefits it is difficult to measure. We now don't know if we used BIM in our project will help to deliver that project in time or not. We trying to look now on the percentage of our projects who's finished in time and what are the relation with using BIM in these project. I think we need more time and information to be 100% that BIM can improve our project. CS5-1"

4. The desired benefits

Both interviewees proposed different types of benefits, like managing risk, reducing cost, improving efficiency, improving design quality, and improving facility management. CS5-1 and CS5-2 commented that:

"managing risk, reduce cost, improving efficiency, improve the design quality, and improve facility management. CS5-1"

"To have better outcomes and improve the cost-quality relationship. CS5-2"

A benefits assessment has been carried out on organisation E, shown in Table 6.26. It can be seen that BIM uses benefits have reached a different level of maturity. This means that these benefits are affected by the client's BIM abilities, which in their current situation prevents them from achieving a good level of maturity for some benefits. There are a number of benefits at a low assurance level, namely between 1 and 2, which means the client is unable to predict these, which reflects a weakness in those BIM competencies which have not reached the required maturity level. This may give a positive impression of the relationship between BIM maturity competencies and BIM uses benefits.

Table 6.26: Benefits assessment results for organisation E

Current BIM uses	Benefit	Level 1 (Logical)	Level 2	Level 3 (Expected)	Level 4	Level 5(Definite)
Design Review	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
Energy analysis	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
Lighting analysis	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
Recording modelling	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
Asset maintenance scheduling	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
Asset management	Benefit 1					
	Benefit 2					

	Benefit 3					
	Benefit 4					

6.8.2.5 Documents analysis

Organisation E prefers to not share any copies of their EIRs and just confirm that they use a standards version of an EIR that is provided by the task group. However, they are now working with their external consultant to amend it due to their organisation's needs. Working according to the standards EIR is good step however, it is still one of the initial steps in BIM implementation process. As CS5-1 comments:

"We used the standards EIR as a template. We will select some parts from it. For example, we don't have a digital plan of work we used the old method. We changed it to make sure it meets our current method of work. CS5-1"

It would have been beneficial to examine the current BIM uses in organisation E in order to explore for what purpose BIM has been used and to what extent in terms of their project life cycle stages (Table 6.27). It would have helped the investigation into the relationship between current BIM uses and client requirements. Oorganisation E is using BIM at different stages with more used in the design stage, and some in-use stage; this reflects a good level of BIM knowledge and understanding. Expanding BIM uses to cover some areas in operation and maintenance stage means that client organisation realised the real value of BIM which come after the construction is completed.

Table 6.27: BIM uses in organisation E

No	BIM use	Stage
1	Design review	Design stage
2	Energy analysis	Design stage
3	Lighting analysis	Design stage
4	Record modelling	Hand over stage
5	Asset maintenance scheduling	In-use stage
6	Asset management	In-use stage

6.9 Case study findings for client organisation F

This section discusses the data that was collected from client organisation F. It provides the background of the organisation, which is followed by the data collected from the interviews and documents. These will be analysed and discussed in detail according to their relevant categories.

6.9.1 Client organisation F background

As a university, organisation F essentially has two types of funding source; public funds from Government and private funds that mainly come from students. This type of organisation is classified as a mixed client due to this combination of finance sources. Organisation F started to implement BIM projects from 2011 on the advice from their project manager to implement this innovation. At that time, they had little idea about BIM so depended on their contractor to develop their BIM model. After that project, the organisation ran two big projects during which BIM was implemented in an appropriate way where the EIR was created at an early stage. Their BIM implementation is not driven by the Government mandate nor is it driven because of university pressures. Instead, it is driven by the desire to do something innovative and the client found that they could do much better by not just modelling. Currently, they use BIM as a structured way of sharing information.

The details of the interviewees are presented in Table 6.28. As with previous case studies, the interviewees have different levels of experience and work in different roles. This will, again, improve the interviews' data richness concerning the range of information and level of detail.

Table 6.28: List of the interviewees for organisation F

Name	Background	Area of Expertise	Current role	Experience(years)
CS6-1	Building surveying	Project Management	BIM Champion	30
CS6-2	Architect	Design management	BIM Coordinator	32

6.9.2 Interview answers and discussion

In this section, the responses to the questions were collated to reflect the themes and codes emerging from the analysis of each particular issue. The following titles, namely; the main motivation factors, the critical success competencies, BIM maturity, and BIM benefits are the titles for the following subsections, under which the results of the interviews were analysed and discussed.

6.9.2.1 The main motivation of using BIM

According to CS6-1 and CS6-2, there are number of motivation factors that influenced organisation F to implement BIM. Firstly, the organisation mission was a factor in that they wanted to be in a leading position in terms of innovation, and this motivated them to implement BIM. The second factor was the BIM benefits; it was felt that this would help them to operate their development more efficiently. Finally, the Government mandate also motivated organisation F to implement BIM, as CS6-1 and CS6-2 explained:

"To be clear our BIM implementation is not driven by government mandate and is not driven because of the university pressures. It is driven because we want to do something innovated and found that we can do much better not just modelling. CS6-1"

"The designer and contractor were willing to use BIM in our project in first place that pushes us to use BIM. […] Another driver for implementing BIM is government mandate and we want to be ahead of BIM implementation. CS6-2"

Client organisation F ranked their motivation factors as the organisation mission to be a leader in innovation in the construction industry; this influenced their decision to implement BIM in the first place. Moreover, they added BIM benefits as the second motivation factor, which they realised after using BIM; this motivated them to implement it in other projects. However, the Government mandate is still a motivation for them to implement BIM in their projects, although this is ranked third.

6.9.2.2 Critical success competencies for BIM implementation

Under this theme there are three sub themes, namely client leadership, EIR, and data validation:

1. **Client leadership**

   CS6-1 and CS6-2 believe that the client has to lead the BIM implementation process to ensure that the supply chain will produce a BIM model that meets their requirements. In addition, they believe that the client can manage a BIM implementation only if he has sufficient ability to lead, otherwise external expertise can support him to manage BIM information. This was explained by CS6-1 and CS6-2 as follows:

"Certainly, I think first of all the clients need to know BIM because if they not, their supply chain will give them anything and called it BIM. So the clients need to know and understand BIM. Once you understand then you will aware about what benefits you can get from BIM. CS6-1"

"yes if and only if the client has sufficient level of competencies which enable him to lead this process in a proper way and make sure the BIM model will have only what he wants. No, if the client doesn't have enough competencies to do this job so in this case you may need to external expertise to support you to develop your EIR and validate the information coming from the supply chain. CS6-2"

Both interviewees identify several factors as client BIM leadership criteria, and these are; the BIM manager, BIM skills, BIM training, and a BIM champion. This was demonstrated by CS6-1 and CS6-2:

"need information manager because at the end of the day as a client we need to manage the information inside the model rather than the model itself *[…]. CS6-1"*

"The client must have enough BIM skills and training to enable him to understand BIM and how information will present the BIM model. CS6-2"

2. Employer Information Requirements (EIR)

Both interviewees have the same opinion regarding the importance of Employer Information Requirements (EIR). They believe that this document will help them to gather the required information to solve their projects' problems. In addition, they agree that the client needs good BIM understanding and a certain range of competencies to develop an EIR. These competencies can include; BIM standards, data sharing, a BIM champion, and an OIR, as indicated by CS6-1 and CS6-2:

"[…] the EIR is to provide information that can help you to solve your problems in the project. […] I think we need an external help and guidance which will help us to develop our EIR. I think you need to know what you need at the end of the model. CS6-1"

"[…] So I think we need to understand the business side of the project like asset management and facility management. […] The lack is to bring capital and operation teams together. If the client wants to optimise his EIR he needs to bring the facility management team at beginning. CS6-2"

3. Data validation

Client organisation F is currently using an external consultant to validate the BIM models, which are provided by their supply chain. However, both interviewees agreed that having the in-house capability to validate the information will better optimise BIM benefits. In addition, they indicate that they must have some competencies in order to be able to validate the BIM model outcomes. These competencies include; BIM skills, technical expertise, standards, and data sharing. This was explained by CS6-1 and CS6-2:

"[…] For our organisation we recognise that we cannot do it inside so we employ an external facilitator which have the good technical capabilities to check deliverables among data drops. CS6-2"

"if we want to do that in the house we need skills, checking platform, technical expertise, and standards, to do that but currently we don't have the ability to do that. Now we receiving a report from our consultant explain the current model situation and for example how clash detection the have and other details. CS6-1"

According to the participants' answers, a number of competencies have been identified which reflect those that a client must possess to develop an EIR, validate the BIM outcomes, and those that make client capable of leading a BIM implementation process throughout a project lifecycle. Table 6.29 represents these competencies for organisation F.

Table 6.29: Critical success competencies for organisation F

Client role	Required Competencies
Develop EIR	• Standards • Training • Data Sharing method • BIM skills • Education • Organisation mission
Validate BIM model outcomes	• BIM Skills • Data sharing method • Standards • BIM technology • Data protection • Role and responsibilities • BIM champion • Validation process
Client leadership	• BIM committee • Training • Data Sharing • Change readiness

In Table 6.29, it can be seen that organisation F selects different competencies for different roles. Organisation F believes that developing an EIR requires standards, training, data sharing methods, BIM skills, education, and an organisation mission as essential competencies that support a client organisation in asking the right questions. They believe that these competencies will mean that the required skills are in place as well as the ability to share information and ensure these requirements reflect an entire organisation's needs not just a particular project's.

From the same table, it can be deduced that organisation E added new competencies to enable them to validate BIM model outcomes. These competencies include; roles and responsibilities, BIM technology, BIM validation, data protection, and a BIM champion, which emphasises that organisation F has a good understanding of the validation process and what they need in order to validate the information that comes from their supply chain.

For client leadership, organisation F adds a BIM committee and change readiness as new competencies that will enable them to lead a BIM implementation process. Selecting just these new competencies suggests that there is a lack of understanding about BIM leadership inside the organisation; this may be due to the fact that organisation F is still in the early stages of BIM implementation.

In addition, it can be seen that organisation F selects same competencies for different roles, like standards and data sharing methods, and that indicates they believe that being more mature in these competencies will enable a client to move from just developing an EIR to validating the information, and that greater maturity in these competencies will enable a client to lead a BIM implementation process. This emphasises the importance of the maturity level for these competencies and its effects on a client's ability in BIM.

6.9.2.3 BIM maturity

Under the theme of BIM maturity, four sub-themes were elicited, namely the EIR-maturity relationship, maturity improvement, maturity assessment and the maturity level. These are further outlined below:

1. **EIR-maturity relationship**

   Both interviewees agree that developing a client's maturity will help to make the requirements clear to the supply chain, which can lend support to provide them accurately. It can be concluded that organisation F understands that improving their BIM maturity will help them improve their EIR. However, the absence of such a model will leave a substantial barrier in managing BIM as a change process, and in guiding them to plan and implement improvements in BIM uses effectiveness. This was demonstrated by CS6-1:

"[…] while EIR explain to the supply chain what client want at the end and it needs to be simply and let the design and contractor teams make that happened. The EIR needs to be clear about what client want at the end so as much as your maturity is good your EIR will be clear. CS6-1"

2. **The maturity improvement**

The interviewees believe that they need to improve their maturity in order to improve their BIM understanding. Both interviewees agree that this will improve a client's work efficiency and meet their desired quality:

"our work going better more efficiently and at desired quality. CS6-1"

"Increasing your maturity will help you to increase your BIM understanding which helps you to develop your EIR and use the model for operation and maintenance. CS6-2"

Furthermore, it can be seen that organisation F stresses that maturity improvements will help them improve their work in terms of quality and efficiency. Therefore, developing such a BIM maturity assessment model has importance to client organisations.

3. **Maturity assessment**

Both interviewees agreed that they did not assess their organisation against any BIM maturity assessment model, even BIM level 2. CS6-1 confirmed that:

"No framework because we are new in BIM. We are not focusing on BIM level 2. CS6-1"

4. **The maturity level**

Both interviewees indicate that they do not assess their organisation against any organisational maturity model and they do not have any particular level of maturity they are aiming to reach. They only perceive Level 2 BIM as the target for their project, as CS6-1 confirms:

"We only have BIM level 2 as maturity target" [CS6-1]

Organisation F seems not to have heard about the term organisation BIM maturity and focuses on BIM level 2 assessment to evaluate their work progress and future improvements.

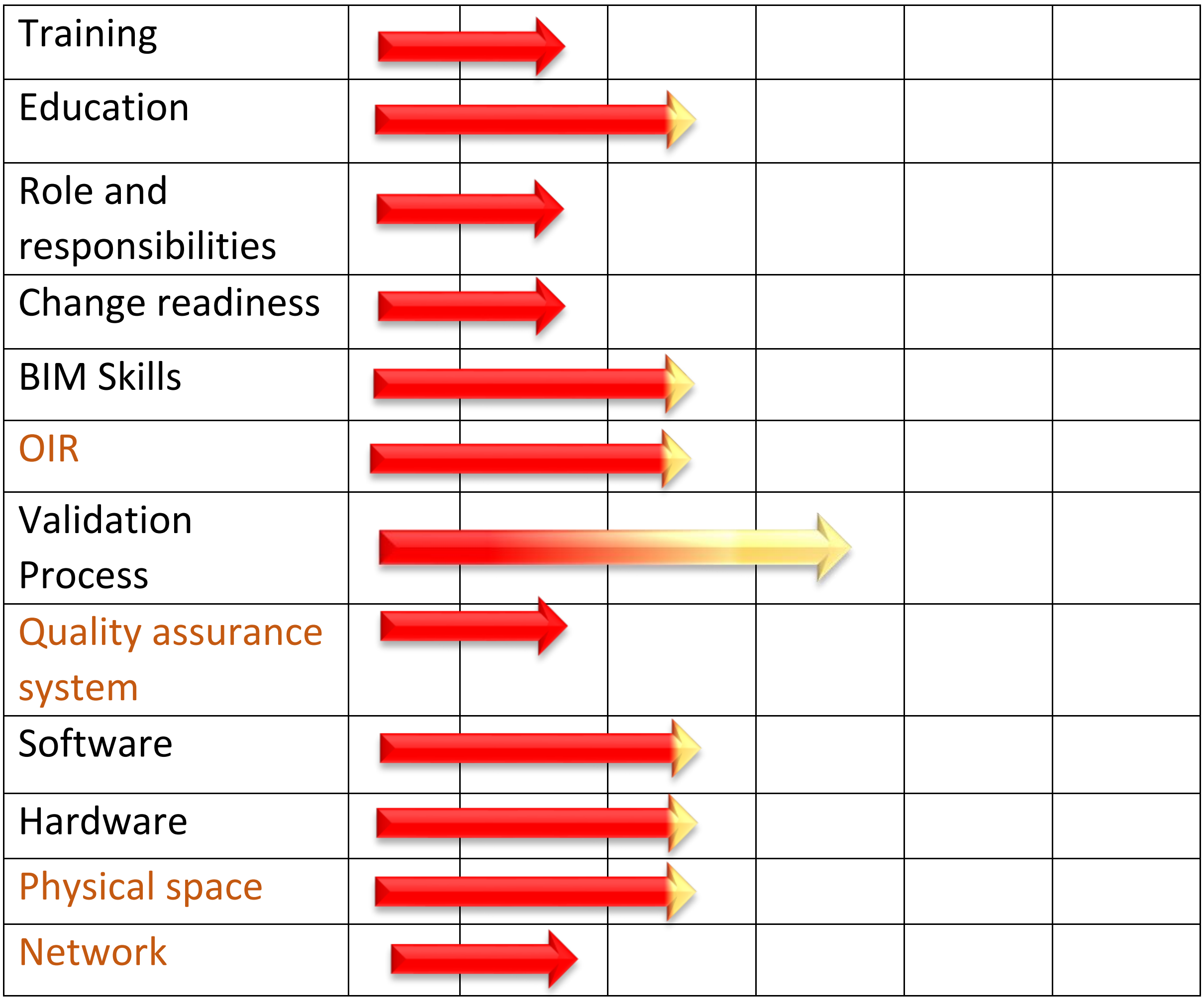
However, the absence of such a maturity model could prevent the organisation from improving the competencies that will enable them to fulfill their role as a client.

Organisation F has been assessed against the proposed BIM maturity model, and Table 6.30 shows the maturity assessment results. In general, for most competencies, they are between level 1 and 2, which can be seen as a low maturity level and this mean that organisation F is in early stages of the BIM implementation process. As previously indicated, the red competencies in this table refer to the competencies that the organisation could not recognise as success factors in the BIM implementation process.

The absence of an organisation maturity model could prevent client F from managing improvements in their competencies' maturity. In addition, it could prevent them from exploring other competencies that may affect their BIM implementation. For these reasons, it can be seen that improving maturity for some competencies and not for others may be guided by personal views and limited BIM experiences. Therefore, providing such a model could help client organisations to explore other competencies that they have not considered and that may affect their BIM implementation. It could also help the client to monitor their BIM maturity development and invest in the right competencies rather than waste time and cost in developing those that may not help them to improve their BIM outcomes.

Table 6.30: Organisation F maturity assessment results

Maturity Elements	Not Exist	Level 1	Level 2	Level 3	Level 4	Level 5
Organisation Mission	→	→				
BIM Vision	→	→				
BIM Champion	●					
Management support	→	→				
Data Sharing	→	→				
Standards	→	→				
Organisation Hierarchy	●					
BIM Committee	●					



6.9.2.4 BIM benefits

Four sub-themes are identified under the BIM benefits theme, which are the benefits-EIR relationship, the benefits-maturity relationship, benefits assurance and desired benefits:

1. **The benefits-EIR relationship**

    Both interviewees believe that there is a relationship between the EIR and BIM benefits. This relationship is developed through creating a clear EIR, which will increase the BIM benefits. This was demonstrated by CS6-1:

    "[…] when your EIR is good enough and has the right questions it definitely leads to gather more and more benefits. CS6-1"

    Believing that there is a relationship between the EIR and the desired benefits of BIM reflects good BIM knowledge and understanding of the organisation. This emphasises that improving knowledge and understanding, or BIM maturity, can help the client to identify the critical success factors that provide support in gathering the benefits through an EIR.

2. **The benefits-maturity relationship**

Both interviewees observe that there is a positive relationship between BIM maturity and BIM benefits. However, they feel that the term maturity is not limited to client maturity but must include all project supply chain maturity. This indicates that client organisation F has a clear understanding of the benefits maturity relationship. In addition, organisation F emphasises the importance of all supply chain maturity improvements, rather than just the client; this highlights the importance of a maturity model in the BIM implementation process. However, the absence of such a relationship can prevent them from adopting a structured improvement plan that will lead to an increase in BIM benefits. As CS6-1 argues:

"[…] so get more benefits is not only depending on your organisation maturity but it also depends on your supply chain maturity […]. CS6-1"

3. **Benefits assurance**

The interviewees believe that they are currently achieving benefits from using BIM in their projects. In addition, they are trying now to benchmark their work in BIM, which will enable them to compare and analyse. As CS6-1 comments:

"we believe that BIM can support and develop our business. Our company spent lots of money in investing in BIM but how that can compare to long term benefits it is difficult to measure. We now don't know if we used BIM in our project will help to deliver that project in time or not. We trying to look now on the percentage of our projects who's finished in time and what are the relation with using BIM in these project. I think we need more time and information to be 100% that BIM can improve our project. CS6-1"

4. **The desired benefits.**

Both interviewees propose different types of benefits, such as managing risk, reducing cost, improving efficiency, improving the design quality, and improving facility management. Mainly the desired benefits are located within design and construction stage which reflect limited BIM understanding. However, using BIM to improve facility management can be considered as a good sign of improvement; this was indicated as follows:

"managing risk, reduce cost, improving efficiency, improve the design quality, and improve facility management. CS6-1"

"To have better outcomes and improve the cost-quality relationship. CS6-2"

A benefits assessment has been carried out on organisation F in order to compare their current benefits assurance level with the maturity assessment results (Table 6.31). It can be concluded from the Table that organisation F is currently lacking in ability to predict some BIM uses benefits, which mainly places their assurance level between 1 and 2. As illustrated, organisation F shows limited improvement in some competencies; this lack of improvement has a direct effect on organisation F's ability to predict some BIM uses benefits. In the same context, a good improvement in some maturity competencies would enhance organisation F's ability to predict other BIM uses benefits. This can give a positive impression of the relationship between BIM maturity competencies and BIM uses benefits.

Table 6.31: Benefits assessment results for organisation F

Current BIM uses	Benefit	Level 1 (Logical)	Level 2	Level 3 (Expected)	Level 4	Level 5(Definite)
Phase Planning	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
	Benefit 7					
Design authority	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
Design review	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					

	Benefit 5					
	Benefit 6					
Clash detection	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					
	Benefit 5					
	Benefit 6					
Record modelling	Benefit 1					
	Benefit 2					
	Benefit 3					
	Benefit 4					

6.9.2.5 Documents analysis

Organisation F runs project A, which is one of the first to deliver fully integrated modelling in a BIM environment across design, construction and Facilities Management (FM). Organisation F wanted a single source of information on the building that everyone could access. It also wanted the electronic management of files linked to 3D models in order to give it a well-organised database. Part of the client's Employer's Information Requirements was to establish a library of components down to the detailed level of wall sockets and radiators. This provides opportunities for managing each item throughout its life from the design to the maintenance of the building. Organisation F believes that meeting EIR targets would not be possible with generic BIM content. The required Level of Detail (LOD) and Level of Information (LOI) together known as the Level of Definition is only achievable with manufacturer specific data.

It would be beneficial to examine current BIM uses in organisation F in order to explore to what purpose BIM has been used and to what extent in terms of project lifecycle stages, as shown in the Table 6.32. It would have provided the chance to investigate the relationship between current BIM uses and client requirements. It can be seen from the Table that organisation F is using BIM at different stages with more use in the design stage, which potentially reflects a limited level of BIM knowledge and understanding.

Table 6.32: BIM uses in organisation F

No	BIM use	Stage
1	Phase planning	Design stage
2	Design authority	Design stage
3	Design review	Design stage
4	Clash detection	Design-construction stages
5	Record modelling	Hand over stage

Early stage BIM requirements

Organisation F has different versions of its EIR, which represents the needs of the departments that created them within the organisation. Creating different versions of an EIR could arise from the nature of BIM implementation within organisation F, which may involve working in silos. Currently, organisation D puts a lot of efforts into producing one format of their EIR that reflects the organisation's needs as one unit.

Current BIM requirements

The latest version of the EIR used by organisation F is the standard EIR template. They use a standard template as a base and include a few amendments to reflect their needs. Trying to use a standard version of an EIR represents a considerable improvement in BIM understanding and knowledge within the organisation and they are currently in a good position to take a lead in their projects. At present, they are using an external consultant to support them in developing a one format EIR. However, they are looking to develop their competencies and improve their in-house BIM skills. The current BIM maturity assessment results also show that organisation F attained very good maturity levels, especially for BIM technology. However, they need to improve some of their competencies, such as introducing a BIM champion, improving standards, the validation process, and a quality assurance system.

6.10 Cross-sectional analysis

A cross-sectional analysis has been carried out to perfom a comparison between the case studies; the aim of this is to produce one view across different themes that represents the UK construction client. A cross-sectional analysis has been carried out for the four main areas, which are; motivation, BIM competencies, BIM maturity, and BIM benefits. These represent the main areas for the BIM implementation process according to both the literature review and the qualitative data analysis. It is worth noting that the cognitive map that has been used in the motivation factors is also considered a template for the other themes, so for this reason it has been shown only in the motivation factor sub-section.

6.10.1 Motivation factors

All the case studies identified different types of factor as motivations for them to implement BIM in their projects. This cross-sectional analysis has been supported by NVIVO 11 program. The cognitive map for the motivation factor is shown in Figure 6.4, which indicates that the clients have been classified into three main types, namely public, private, and mixed. Each identified factor has to follow a different comparison analysis path for inclusion in the final list of motivation factors. A word frequency analysis was used to construct a 'word cloud' (graphic representation of the word frequency) which can help to see common word among the interviewees' responses, to which a content analysis technique was applied. This is shown in Figure 6.5. The word frequency analysis expressed that the Government strategy and the BIM benefits are most frequent factors identified as a motivation for the UK construction client to implement BIM.

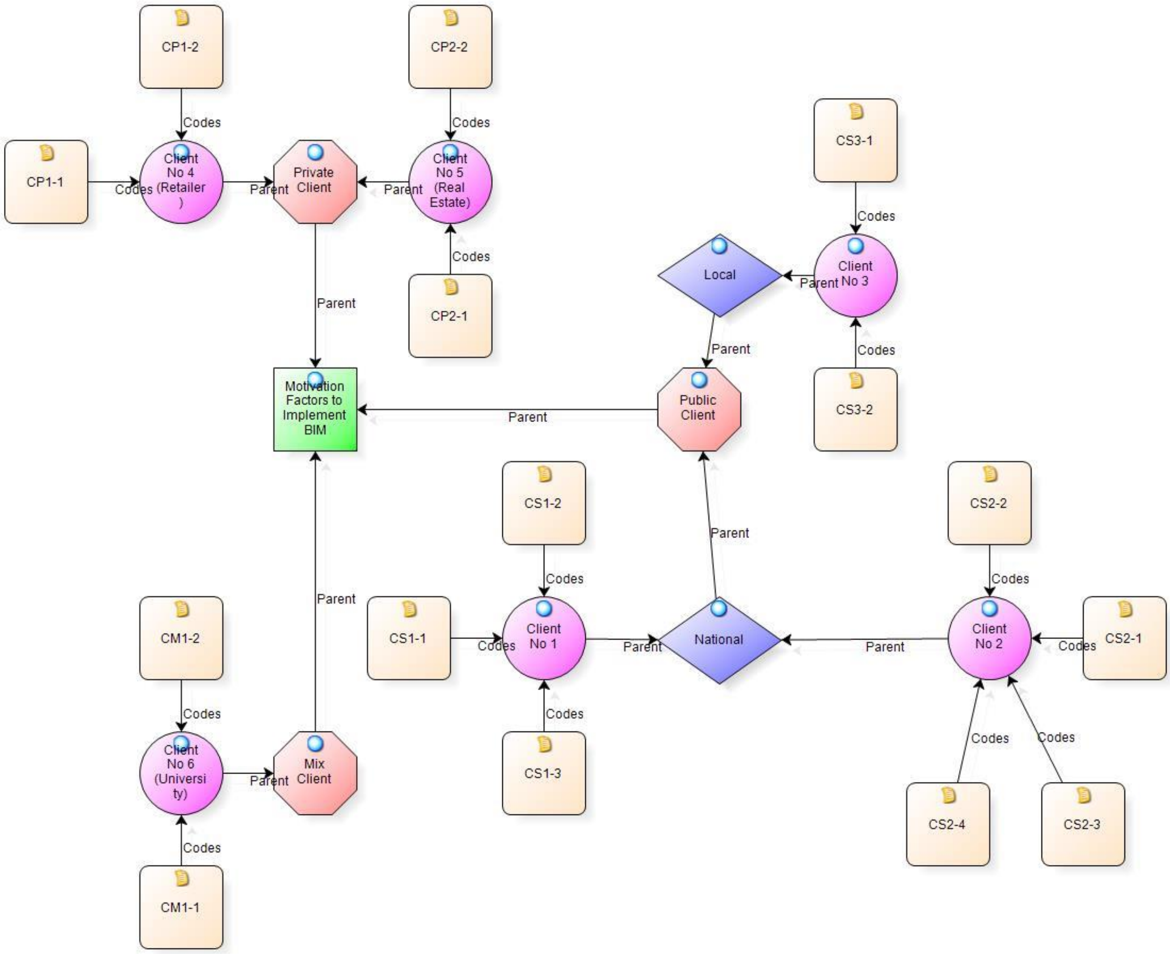


Figure 6.4: Cognitive map for motivation factors

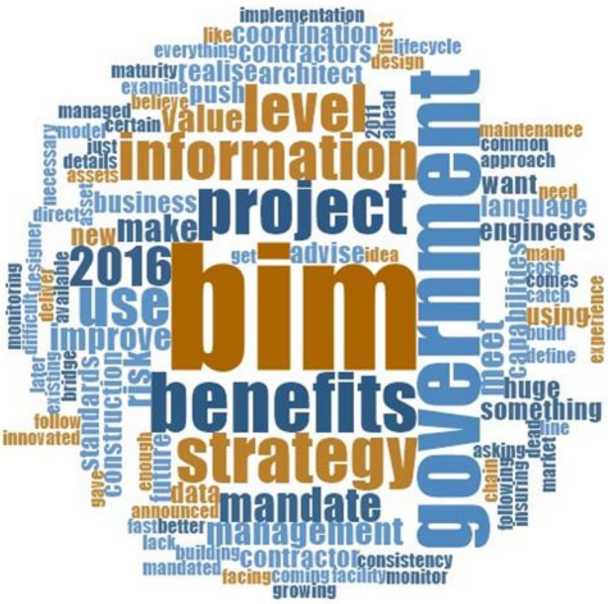


Figure 6.5: Word frequency analysis of motivation factors

The final list of motivation factors regarding client types has been shown in Table 6.33. From the Table, several points can be identified as follows:

1. National public clients have the same motivation factor sequences, which emphasise that the Government mandate was the main motivation factor. In addition, after a period of using BIM, they realised that the benefits can be considered as another motivation to expand their BIM uses among their different types of projects.

2. Despite the prevalence of the Government mandate as a motivation for most clients, BIM benefits are also a motivation factor for all clients to implement BIM. This leads to a conclusion that further clarification would be useful regarding BIM benefits for different types of BIM uses, and how to achieve them. This would potentially encourage BIM implementation amongst UK construction clients who have been considered one of the main barriers to implementing BIM across the whole UK construction industry.

3. Stakeholder advice also has been considered as one of the main motivation factors for client organisations. Due to the UK government strategy regarding BIM implementation, the overall industry BIM knowledge and understanding have been increased significantly. Therefore, the contractors and design firms were convinced of the importance of BIM and start advising client organisations to implement BIM. Despite the importance of stakeholder as motivation factor, however, without clients' leadership and independency it will be difficult to optimise the desired benefits of BIM. Client leadership is vital to the success of any project and in enabling the construction industry to perform to its best; this is because it enables a client to build the requirements that will optimise the proposed project's efficiencies and enable them to validate these project outcomes through all lifecycle stages as have been explained in chapter 2.

Table 6.33: Motivation factor for different types of the client organisation

Motivation factors	Public Client			Private		Mix Client
	National		Local	Retailer	Real Estate	University
	PN1	PN2	PL1	PR1	PRE1	MU1
Rank 1	Government Mandate	Government Mandate	Stakeholder advice	Stakeholder advice	BIM benefits	Organisation Mission
Rank 2	BIM benefits	BIM benefits	BIM benefits	Industry BIM maturity	Government Mandate	Stakeholder advice
Rank 3	Stakeholder advice	Stakeholder advice	Government Mandate	BIM benefits	Industry BIM maturity	BIM benefits

6.10.2 Critical success BIM competencies

The cross sectional analysis has been carried out on the six case studies to identify the required competencies to enable a client organisation to fulfill their roles in developing their EIR, validating their BIM model outcomes, and leading a BIM implementation process. Each role will be discussed individually.

6.10.2.1 Employer Information Requirements (EIR)

Each client identified a number of competencies that enable them to develop their EIR. The 'word cloud' constructed from the word frequency analysis applied a content analysis technique to the interviewees' answers (Figure 6.6). The word frequency analysis identified that understanding BIM is the main challenge to client organisations in developing their BIM requirements. Each client organisation identified different types of competencies that enable them to understand BIM effectively. Moreover, it can be seen that 'standard' has been identified as the most frequent word, which reflects that all clients suggest that a standard as a competency can help them to understand BIM.

Figure 6.6: Word frequency analysis of EIR competencies requirements

Table 6.34 presents the competencies that client organisations identified as improving their ability to develop their EIR. These competencies have been presented according to each client organisation. From the table, different clients identified different types of competencies even though some organisations are considered the same type, such as national clients. Also, several statements can be concluded from the Table as follows:

1. All public clients' emphasis that standards, data sharing, and BIM vision are the core competencies regarding the ability to build their requirements. In contrast, Private clients share the same view as pointed standards and data sharing are the core competencies. However, they are added data protection and BIM skills to core competencies and excluded BIM vision. The main reason beyond this differences is the government control on public client which may demands proper vision before start to implement BIM. The comparison with mix client is not applicable because only one case has been investigated in this research and consider the answers as mix client view is not sufficient.
2. Some competencies have been identified by more than half of the client organisations, such as standards, BIM vision, BIM skills, and data protection which means that these competencies have wide agreement among UK construction clients as essential for BIM implementation. However, only a few were acknowledged by one client only, such as physical space which indicates that each client has different view regarding critical success BIM competencies.
3. As mentioned, most of the client organisations observed that standards, data sharing, BIM vision and BIM skills are the essential competencies that enable client organisations to develop an EIR that reflects their needs and leads to achieving the desired BIM benefits. Indeed, standards help to structure the required information and specify the data format, BIM vision helps to identify where and when these should be used, BIM skills assist in understanding BIM modelling and the outcomes, and finally, data protection supports client organisations to share their information in a secure environment. Therefore, identifying these competencies in particular, reflects a good level of BIM understanding among the participating clients.
4. It is important to note that the level of BIM understanding and knowledge amongst the client organisations may affect their ability to choose the right competencies for their business needs because if client organisations don not understand BIM in term of information, process, benefits, etc, it will really difficult for them to identify what improvement they need to perform. Therefore, providing evidence of a relationship between BIM benefits and maturity competencies can help client organisations to select the most appropriate competencies by matching their business needs with the BIM benefits.

Table 6.34: Required competencies to develop EIR for different types of client

NO	Competencies	Public Client			Private		Mix Client	Frequency Ratio
		National		Local	Retailer	Real Estate	University	
		PN1	PN2	PL1	PR1	PRE1	MU1	
1	Standards	√	√	√	√	√	√	100.0%
2	Data Protection and security	√			√	√		50.0%
3	Physical space	√						16.7%
4	Training	√					√	33.3%
5	Data Sharing method	√	√	√	√	√	√	100.0%
6	BIM Vision	√	√	√		√		66.7%
7	BIM skills		√	√	√	√	√	83.3%
8	Education				√		√	33.3%
9	Organisation mission					√	√	33.3%

6.10.2.2 Validation BIM model outcomes

Clients identified a number of competencies that enable them to validate the information from their supply chain and ensure it meets their needs. The word frequency analysis used to construct the word cloud on which a content analysis technique was applied is shown in Figure 6.7. The analysis identified that the availability of standards and the right information are the main challenges to client organisations in validating the information for their BIM model outcomes. Each client organisation identified different types of competencies that will enable them to effectively validate the outcomes. Moreover, it can be seen that BIM skills have been identified as the most frequent word, which reflects that all clients suggest that BIM skills as a competency can help them review the BIM model and check the outcomes.

Figure 6.7: Word frequency analysis of validation process competencies requirements

Table 6.35 presents the competencies that client organisations identified as necessary to improve their ability to validate their BIM model outcomes. These competencies have been presented according to each client organisation. Different clients identified different types of competencies even though, as before, some organisations are classed as the same type. Also, several statements can be concluded from the Table:

1. All public clients' highlighting that standards, data sharing, BIM skills, data protection, and BIM champion are the core competencies regarding the ability to validate BIM model. In contrast, Private clients share exactly the same view as pointed standards, data sharing, BIM skills, data protection, and BIM champion are the core competencies. This can illustrate that ability to validate BIM model can be supported by certain competencies regardless clients' type.

2. All participating clients proposed that BIM skills, standards, and a BIM champion are the main competencies that will support clients in the information validation process. In addition, data sharing, roles and responsibilities, data protection, BIM technology, and the validation process have been identified by more than half the clients as essential competencies that enable them to validate BIM model information. Identifying these sorts of competencies, such as roles and responsibilities, BIM technology, and BIM champions emphasise the importance of successful collaboration within the entire client organisation; this is due to the clarification of the employee's role and the improvement in their technical abilities. This collaboration represents a critical success factor for any validation process. In addition, the validation process, as

a competency, helps client organisations to establish documentary evidence for current and/or for future validation processes.

3. It can be seen that the participants selected some of the same competencies for developing an EIR and the validation process. This can be seen as evidence that improving some competencies can improve a client's ability to perform different kinds of roles, which can consequently improve the efficiency of the BIM uses. In addition, this can indicate that improving maturity has a significant effect on a client's ability to perform their role.
4. The differences in the selected competencies required to perform the validation role reflect that each client has different needs that can be met by improving different types of competency. Therefore, to avoid investing in the development of non-essential abilities, it is crucial to establish a relationship between maturity competencies and BIM uses benefits as this will enable clients to improve only those that can produce value for their business.

Table 6.35: Required competencies to BIM model outcomes

NO	Competencies	Public Client			Private		Mix Client	Frequencies Ratio
		National		Local	Retailer	Real Estate	University	
		PN1	PN2	PL1	PR1	PRE1	MU1	
1	BIM Skills	√	√	√	√	√	√	100.0%
2	Data sharing method	√	√	√	√		√	83.3%
3	Standards	√	√	√	√	√	√	100.0%
4	BIM technology	√	√		√	√	√	83.3%
5	Data protection	√	√	√			√	66.7%
6	Role and responsibilities		√			√	√	50.0%
7	Network			√		√		33.3%
8	Quality assurance system				√			16.7%
9	BIM champion	√	√	√	√	√	√	100.0%
10	Validation Process	√	√				√	50.0%

6.10.2.3 Client leadership

Clients identified a number of competencies that enable them to lead a BIM implementation process. A content analysis technique was applied to the word cloud for this theme, which was formed from the interviewees' answers; the word cloud is shown in Figure 6.8. The word frequency analysis identified that understanding BIM is the main challenge to client organisations in leading the BIM implementation process. Each client organisation identified different types of competency that will enable them to effectively understand BIM. Moreover, it can be seen that developing an organisation's needs or requirements has been identified as the most frequent word; thus, all clients suggest organisation requirements as a key competency that can help them to understand BIM and consequently lead the implementation process.

Figure 6.8: Word frequency analysis of leadership competencies requirements

Table 6.36 presents the identified competencies that the client organisations proposed; it was understood that these will improve their ability to lead a BIM implementation process. These competencies have been presented according to each client organisation. Different clients identified different types of competency even though some organisations are the same type. Also, the table indicates the following:

1. All public clients' emphasis that standards, data sharing, and OIR are the core competencies regarding the ability to lead BIM implementation process. In contrast, Private clients have completely different view as pointed BIM skills, BIM champion,

and BIM technology are the core competencies. The main reason beyond this difference is the level of understanding regarding BIM implementation leadership and the willingness to be leader. Public clients show good level of BIM leadership understanding and there are in good position to lead BIM implementation process as they have government full support. However, private clients show more caution regarding leadership and currently they are not ready to take this risk. The comparison with mix client is not applicable because only one case has been investigated in this research and consider the answers as mix client view is not sufficient.

2. The participating clients identified that OIR is a unique critical success competency for this role. Without clear requirements that reflect the organisational needs it is difficult for the client to lead a BIM implementation process. In addition, improvements in other competencies, such as BIM skills, BIM technology, standards, and data sharing, have their impact on improving a client's ability to lead a BIM implementation process.
3. As mentioned previously, the differences in selecting the required competencies to perform the validation role suggests that each client has different needs that can be met by improving different types of competency. Therefore, to avoid investing in developing unnecessary abilities, it is crucial to establish a relationship between maturity competencies and BIM uses benefits. This will enable clients to improve only the competencies that can produce value for their business.

Table 6.36: Required competencies to enable the client to lead BIM implementation

NO	Competencies	Public Client			Private		Mix Client	Frequency Ratio
		National		Local	Retailer	Real Estate	University	
		PN1	PN2	PL1	PR1	PRE1	MU1	
1	BIM Champion				√	√		33.3%
2	BIM manager				√		√	33.3%
3	BIM committee				√			16.7%
4	BIM Skills		√	√	√	√		66.7%
5	Training				√		√	33.3%
6	BIM technology		√	√	√	√		66.7%
7	Management support.			√	√			33.3%
8	Organisation information requirements	√	√	√		√		66.7%

9	Data Sharing	√	√	√			√	66.7%
10	Standards	√	√	√		√		66.7%
11	Quality assurance		√					16.7%
12	BIM Vision			√		√		33.3%
13	Change readiness					√	√	33.3%

6.10.2.4 Critical success competencies summary

It can be concluded that the case studies selected different types of competency to fulfill their roles as client organisation; this ranged from developing their EIR and moving to information validation to finally leading BIM implementation process. Table 6.37 shows these competencies listed with their frequencies amongst the client organisations. This Table reveals several conclusions, as follows:

1. The organisation hierarchy is the only one not identified by participating client organisations as a critical success competency. This suggests that the proposed BIM maturity assessment model, which has been developed through a literature review and from expert opinion, can be used to assess the UK construction clients against the BIM implementation process.
2. Each client organisation has a unique business case that reflects their needs, differing even between the same client type. This business case will direct their BIM uses selection and the required competencies that will enable them to improve their current business through a BIM implementation.
3. The level of BIM understanding and knowledge within client organisations will also affect the client's ability to choose competencies which enable them to fulfill their role. Therefore, a client organisation needs a maturity model that can be used for self-assessment in order to identify weaknesses and strengths to guide future improvements.
4. The differences in selecting the required competencies to perform a validation role reflect that each client has different needs that can be met by improving different types of competency. Therefore, to avoid investing in the development of unnecessary competencies, it is important to establish a relationship between maturity competencies and BIM uses benefits. This will enable clients to improve only those competencies that can produce value for their business.

Table 6.37: Critical success competencies for UK construction client

Maturity Element/Client Type	PN1	PN2	PL1	PR1	PR2	M1	Frequency Ratio
STRATEGY							
Organisation Mission					√	√	33.3%
BIM Vision	√	√	√		√		66.7%
BIM Champion	√	√	√	√	√	√	100.0%
Data Sharing	√	√	√	√	√	√	100.0%
Management Support			√	√			33.3%
BIM Committee				√			16.7%
Standards	√	√	√	√	√	√	100.0%
Organisation Hierarchy							0
PEOPLE							
Training	√			√		√	50.0%
Education				√		√	33.3%
Role and responsibilities		√			√	√	50.0%
Change readiness					√	√	33.3%
BIM Skills	√	√	√	√	√	√	100.0%
PROCESS							
OIR	√	√	√		√		66.7%
Validation Process	√	√				√	50.0%
Quality assurance system	√	√		√		√	66.7%
TECHNOLOGY							
Software	√	√	√	√	√	√	100.0%
Hardware	√	√	√	√	√	√	100.0%
Physical space	√						16.7%
Network			√		√		33.3%

Therefore, achieving client BIM objectives does not necessarily mean that a client must improve all BIM competencies, as the previous maturity model suggests. Instead, a client's business needs will assist in the identification of required competencies and the level of improvement needed to help the client achieve their desired benefits. In addition, it can be seen that some clients chose the same competencies for different roles, which means that the client is aware that improving the maturity of these competencies will help them to improve their BIM ability and perform different type of roles; for example, moving from just developing an EIR to validating the information may help them to lead a BIM implementation process, as shown in Figure 6.9. It can be concluded there are some certain competencies that client organisations need to develop in order to fulfill certain role. For example, developing EIR require from client organisations to develop certain type of competencies such as BIM vision, standards, data sharing, and BIM skills. In addition, information validation role also requires certain competencies such as data protection, BIM champion, and BIM technology. Improving client organisations ability to perform these two roles and improving OIR as a competency will allow them to lead BIM implementation process across their supply chain and increase their chance to optimise the desired benefits of BIM uses. It is also worth to mention that connecting clients' roles with certain competencies not necessarily means that the other competencies are not important but it will help client organisation to set up their development priorities in limited time and/or cost conditions.

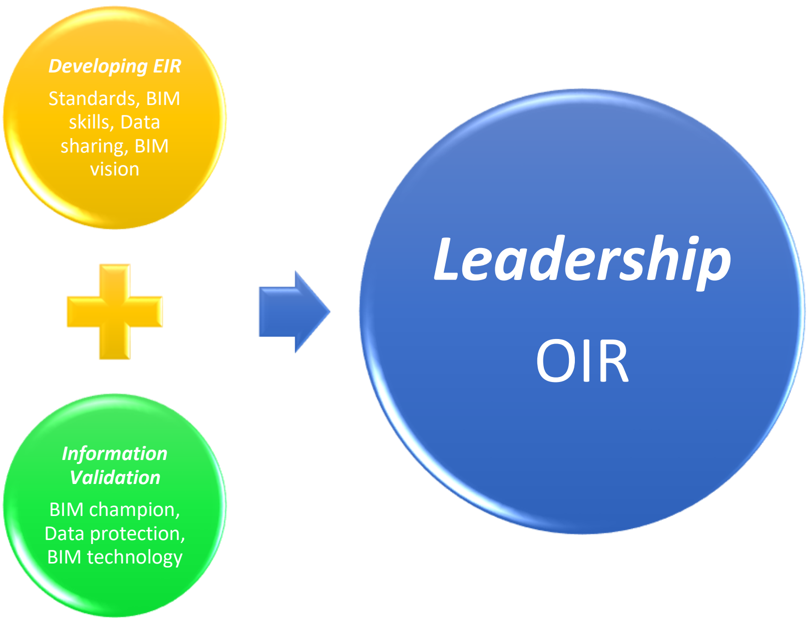


Figure 6.9: Critical success competencies for client main roles

6.10.3 BIM maturity

It can be noted that the participating client organisations were aware of the importance of developing maturity in terms of improving a clients' ability to express their requirements and improve their chance of achieving the desired BIM benefits. However, the absence of a model that provides guided development steps can prevent clients from improving their BIM understanding and knowledge. In addition, it can be seen from the maturity assessment results across the six case studies that clients are mature in certain competencies and still at a basic development level for others; this suggests that currently, client organisations have no guide to select and improve competencies that affect their businesses. Without such a guide, client organisation are more likely to work randomly in the development of BIM competencies, which may cost them significant effort without valuable return. All the aforementioned points indicate that developing an organisation BIM maturity assessment model could be crucial for the UK construction client in better managing the significant change that BIM implementation process requires and to guide their efforts in making valuable improvements in terms of their business needs.

6.10.4 BIM benefits

Each client organisations have different types of BIM uses. Some of them has been used BIM mostly for design and construction stages only while the other has the ability to extend their BIM uses to cover in-use stage. Using BIM in different areas reflects that each client organisation has different desired benefits of BIM. Therefore, providing the requirements to use BIM in these areas is crucial for client organisations in order to increase their chance to achieve their desired benefits. Providing a maturity model connected with benefits will help client organisations significantly to invest only on the required competencies.

Most clients were aware of the relationship between BIM competencies and BIM benefits. They explained their understanding about this relationship by suggesting that improving BIM competencies will increase BIM benefits. However, despite their understanding and awareness they were unable to formulate this relationship in a way that could help a client organisation select appropriate competencies to optimise their current BIM uses benefits. In addition, the clients need to know which level of maturity would enable them to achieve their desired benefits without wasting time and cost in invaluable improvements and developments.

In the same context, the benefits assurance assessment results reveal that client organisations are able to predict some benefits accurately and not able in others which is reflected directly in their BIM competencies current maturity level. The limitations in certain competencies prevent the client from asking the right question in their EIR, such as the level of detail, and how and when they need certain information. These limitations have a direct effect on the BIM model outcomes, which can subsequently lead to a loss of valuable benefits. Therefore, it is crucial for client organisations to identify a relationship between BIM maturity competencies and BIM uses benefits that will help them improve only those competencies that are able to provide value to their business by using BIM in project lifecycle.

6.11 Summary

This chapter presented the procedures undertaken to validate the proposed BIM maturity competencies. The development and deployment of qualitative data collection techniques and the analysis procedures to interpret the results were described. This chapter presented the findings of the case studies. Throughout this chapter, the proposed BIM maturity competencies have been considered valid and will be used in the next step of validation. The next chapter presents the second validation step which will be used to formulate the relationship between BIM maturity competencies and BIM uses benefits by using descriptive and advanced quantitative analysis techniques on the online questionnaire responses. In addition, using the formulated relationship to assess BIM implementation in the previous six case studies.

Chapter 7: Quantitative Data Analysis

7.1 Introduction

In the previous chapter, the qualitative data collection and analysis were discussed. This chapter represents the second validation step, namely to accomplish one of the main objectives of the study by holistically investigating the relationship between BIM maturity competencies and BIM uses benefits. This chapter discusses the process of exploring this relationship through the data collection and analysis procedures for the questionnaire survey used in the validation process. Following this, the quantitative methods employed as part of the mixed method research are presented. Sixty-five from 26 organisation-based responses to the questionnaire survey are analysed, and conclusions drawn from the data are discussed.

7.2 Data Collection Procedures

More than one hundred invitations were sent via email to the proposed participants. The invitation criteria were, to; firstly, be employed in a client organisation, and secondly, be engaged in the BIM implementation process for that organisation. The questionnaire is structured into three main sections. In the first section are the general questions that mainly focus on participant's background and information related to their organisation. The second section assesses the participant's organisation against the proposed BIM maturity matrix. This assessment contains questions under four main categories: strategic environment, people, process, and technologies. Each question represents one of the BIM maturity competencies where the possible responses represent the maturity levels ranging as follows; from '0=not exist', '1=initial', '2=identified', '3=managed', '4=integrated', and finally to '5=optimised'. The third and final section focuses on BIM uses benefits, which contain an introduction page where all the benefits assurance levels have been defined to help the participant understand the classification philosophy before responding to the questions. As mentioned previously, 21 BIM uses have been identified, which represents the potential areas in which the client can use BIM. All BIM uses have been presented in the questionnaire with their corresponding benefits. However, the participants were given the freedom to choose between these BIM uses to reflect their actual BIM current uses in their organisation. For each BIM use, there are two main stages; the first will determine whether the participants are currently using BIM in that area. If they answer yes, this will lead them to the next stage where all BIM use benefits assessment questions have been demonstrated. The same follows with maturity, where the BIM benefits assurance is divided into five levels, starting from '1= Logical', 2='Intermediate level', '3=expected', 4= 'Intermediate level', and finishing with '5=definite'. The last page of the questionnaire contains thanks and an appreciation letter to the participant. Finally, the online questionnaire design and questions are detailed in Appendix D.

7.3 Data analysis procedure

Each individual question/statement in the maturity and benefits section of the questionnaire is referred to as 'scaled data' where multiple questions/statements are combined for analytic purposes (Bryman and Cramer, 2009). According to Saunders et al. (2009), descriptive statistics report the central tendencies of scaled data. Also, a correlation analysis will be carried out to identify the relationship between maturity competencies and BIM uses benefits. In the presentation of the findings of the data, questions relating to each part that emerged from the conceptual framework will be discussed individually before the final testing of the overall framework is presented.

Figure 7.1: Quantitative analysis procedure

The analysis procedure contains several steps, as shown in Figure 7.1. These steps have been discussed in detail as follows:

1. **Data collection and download:** More than one hundred invitations were sent via email and the LinkedIn website to proposed participants. The survey has been left open for more than one year to collect as many validated answers as possible. All collected data have been download and saved from the Survey Monkey website and saved in different places to ensure it will not be lost. In total, sixty-five participants' responses have been downloaded.
2. **Validity check:** As an essential step of analysing the data, the missing responses from the questionnaire were addressed. Often in questionnaires, missing data can exist for the following legitimate reasons: the participants refuse to answer the questions (no response), the respondent does not know the answer or has an opinion (no opinion), or the participant mistakenly omits the question (Grilo and Jardim-Goncalves, 2010; Niculescu and Gu, 2012). All participants' answers have been checked to make sure they were valid. Only 65 responses were valid with 68.34% valid ratio. Most of the invalid answers come from participants who did not complete the questionnaire and just filled in the general questions or the maturity questions. Without answering all questions, it is impossible to run a correlation analysis to identify the relationship between BIM maturity competencies and BIM uses benefits.
3. **Descriptive analysis:** Descriptive statistics are brief descriptive coefficients that summaries a given data set; these can be either a representation of the entire population or a sample of it. Descriptive statistics are broken down into measures of central tendency and measures of variability, or spread. Measures of central tendency include the mean, median and mode, while measures of variability include the standard deviation or variance, and the minimum and maximum variables (Saunders et al., 2009). In addition, internal consistency needs to be checked, which is the concept of correlating responses to a question with all other responses to the questionnaire to ensure internal consistency (Saunders et al., 2009). Cronbach's Alpha is the most common method of checking the internal consistency of scaled data and is used to check for internal consistency of the data (Saunders et al., 2009; Gliem & Gliem, 2003). However, this analysis is conducted for all the scaled item responses and not for each individual item, as suggested by (Gliem and Gliem, 2003). Descriptive analysis results will be discussed individually for each question in a separate section. However, the descriptive analysis for each BIM use will be explained with correlation analysis to conclude a general view regarding each BIM use.

4. **Inferential analysis:** This type of analysis can be defined as a set of measurements can almost always be regarded as measurements on a sample of items from a population of these items, as it is usually impractical or impossible to measure every item in the population. Thus we have to make inferences about the population from the sample. Inferential analysis can help determine strength of relationship within a sample. In other words, it can be used to assess the strength of the impact of independent variables on outcomes. The following types of inferential analysis are relatively common which are Chi Square Statistic, Anova, Correlation, and Regression. While, this research aims to find the relationship between BIM maturity competencies and BIM uses benefits then correlation analysis will be used. Correlation is a bivariate analysis that measures the strength of association between two variables. In statistics, the value of the correlation coefficient varies between +1 and -1. When the value of the correlation coefficient is exactly ± 1, then it is said to be a perfect degree of association between the two variables. As the correlation coefficient value moves closer towards 0, the relationship between the two variables becomes weaker. Usually, in statistics, there are three types of correlation: Pearson, Kendall rank and Spearman. The difference between the Pearson correlation, on one hand, and the Spearman and Kendal rank correlation on the other is that the Pearson is most appropriate for measurements taken from an interval scale, while Spearman and Kendal are more appropriate for measurements taken from ordinal scales. Examples of interval scales include ‘temperature in Fahrenheit’ and ‘length in inches’, in which the individual units (1 degree Fahrenheit, 1 inch) are meaningful. Things like ‘satisfaction scores’ or maturity levels tend towards the ordinal type since it is clear that ‘5 happiness’ is greater than ‘3 happiness’. While the analysis aims to find the relationship between maturity competencies and BIM uses benefits, which are classified as ordinally scaled, Spearman's correlation coefficient and Kendal rank have the ability to measures the strength of association between two ranked variables, which represented in this study by maturity levels and benefits assurance levels. There are difficulties associated with using Spearman’s test with data from either very small, namely less than 7, or large samples, namely larger than 60 (Saunders et al., 2009). For this research, as the minimum data sample collected is seven then Spearman’s correlation will be used for all BIM uses.

5. **Generic summary**: involves preparing the final table that explains the relationship between BIM uses benefits and BIM maturity competencies. In addition, the implication of these competencies on the client's ability to achieve the desired benefits will also be discussed.

7.4 Descriptive analysis

Quantitative research may produce a huge amount of information, so to make sense of this data it needs to be summarised so that the reader has an idea of the typical values in the data, and how these vary. Descriptive statistics were used to describe or summarise the data so that the reader can construct a mental picture of the data and the people, events or objects. All quantitative studies will have some descriptive statistics, as well as frequency tables. For example, this will involve the sample size, maximum and minimum values, averages, and measures of variation of the data about the average. In many studies, this is the first step, prior to conducting more complex inferential analysis. For all inferential analysis, the SPSS 23 program was used. As discussed in Chapter 4, the two main types of descriptive statistics encountered in this research are measures of central tendency, (averages) and measures of dispersion.

Nevertheless, a test of the questionnaire reliability was first carried out in order to study the internal consistency. The reliability of an instrument is the degree of consistency that is attributed to that which it is supposed to be measuring (Grilo and Jardim-Goncalves, 2010; Niculescu and Gu, 2012). Cronbach's alpha is an acceptable and common method for checking the internal consistency of data (Lee, 1991); however, its use is suggested when the questions/items used are measuring a related construct. In the case of this research, all statements are presented to validate the conceptual framework that aims to explain the relationship between BIM maturity competencies and BIM uses benefits. Cronbach's alpha, as calculated for the scaled items in the statistical software SPSS 23, is presented in Table 7.1. Gliem and Gliem (2003) propose that, if the alpha value is above 0.8, it indicates a good internal consistency within the data. For the various fields in this questionnaire, values of Cronbach's alpha ranged from 0.796 to 0.964, which means this range is excellent. The alpha for all 41 validated responses over the sixteen statements was found to be 0.911. Hence, the evidence presented suggested that the questionnaire was valid and reliable.

Table 7.1: Cronbach's alpha for each question and the entire questionnaire

No	Field	Cronbach's alpha
1	Maturity assessment	0.941
2	Existing condition modelling benefits assessment	0.836
3	Cost estimate benefits assessment	0.941
4	Phase planning benefits assessment	0.91
5	Design authority benefits assessment	0.929
6	Design review benefits assessment	0.94
7	Engineering analysis benefits assessment	0.918
8	Energy analysis benefits assessment	0.866
9	Lighting analysis benefits assessment	0.926
10	Sustainability evaluation benefits assessment	0.964
11	Code validation benefits assessment	0.909
12	3D Coordination benefits assessment	0.91
13	Construction system design benefits assessment	0.941
14	Site analysis benefits assessment	0.795
15	Digital fabrication benefits assessment	0.954
16	3D Control and planning benefits assessment	0.937
17	Record model benefits assessment	0.929
18	Asset maintenance scheduling benefits assessment	0.96
19	Asset systems analysis benefits assessment	0.935
20	Asset management benefits assessment	0.831
21	Space management and tracking benefits assessment	0.95
22	Disaster management benefits assessment	0.964
	Total	0.911

7.4.1 Participants BIM experience

The participants' experiences in BIM are shown in Figure 7.2. Of the participants, 22.8% had less than one year's BIM experience, whilst 45.6% had between two and five years, and 21% had between five and 10 years. Finally, 10.6% of the participants had more than 10 years BIM experience.

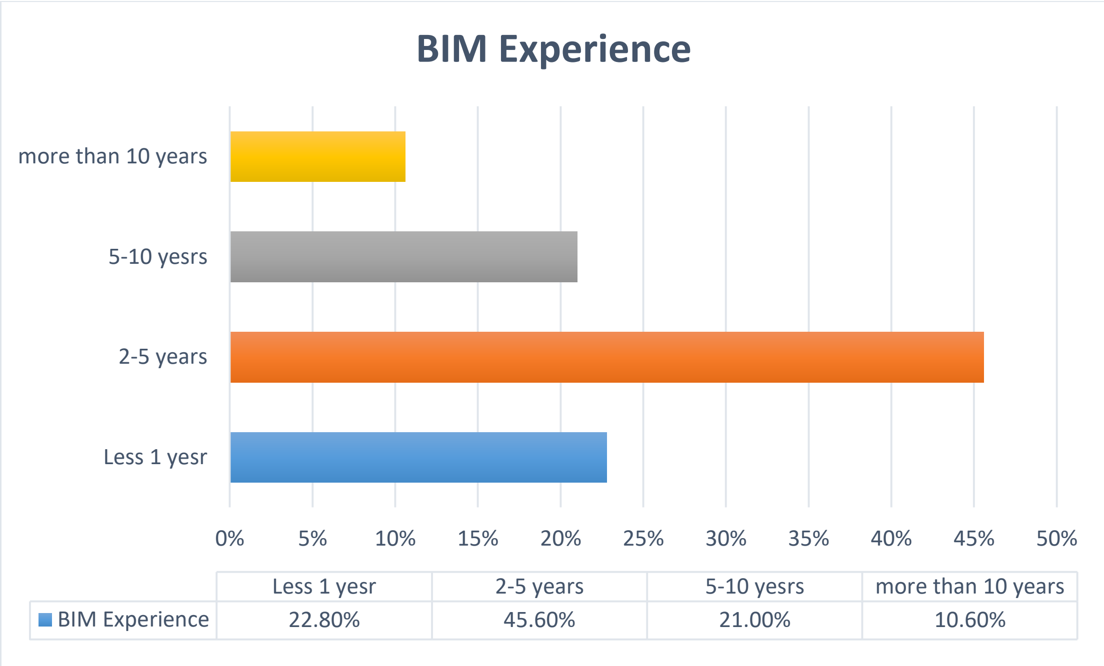


Figure 7.2: Participants' BIM experience

The majority of the participants had between two and five years BIM experience, which may reflect the effect of the UK Government's recent mandate to increase the number of people who are involved in BIM implementation. However, the percentage of the people who have more than 10 years BIM experience is 10.6% lower; this suggests a lack of people who are highly experienced in BIM, which could prevent the adoption of BIM achieving a high level of efficiency.

7.4.2 Participants BIM position

It is useful to identify the current positions of the participants to check if they are qualified to answer the survey questions. The highest number of responses, 41.67%, identified as working as a BIM manager, which currently represents the most common role in the BIM market (Porwal and Hewage, 2013). Furthermore, the positions BIM coordinator and BIM technician represent 28.3% and 25%, respectively, and this could reflect common roles now operating within BIM implementation in client organisations. BIM consultants were the group with the lowest response rate of only 5%; this result could be due to a lack of people with a high level of BIM experience who can perform a BIM consultancy role (Figure 7.3).

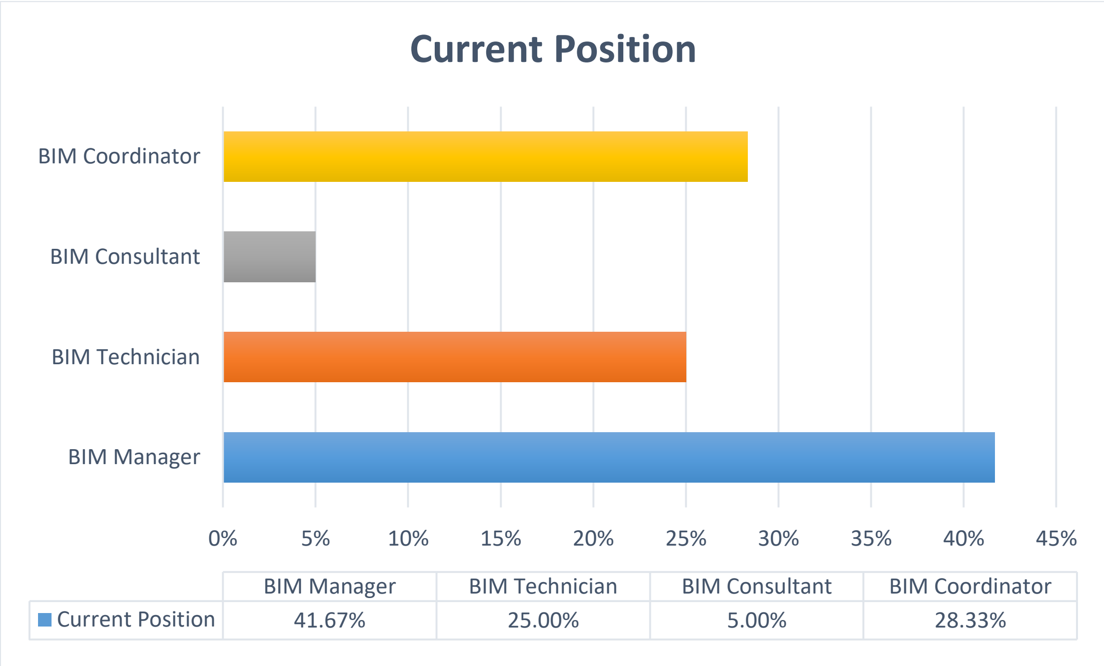


Figure 7.3: Participants’ current position

7.4.3 Participants client Type

It is crucial to identify participants' organisation types as public, private, or mixed client due to the effect on current BIM implementation and desired BIM benefits, as explained in Chapter Six. More than half of the participants were found to be from private client organisations, while those from public client organisations represent 38.67%. Only 10.2% were from mixed clients (Figure 7.4). This survey involved mix of client types, which enhances the ability of the questionnaire to represent the range of UK client organisations. In addition, this study attracted more private clients due to its aims to clarifying BIM uses benefits which has been identified as the main motivation factor to private clients.

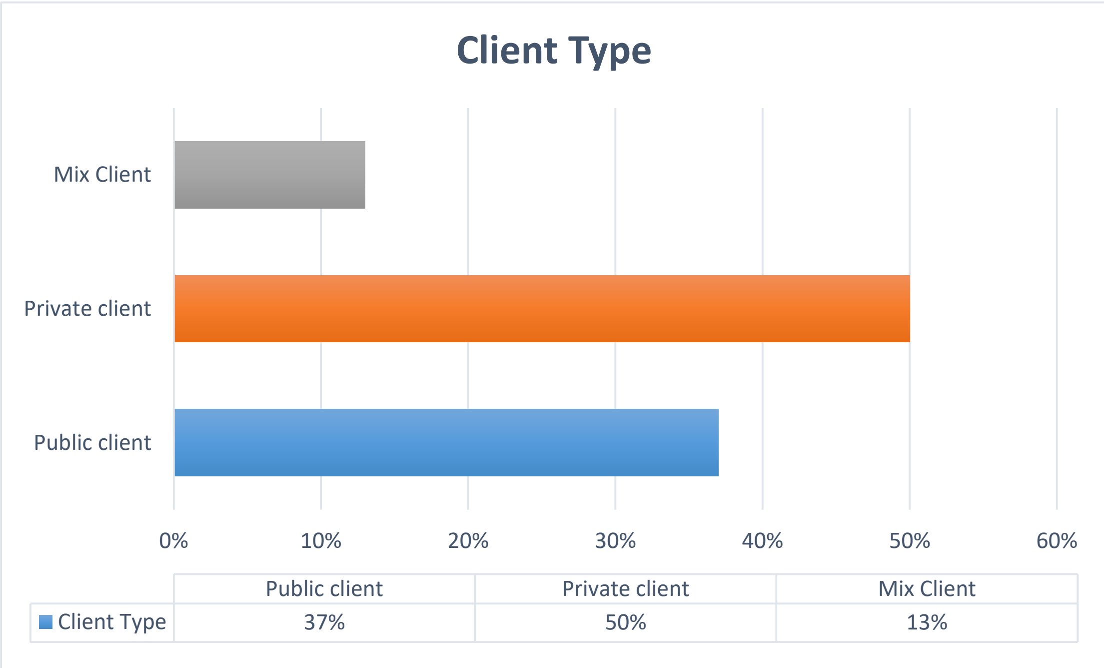
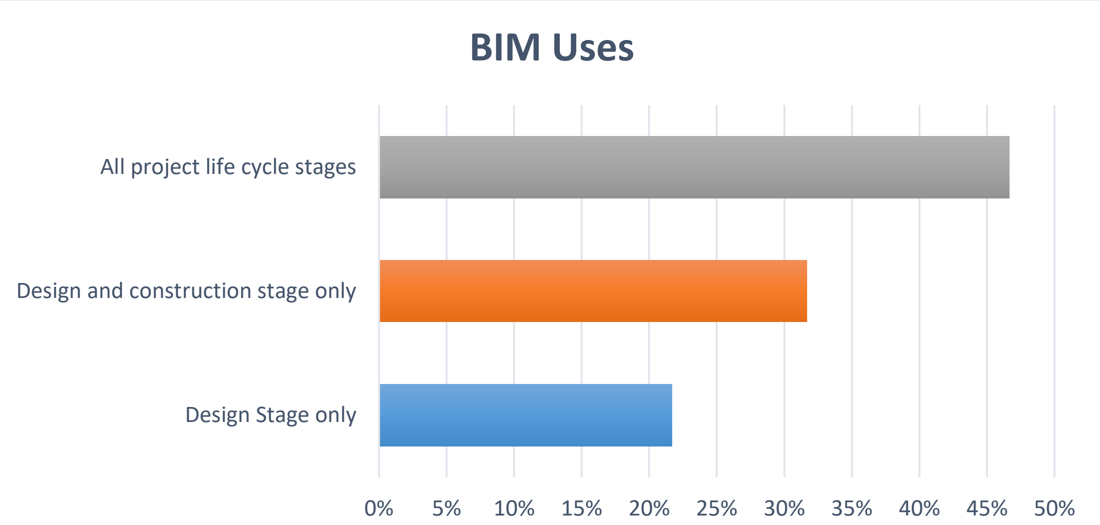


Figure 7.4: Participants' organisation type

7.4.4 Current BIM uses with respect to project life cycle stages

In relation to BIM uses frequencies, it can be concluded that most of the participants are using BIM at all stages of their project lifecycles (Figure 7.5). This indicates that BIM can produce benefits for the client at any time throughout the project lifecycle. The reason why some clients are only currently using BIM in the design, or design and construction stages is due to limited client ability in applying BIM beyond the construction stage which request considerable level of BIM knowledge and understanding. This could reflect their ability to build a good EIR or validate the information coming from their stakeholders.



	Design Stage only	Design and construction stage only	All project life cycle stages
BIM Uses	21.67%	31.67%	46.67%

Figure 7.5: BIM uses frequencies

7.4.5 Maturity Competencies

The maturity assessment results for all participants will be discussed to establish the current BIM maturity level for UK construction clients. Each BIM maturity category is discussed below:

1- **BIM maturity strategic competencies**

Table 7.2 below shows the assessment results for all BIM strategic competencies and the descriptive analysis for each competency. It can be seen that most of the competencies, such as BIM champion, management support, standardisation, and organisation hierarchy, are between level 1 and level 2, which could be considered a low level of maturity. However, organisation mission, BIM vision, and data sharing appear differently from the previous competencies where greater percentages from the client organisation reached a good and high level of maturity. This suggests that UK clients seem ambitious regarding their BIM implementation throughout their project lifecycle. Meanwhile, 40% of the participants did not have a BIM committee or had an ad-hoc one, and this suggests that most of the clients are not aware of that a BIM committee as a competency may support BIM implementation within a client organisation.

The descriptive analysis shows that the median for most of the competencies range between 2 to 3, which suggests that these competencies are at a medium maturity level. The only exceptions that have been found are for management support, which is over three, and thus indicates a good maturity level, and for the BIM committee, which is 1.85 and thus could indicate a low maturity level. From the standard deviation results, it can be concluded that most of the competencies have a high standard deviation, which implies that the data points are spread out over a wide range of maturity levels. This can lead to conclude that UK construction clients are currently have different level of BIM maturity and it cannot be give one maturity level to reflect the current situation.

Table 7.2: BIM maturity assessment results for strategic competencies with descriptive analysis

No	BIM maturity competencies	Assessment results %						Descriptive analysis		
		L0	L1	L2	L3	L4	L5	Median	Mean	Standard deviation
Strategic competencies										
1	Organisation Mission	7.1	19.0	11.9	21.4	14.3	26.2	2.81	3.00	1.66
2	BIM Vision	7.1	21.4	9.5	23.8	23.8	14.3	2.65	3.00	1.52
3	BIM Champion	0.0	28.6	26.2	16.7	14.3	14.3	2.38	2.00	1.36
4	Management Support	9.5	21.4	31.0	9.5	4.75	23.85	2.69	2.00	1.68
5	Data Sharing Method	6.0	16.7	19.0	16.7	34.5	7.1	3.04	3.50	1.29
6	Standardisation	0.0	21.4	35.7	11.9	23.8	7.1	2.50	2.00	1.25
7	Organisation Hierarchy	0.0	31.0	31.0	19.0	9.5	9.5	2.23	2.00	1.22
8	BIM committee	21.4	19.0	26.2	14.3	9.5	9.5	1.85	2.00	1.51

2- BIM maturity People competencies

Table 7.3 demonstrates the assessment results for all BIM people competencies and the descriptive analysis for each competency. From the Table, it can be seen that most of the competencies are between levels 1 and 2, which could be considered a low level of maturity. However, the BIM skills competency shows a higher level than the others, which could be considered a medium maturity level. The above result highlights the current weaknesses in people-based BIM competencies within client organisations, which may be affected by the current UK clients' aim to focus on the project level (achieving level 2) and to depend on external consultants rather than develop their current employees' BIM competencies. In addition, client ignorance of the existence of these competencies affects their improvement.

The descriptive analysis shows that the median for most of competencies ranges between 2 and 2.5; this implies that these competencies are at a medium to low level of maturity. The only exceptions that have been found are for BIM skills, which is over 2.5. From the standard deviation results, it can be concluded that most competencies have a low to medium standard deviation, which indicates that the data are clustered closely around the mean. Thus, it can be concluded that the participants' organisations are still at a low BIM maturity level regarding their people competencies. The main exception to this is for level of readiness, which has a high standard deviation which means that currently UK construction clients have different views regarding this competency, some of them realise the importance of this competencies and improve it to reach high maturity level while the others still in low maturity level.

Table 7.3: BIM maturity assessment results for people competencies with descriptive analysis

No	BIM maturity competencies	Assessment results %						Descriptive analysis		
		L0	L1	L2	L3	L4	L5	Median	Mean	Standard deviation
People competencies										
9	Training	2.4	31.0	38.1	9.5	14.3	4.8	2.12	2.00	1.22
8	Education	4.8	23.8	35.7	14.3	14.3	7.1	2.27	2.00	1.29
10	Roles and Responsibilities	4.8	28.6	42.9	4.8	9.5	9.5	2.00	2.00	1.24
11	Level of Readiness	2.4	26.2	26.2	19.0	0.0	26.2	2.50	2.00	1.58

No	BIM maturity competencies	Assessment results %						Descriptive analysis		
		L0	L1	L2	L3	L4	L5	Median	Mean	Standard deviation
12	Skills	0.0	16.7	14.3	47.6	16.7	4.8	2.69	3.00	1.07

3- BIM maturity process competencies

All the BIM process competencies assessments and the descriptive analysis results have been shown in Table 7.4. It is evident that more 50% of the participants evaluated their processes competencies, such as OIR and validation processes, at between level 1 and level 2, which could be considered a low level of maturity. However, the quality assurance system competency is relatively equally distributed between levels 1 to 4. The above result highlights that, despite Government efforts to simplify the OIR through BS 1192-3, only 25% of clients have integrated it within their organisation's current process. These client behaviours may have resulted from a lack of understanding about the importance of process competencies on BIM implementation, which can be minimised by connecting these competencies with BIM benefits.

The descriptive analysis shows that the median for most competencies ranges between 2 and 2.46, which indicates that these are at a medium to low level of maturity. The standard deviation results indicate that the process competencies have a low standard deviation, which shows that the data are clustered closely around the mean. This also indicates that the participants' organisation may lack development in their BIM process competencies.

Table 7.4: BIM maturity assessment results for process competencies with descriptive analysis

No	BIM maturity competencies	Assessment results %						Descriptive analysis		
		L0	L1	L2	L3	L4	L5	Median	Mean	Standard deviation
Process competencies										
13	OIR	NA	26.2	26.2	21.4	14.3	11.9	2.46	2.00	1.34
14	Validation Process	NA	26.2	40.5	7.1	23.8	2.4	2.31	2.00	1.17
15	Quality assurance system	NA	38.1	19.0	21.4	21.4	0.0	2.27	2.00	1.13

4- BIM maturity technology competencies

The assessment results for all BIM technology competencies are shown in percentages and the descriptive analysis for each competency is illustrated in Table 7.5. It can be concluded that more 50% of the responders evaluated their technology competencies at between levels 1 and 2; this could be considered a low level of maturity. However, 19% of the participants stated that they are fully mature in software and hardware competencies. As explained in Chapter 2, the client role in BIM implementation may not necessarily require full maturity in software and hardware, as the client mainly needs software and hardware to read, validate, and share BIM models, rather than create BIM models.

The descriptive analysis shows that the median for most of the competencies ranges between 2 and 2.62, which means that these competencies are at a medium to low maturity level. The standard deviation results show that technology competencies have a low standard deviation, such as physical space and networks, which shows that the data are clustered closely around the mean. This suggests that a lack of development regarding these two competencies represents the current situation in the participants' organisations. In addition, software and hardware competencies have a relatively higher standard deviation which indicates that the data points are spread out over a wider range of maturity level and imply that participants' organisations have a different view regarding BIM software and hardware development.

Table 7.5: BIM maturity assessment results for technology competencies with descriptive analysis

No	BIM maturity competencies	Assessment results %						Descriptive analysis		
		L0	L1	L2	L3	L4	L5	Median	Mean	Standard deviation
Technology competencies										
16	Software	0.0	38.1	9.5	19.0	14.3	19.0	2.62	2.50	1.55
17	Hardware	0.0	33.3	33.3	9.5	4.8	19.0	2.38	2.00	1.47
18	Physical space	2.4	28.6	45.2	2.4	14.3	7.1	2.12	2.00	1.28
19	Network	0.0	26.2	26.2	28.6	9.5	9.5	2.46	2.00	1.22

7.4.6 BIM uses frequency

From Figure 7.6, it can be understood that most client organisations involved in this study are currently using BIM in Design Review, for Clash Detection, and Record Model; this represents the common role among clients in validating information coming from the supply chain and providing required information for the in-use stage. The other BIM uses have different frequencies, which reflect the client's ability to use BIM in different areas. However, Sustainability Evaluation, Code Validation, and Disaster Management have the lowest frequencies, which reflect that this BIM use demands clients with considerable experience in these particular fields. In addition, client organisations currently depend on their supply chain to provide any information related to these areas.

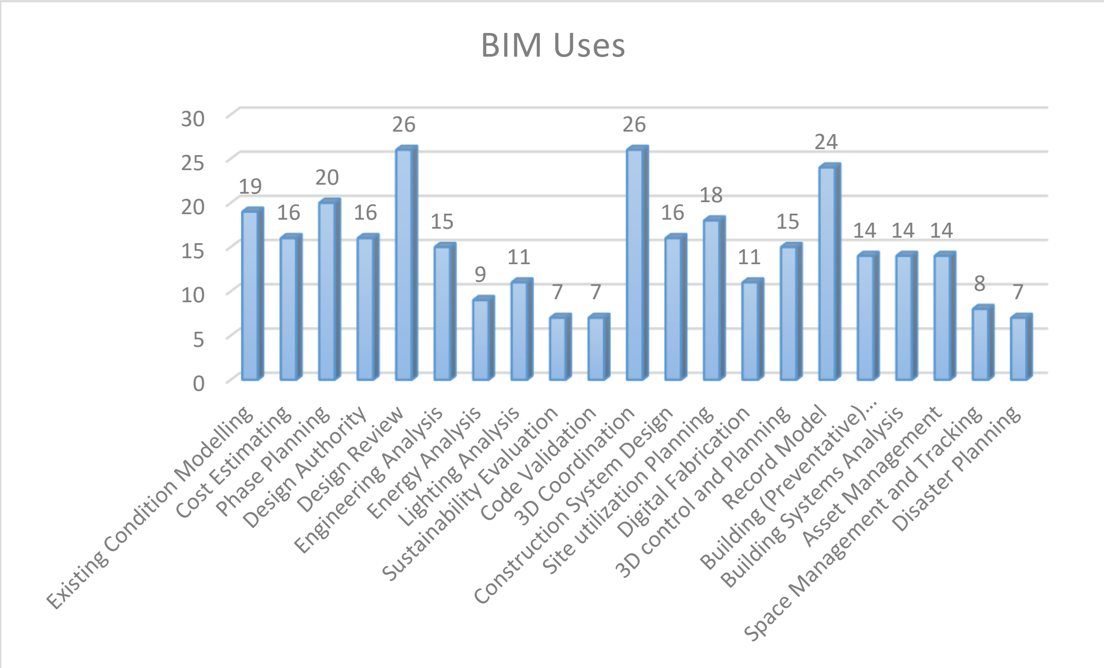


Figure 7.6: BIM uses frequencies

7.4.7 Descriptive analysis summary

The following can be concluded from the descriptive analysis results that have been presented. Most participants' experiences ranged from one to five years, which suggests the impacts of the UK Government's BIM strategy on increasing the number of people interested in BIM implementation. In addition, all participants' current positions in their client organisations gives the impression that they are qualified to answer questions related to the BIM maturity and BIM benefits in their organisations.

It can be concluded that this survey covers a sufficient range of client types, which include public, private, and mixed clients. The majority of participant client organisations are using BIM across all project lifecycle stages, and this gives the impression that the UK construction clients realise BIM's real value, which extends the design and construction stages.

Moreover, the BIM maturity assessment results reveal that the participants' organisations are currently suffering from a lack of development within most of competencies. The main reason for this could be the absence of a BIM maturity model that could assist client organisations in managing this significant change.

Currently, most participants' organisations are using BIM in three main areas, which are; Design Review, Clash Detection, and Record Model. This suggests that client organisations just use BIM for information validation; however, the real value in BIM uses can be seen in employing BIM after project completions. This could also be the result of a lack of understanding about BIM benefits among the participants' organisations.

7.5 Descriptive and Inferential analysis for BIM uses

The inferential analysis aims to identify patterns in the data; for example, whether there is a link between two variables, or whether certain groups are more likely to show certain attributes. This analysis aims to draw lessons from the sample that can be generalised to the wider population. As this research aims to identify the relationship between BIM maturity competencies and BIM uses benefits, the inferential statistical analysis, called correlation, will be used. As explained in the introduction of this chapter, the Spearman correlation method will be used to identify the relationship. For each BIM use benefits, an evaluation of results from the 21 uses that have been identified (Figure 7.6) will be presented, and both descriptive and inferential analyses will be carried out on the data.

7.5.1 Existing Condition Modelling

This BIM use can be described as a process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility. Nineteen from the 26 organisations participating in this study are currently using BIM within Existing Condition Modelling. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and to identify the relationship between BIM use benefits and the maturity competencies.

7.5.1.1 Descriptive analysis

Figure 7.7 shows the average assurance level for all benefits and, it can be seen that the first three benefits, which to increase the efficiency and accuracy of existing conditions' documentation and representation (benefit 1); help in future modelling and 3D design coordination (benefit 2); and provide an accurate representation and visualisation (benefit 3), are over level three (expected level). This means that current client organisations are able to predict these benefits depending on their current BIM maturity competencies developments. However, the final three benefits, which are real-time quantity verification for accounting cost estimation purposes (benefit 4); disaster planning (benefit 5); and time-saving utility design (benefit 6), are still below level three (expected level). This means that the clients' BIM maturity competency developments are not sufficient to support client organisations in predicting these benefits. The mean, median and standard deviation for these benefits are shown in Table 7.6 in which it can be concluded that benefits 1, 2, and 6 show that their median is bigger than the mean. This means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean can be more useful to represent the current assurance for benefits 1, 2, and 6. Meanwhile, benefits 3, 4, and 5 have a positive skew in their distribution where there is a higher score on the right, pulling the median up more than the median. The median, in this case, could be more useful to represent the actual assurance level for benefits 3, 4, and 5. This indicates that using mean in most to existing BIM maturity models will not necessarily reflect the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation that can give an indication where most of the data are located.

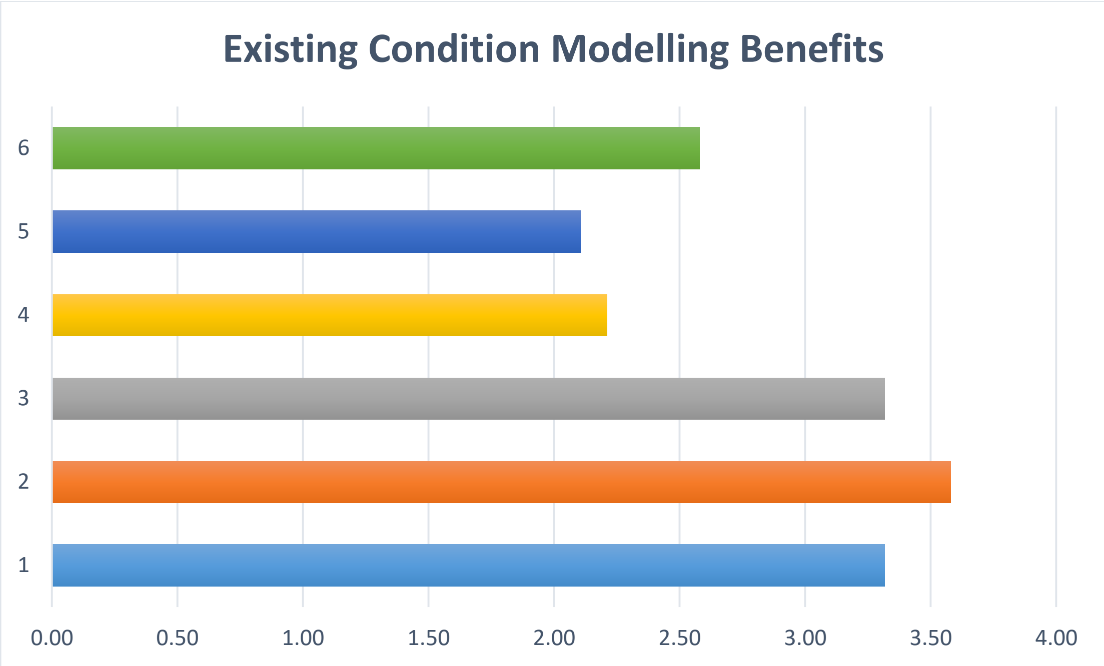


Figure 7.7: Benefit assurance evaluation for Existing Condition Modelling

Table 7.6: Descriptive analysis of Existing Condition Modelling benefits

	Mean	Median	SD
Benefit 1	3.32	4	1.42
Benefit 2	3.58	4	1.30
Benefit 3	3.32	3	1.34
Benefit 4	2.21	2	1.23
Benefit 5	2.11	2	1.15
Benefit 6	2.58	3	1.17

7.5.1.2 Inferential analysis

A Spearman's correlation was carried out, using the SPSS 23 program, to evaluate the relationship between BIM use benefits in Existing Condition Modelling and the BIM maturity competencies. In total, 19 participants from client organisations are currently using BIM in this area, and a correlation analysis has been carried out via four stages. The first stage displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second visualises the correlation between benefits and competencies by drawing the relationship using Microsoft Excel 2016. This representation will be demonstrated for this BIM use only to avoid a significant amount of figures. The third stage summarises the relationship by listing all the related competencies regarding their degree of correlation. Finally, a comparative table will be established to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.7 indicates that each benefit shows a different level of positive correlation with some BIM maturity competencies; these ranged from a significant correlation where the ρ-value was less than 0.01, to a moderate correlation where the ρ-value was equal to 0.055. Based on the correlation analysis, benefit 1 shows significant correlation with only the data sharing method. In addition, it displays a positive correlation with standardisation, validation process, and all technology competencies. Benefit 2 only expresses a significant correlation with data sharing method, standardisation, validation process, and network. In addition, the same benefit demonstrates a positive correlation with organisation mission, BIM skills, OIR, quality assurance system, and all technology competencies. Benefit 3 only indicates a significant correlation with the data sharing method. In addition, the same benefit displays a positive correlation with standardisation, BIM champion, BIM skills, OIR and network. Benefits 4 and 5 did not demonstrate any correlation with any BIM maturity competencies, which is potentially due to a lack of ability within client organisations to predict these benefits; this prevents them exploring which competencies can affect these benefit achievements. Benefit 6 shows a significant correlation with only the BIM committee, and expresses a positive correlation with standardisation.

Table 7.7: Spearman correlation results for Existing Condition Modelling

Maturity competencies			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5	Benefit 6
Spearman's rho	Organisation Mission	Correlation Coefficient	.267	**.532***	.347	.118	-.059	.364
		Sig. (2-tailed)	.269	.019	.145	.632	.811	.126
		N	19	19	19	19	19	19
	BIM Vision	Correlation Coefficient	.138	.204	.219	.223	-.003	.304
		Sig. (2-tailed)	.572	.403	.368	.358	.991	.206
		N	19	19	19	19	19	19
	BIM Champion	Correlation Coefficient	.398	.411	**.459***	.128	.088	.374
		Sig. (2-tailed)	.091	.081	.048	.602	.719	.115
		N	19	19	19	19	19	19
	Management Support	Correlation Coefficient	.293	.315	.438	.131	.033	.315
		Sig. (2-tailed)	.223	.189	.061	.593	.895	.190
		N	19	19	19	19	19	19
	Data Sharing Method	Correlation Coefficient	**.723****	**.780****	**.609****	.223	.346	.178
		Sig. (2-tailed)	.000	.000	.006	.359	.147	.466
		N	19	19	19	19	19	19
	Standardisation	Correlation Coefficient	**.538***	**.724****	**.526***	.191	.192	**.468***
		Sig. (2-tailed)	.017	.000	.021	.432	.431	.043
		N	19	19	19	19	19	19
	Organisation Hierarchy	Correlation Coefficient	.144	.378	.390	.213	.198	.399
		Sig. (2-tailed)	.556	.111	.099	.381	.417	.090
		N	19	19	19	19	19	19
	BIM committee	Correlation Coefficient	-.028	.291	-.005	-.077	.212	**.639****
		Sig. (2-tailed)	.910	.227	.983	.754	.384	.003
		N	19	19	19	19	19	19
	Training	Correlation Coefficient	.358	.358	.367	.159	.016	.276
		Sig. (2-tailed)	.132	.132	.123	.516	.950	.253
		N	19	19	19	19	19	19
	Education	Correlation Coefficient	.011	.163	.230	.426	-.255	.142
		Sig. (2-tailed)	.963	.505	.344	.069	.292	.562
		N	19	19	19	19	19	19

Maturity competencies			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5	Benefit 6
	Roles and Responsibilities	Correlation Coefficient	.176	.379	.288	-.084	-.124	.338
		Sig. (2-tailed)	.472	.110	.231	.733	.614	.156
		N	19	19	19	19	19	19
	Level of Readiness	Correlation Coefficient	.191	.184	.364	-.185	.070	.444
		Sig. (2-tailed)	.432	.450	.126	.449	.776	.057
		N	19	19	19	19	19	19
	BIM Skills	Correlation Coefficient	.438	**.565***	**.501***	-.018	-.124	.145
		Sig. (2-tailed)	.061	.012	.029	.943	.613	.554
		N	19	19	19	19	19	19
	Organisation information requirements (OIR)	Correlation Coefficient	.391	**.552***	**.458***	.183	-.081	.196
		Sig. (2-tailed)	.097	.014	.049	.453	.742	.422
		N	19	19	19	19	19	19
	Validation Process	Correlation Coefficient	**.560***	**.579****	.338	.092	.046	.264
		Sig. (2-tailed)	.013	.009	.157	.709	.851	.276
		N	19	19	19	19	19	19
	Quality Assurance System	Correlation Coefficient	.366	**.481***	.208	.363	.139	.327
		Sig. (2-tailed)	.123	.037	.392	.126	.569	.172
		N	19	19	19	19	19	19
	Software	Correlation Coefficient	**.491***	**.456***	.431	.281	.445	.283
		Sig. (2-tailed)	.055	.050	.066	.243	.056	.240
		N	19	19	19	19	19	19
	Hardware	Correlation Coefficient	**.531***	**.490***	.416	.250	.286	.338
		Sig. (2-tailed)	.019	.033	.076	.302	.235	.158
		N	19	19	19	19	19	19
	Physical Space	Correlation Coefficient	**.456***	**.460***	.360	.331	.234	.185
		Sig. (2-tailed)	.050	.048	.130	.166	.335	.449
		N	19	19	19	19	19	19
	Network	Correlation Coefficient	**.563***	**.682****	**.518***	.205	.120	.148
		Sig. (2-tailed)	.012	.001	.023	.401	.623	.545
		N	19	19	19	19	19	19
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

The correlation statistics can be used to describe and quantify the characteristics of the data. However, visualisation is what enables the researcher to actually see the data, understand the relationships, and examine the harmony of the correlations. Figure 7.8 shows an example of the visualisation results for the relationship between benefit 1 and the correlated BIM maturity competencies. The same procedure has been followed with all benefits. However, the results are not presented to avoid too many figures and to prevent repetition. Figure 7.8 emphasises that benefit 1 has a good relationship with the correlated BIM maturity competencies. In addition, it is possible to recognise the effect of a correlation degree on the relationship, whenever a weak correlation relationship has become closer to becoming flat.

Table 7.8 reviews the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen from the Table, that the first three benefits show a significant correlation with almost the same competencies, and these are; data sharing methods, standardisation, and network. In contrast, benefits 4 and 5 did not show any correlation with any of the BIM maturity competencies. Benefit 6 shows a significant correlation with the BIM committee competency, as a unique relationship.

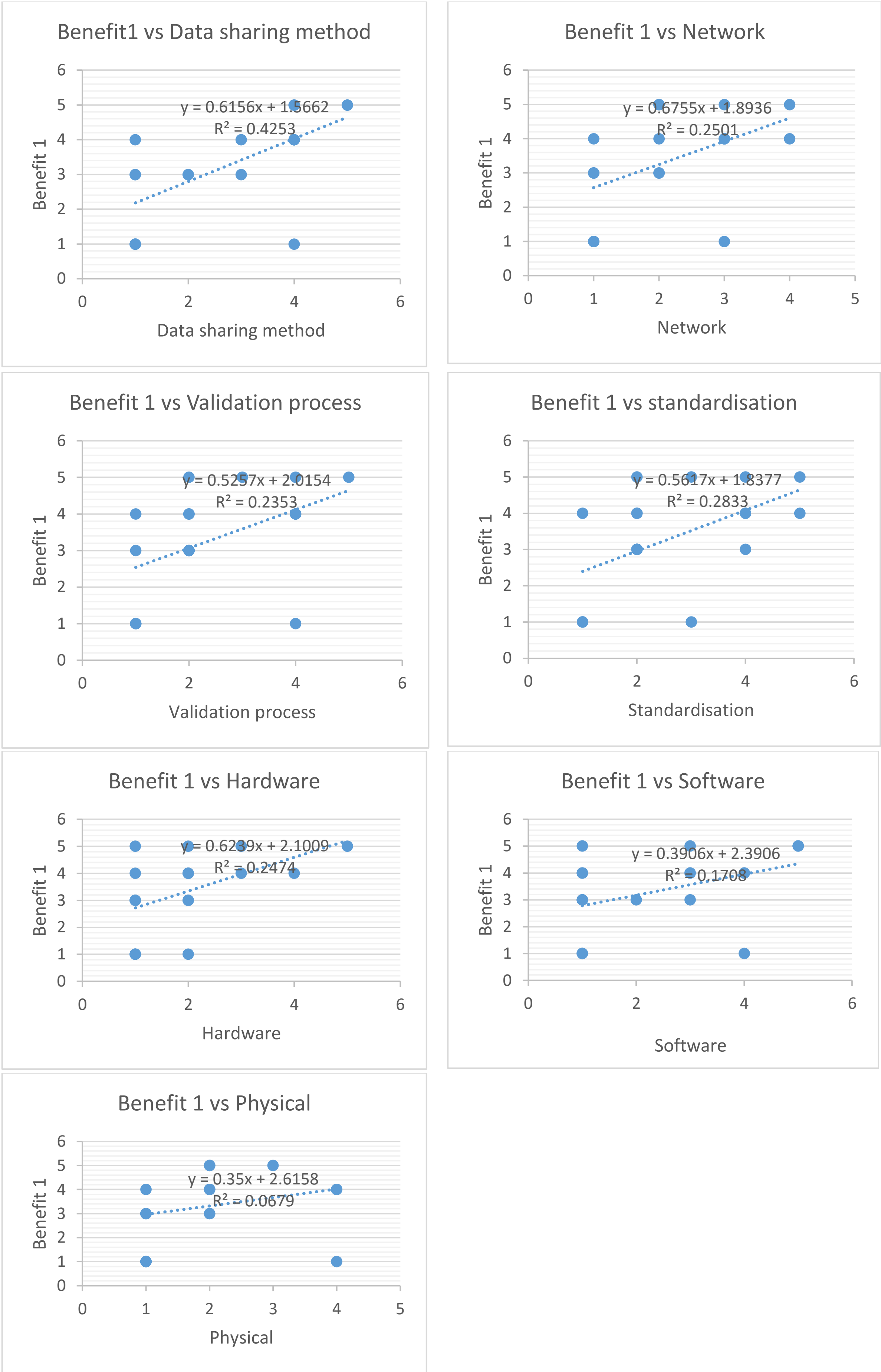


Figure 7.8: Visual representation of the related BIM maturity competencies

Table 7.8: Spearman correlation summary of Existing Condition Modelling benefits

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Increase the efficiency and accuracy of existing conditions documentation and representation.	1. Data sharing method 2. Network 3. Validation process 4. Standardisation 5. Hardware 6. Software 7. Physical space
2	Improve future modelling and 3D design coordination.	1. Data sharing method 2. Standardisation 3. Network 4. Validation process 5. BIM skills 6. OIR 7. Organisation mission 8. Hardware 9. Quality assurance 10. Software 11. Physical space
3	Provides an accurate representation and visualisation of work that has been put into place.	1. Data sharing 2. Standardisation 3. Network 4. BIM skills 5. BIM champion 6. OIR
4	Real-time quantity verification for accounting cost estimation purposes.	NON
5	Improve disaster planning.	NON
6	Time-saving utility design.	1. BIM committee 2. Standardisation

b) Overall relationship

In order to recognise the BIM maturity competencies that affect BIM use in the Existing Condition Modelling area, a comparative table has been drawn to show the requirements, benefits, proposed related, and correlated BIM maturity competencies (Table 7.9). It can be concluded that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if the client organisations aim to achieve the desired benefits from using BIM in

Existing Condition Modelling, they have to develop all correlated maturity competencies. However, if client organisations have limited time and budget for development they can use a correlation ranking to decide which competency to develop first.

Table 7.9: Related maturity competencies of Existing Condition Modelling

Requirements (literature)	Benefits (literature)	Proposed related maturity competencies	Maturity (correlation analysis) competencies
1. The staff are able to manipulate navigate, and review a 3D model. 2. Familiarity with Building Information Model authoring tools. 3. The familiarity with 3D laser scanning tools. 4. The familiarity with conventional surveying tools and equipment. 5. Ability to determine what is the optimum level of detail which may able to add "value" to the project. 6. Ability to select the appropriate software to create the site linked BIM model.	1. Increase the efficiency and accuracy of existing conditions documentation and representation. 2. Improve future modelling and 3D design coordination. 3. Provides an accurate representation and visualisation of work that has been put into place. 4. Real-time quantity verification for accounting cost estimation purposes. 5. Improve disaster planning. 6. Time-saving utility design.	1. BIM skills 2. Training 3. Standardisation 4. BIM champion 5. BIM Vision 6. Software 7. Hardware 8. Quality assurance system	1. Data sharing method 2. Standardisation 3. Network 4. Validation process 5. BIM skills 6. OIR 7. Organisation mission 8. Hardware 9. Quality assurance 10. Software 11. Physical space 12. BIM champion

7.5.1.3 Summary

Based on above correlation analysis, the most significant correlation has been found between the benefits and the data sharing method, network, BIM skills, validation process, and standardisation competencies. This means that client organisations need to improve their maturity in these competencies in order to increase their opportunity of achieving the desired benefits. Moreover, some benefits show a significant correlation with other competencies, as shown in Table 7.8, which will be explained as follows:

1. To increase the efficiency and accuracy of existing conditions, documentation and representation would be required to enhance the data sharing methods, validation process, standardisation, and technical competencies.
2. Improving future modelling and 3D design coordination would require improvements in data sharing methods, standardisation, validation process, and networks.
3. Providing an accurate representation and visualisation of the work that has been put into place would require the enhancement of the data sharing methods, standardisation, and networks. Also improving BIM skills, a BIM champion, and OIR can enhance this benefit but with less impact than the previous competencies.
4. Time-saving utility design would be required to enhance the BIM committee and standardisation competencies.
5. Generally, gathering the benefits from using BIM in Existing Condition Modelling would require an increase in the maturity levels in those competencies that show a significant correlation with the benefits. In addition, continuous improvement of the competencies would, consequently, generate significant value through using BIM in Existing Condition Modelling.

In summary, it can be seen (Table 7.9) that the main competencies that influence BIM implementation in Existing Condition Modelling, and that support client to achieve their desired benefits are the; data sharing method, network, BIM skills, validation process, and standardisation.

7.5.2 Cost Estimate

Using BIM in Cost Estimate can be explained as a process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the life cycle of a project. Only 16 of the 26 organisations contributing to this study are currently using BIM cost estimating. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and identify the relationship between BIM use benefits and the maturity competencies.

7.5.2.1 Descriptive analysis

Figure 7.9 illustrates the average assurance level for all benefits and it can be seen that only benefit 4, which is to provide accurate cost information to client organisations, will help to enhance the decision-making process over the expected level (level three). This means the current development level of client organisations' BIM maturity competencies only enable them to predict this benefit. The other five benefits are still below the expected benefits, which mean that the current client BIM abilities are not enough to support the prediction of these benefits. These five benefits are to: achieve accurate quantities and real-time revisions (benefit 1); stay within budget (benefits 2); use visualisation to improve estimates (benefit 3); focus on value-added activities, for example identifying construction assemblies (benefit 5); generate pricing and factoring risks; and explore alternative solutions within budgets (benefit 6).

The mean, median and standard deviation for these benefits are shown in Table 7.10. It can be seen that all benefits, except 4, show that their median is bigger than the mean; this means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean can be more useful in representing the current assurance situation for benefits 1, 2, 3, 5, and 6. Meanwhile, for benefit 4, the median and the mean are approximately equal which mean the distribution is symmetric and the distribution will have zero skewness. This shows that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation and this can indicate where most of the data are located.

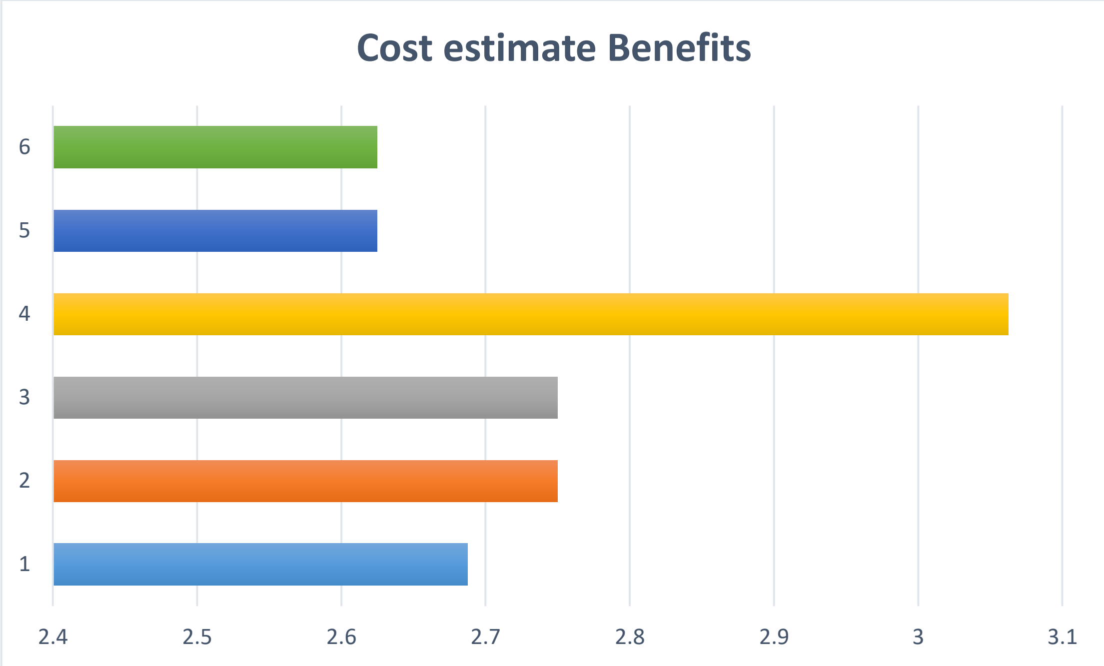


Figure 7.9: Benefit assurance evaluation for Cost Estimate

Table 7.10: Descriptive analysis of Cost Estimate benefits

	Mean	Median	SD
Benefit 1	2.69	3	1.58
Benefit 2	2.75	3	1.24
Benefit 3	2.75	3	1.34
Benefit 4	3.06	3	1.34
Benefit 5	2.63	3	1.31
Benefit 6	2.63	3	1.26

7.5.2.2 Inferential analysis

A Spearman's correlation has been adopted, using the SPSS 23 program; this aims to evaluate the relationship between BIM use benefits in Cost Estimates and the BIM maturity competencies. In total, 16 participants from client organisations are currently using BIM in this area. The correlation analysis has been carried in three stages, where the first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies regarding their correlation degree. Finally, a comparative Table will be developed to compare the BIM uses requirements, benefits, and the related BIM maturity competencies.

a) Correlation factors

Table 7.11 indicates that each benefit displays a different level of positive correlation with some BIM maturity competencies, and that these ranged from a significant correlation, where the ρ-value is less than 0.01, to a moderate correlation, where the ρ-value is equal to 0.048.

Constructed from the correlation analysis, benefit 1 only shows a significant correlation with data sharing method, BIM vision, OIR, validation process, and physical space. In addition, it displays a positive correlation with standardisation, education, organisation mission, and quality assurance system. Benefit 2 only expresses a significant correlation with the data sharing method, standardisation, BIM vision, and physical space but demonstrates a positive correlation with education, organisation hierarchy, quality assurance system, and management support. Benefit 3 only indicates a significant correlation with BIM vision, OIR, and physical space and displays a positive correlation with standardisation, BIM champion, management support, data sharing, and organisation mission, OIR, and network. Benefit 4 shows a significant correlation with BIM vision, data sharing, OIR, and physical space, and expresses a positive correlation with organisation mission, BIM champion, management support, and standardisation. Benefit 5 shows a significant correlation with BIM vision, management support, organisation hierarchy, and physical space, and expresses a positive correlation with standardisation, training, education, and software. Benefit 6 only indicates a significant correlation with BIM vision, organisation hierarchy, and physical space and expresses a positive correlation with organisation mission, management support, data sharing, and OIR.

Table 7.11: Spearman correlation results for Cost Estimate

			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5	Benefit 6
Spearman's rho	Organisation Mission	Correlation Coefficient	**.600***	.397	**.607***	**.575***	.481	**.502***
		Sig. (2-tailed)	.014	.128	.013	.020	.059	.048
		N	16	16	16	16	16	16
	BIM Vision	Correlation Coefficient	**.644****	**.702****	**.715****	**.682****	**.749****	**.735****
		Sig. (2-tailed)	.007	.002	.002	.004	.001	.001
		N	16	16	16	16	16	16
	BIM Champion	Correlation Coefficient	.394	.407	**.519***	**.612***	.432	.363
		Sig. (2-tailed)	.131	.117	.039	.012	.094	.167
		N	16	16	16	16	16	16
	Management Support	Correlation Coefficient	.376	**.561***	**.609***	**.600***	**.661****	**.599***
		Sig. (2-tailed)	.152	.024	.012	.014	.005	.014
		N	16	16	16	16	16	16
	Data Sharing Method	Correlation Coefficient	**.652****	**.629****	**.608***	**.738****	.478	**.606***
		Sig. (2-tailed)	.006	.009	.012	.001	.061	.013
		N	16	16	16	16	16	16
	Standardisation	Correlation Coefficient	**.536***	**.648****	**.542***	**.601***	**.520***	.448
		Sig. (2-tailed)	.032	.007	.030	.014	.039	.082
		N	16	16	16	16	16	16
	Organisation Hierarchy	Correlation Coefficient	.341	**.586***	.340	.307	**.710****	**.686****
		Sig. (2-tailed)	.196	.017	.198	.248	.002	.003
		N	16	16	16	16	16	16
	BIM committee	Correlation Coefficient	-.048	-.063	-.105	-.044	.030	.005
		Sig. (2-tailed)	.859	.815	.698	.872	.913	.986
		N	16	16	16	16	16	16
	Training	Correlation Coefficient	.283	.414	.384	.321	**.584***	.472
		Sig. (2-tailed)	.289	.111	.142	.225	.018	.065
		N	16	16	16	16	16	16
	Education	Correlation Coefficient	**.531***	**.538***	.494	.491	**.566***	.469
		Sig. (2-tailed)	.034	.031	.052	.053	.022	.067
		N	16	16	16	16	16	16
	Roles and Responsibilities	Correlation Coefficient	.227	.290	.275	.312	.346	.183
		Sig. (2-tailed)	.397	.276	.303	.239	.189	.497
		N	16	16	16	16	16	16
	Level of Readiness	Correlation Coefficient	.145	.181	.149	.299	.153	.156
		Sig. (2-tailed)	.592	.503	.581	.260	.572	.564
		N	16	16	16	16	16	16
	BIM Skills	Correlation Coefficient	.366	.351	.460	.462	.410	.366
		Sig. (2-tailed)	.163	.182	.073	.072	.114	.164
		N	16	16	16	16	16	16

	Organisation information requirements (OIR)	Correlation Coefficient	**.783****	.493	**.725****	**.768****	.487	**.565***
		Sig. (2-tailed)	.000	.053	.001	.001	.055	.022
		N	16	16	16	16	16	16
	Validation Process	Correlation Coefficient	**.632****	.459	.524*	.587*	.309	.257
		Sig. (2-tailed)	.009	.074	.037	.017	.244	.338
		N	16	16	16	16	16	16
	Quality Assurance System	Correlation Coefficient	**.586***	**.541***	.426	.529*	.383	.373
		Sig. (2-tailed)	.017	.030	.100	.035	.143	.155
		N	16	16	16	16	16	16
	Software	Correlation Coefficient	.209	.441	.301	.284	**.540***	.402
		Sig. (2-tailed)	.437	.087	.257	.287	.031	.123
		N	16	16	16	16	16	16
	Hardware	Correlation Coefficient	.417	.329	.327	.386	.356	.362
		Sig. (2-tailed)	.108	.214	.216	.140	.176	.169
		N	16	16	16	16	16	16
	Physical Space	Correlation Coefficient	**.637****	**.693****	**.651****	**.627****	**.761****	**.730****
		Sig. (2-tailed)	.008	.003	.006	.009	.001	.001
		N	16	16	16	16	16	16
	Network	Correlation Coefficient	.403	.265	.322	.476	.175	.283
		Sig. (2-tailed)	.122	.322	.224	.062	.516	.289
		N	16	16	16	16	16	16
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Table 7.12 recaps the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen that all benefits show a significant correlation with almost the same competencies, which are OIR, physical space, BIM vision, and data sharing method.

Table 7.12: Spearman correlation summary of Cost Estimate

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Accurate estimate material quantities and generate real-time revisions if needed.	1. OIR 2. Data sharing method 3. BIM vision 4. Physical space 5. Validation process 6. Organisation mission 7. Quality assurance system 8. Education 9. Standardisation

2	Stay within budget constraints while the design progresses.	1. BIM vision 2. Physical space 3. Standardisation 4. Data sharing method 5. Organisation hierarchy 6. Management support 7. Quality assurance system 8. Education
3	Better visualisation for project element that must be estimated.	1. OIR 2. BIM vision 3. Physical space 4. Data sharing method 5. Management support 6. Organisation mission 7. Standardisation
4	Provide accurate cost information to project stakeholders will help to enhance the decision-making process.	1. OIR 2. Data sharing method 3. BIM vision 4. Physical space 5. BIM champion 6. Standardisation 7. Organisation mission
5	Focus on more value adding activities in estimating (identifying construction assemblies, generating pricing and factoring risks) which are essential for high-quality estimates.	1. Physical space 2. BIM vision 3. Organisation hierarchy 4. Management support 5. Training 6. Education 7. Software
6	Exploring different design options and concepts within the owner's budget	1. BIM vision 2. Physical space 3. Organisation hierarchy 4. Data sharing 5. Management support 6. OIR 7. Organisation mission

In order to identify the BIM maturity competencies that affect BIM use in the Cost Estimate area, a comparative table has been provided to show the requirements, benefits, and correlated BIM maturity competencies (Table 7.13). It can be concluded that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits from using BIM in Cost Estimates, they have to develop all correlated maturity competencies. However, if client organisations have limited time and budget for development they can use a correlation ranking to decide which competency has to be developed first.

Table 7.13: Related maturity competencies of the Cost Estimate

Requirements	Benefits	Proposed related Maturity competencies	Maturity correlated competencies
1. Quality assurance system to check design deliverables. 2. Roles and responsibilities. 3. Level of development (LOD) 4. Collaboration 5. Ability to define specific design modelling deliverables.	1. Accurate estimate material quantities and generate real-time revisions if needed. 2. Stay within budget constraints while the design progresses 3. Better visualisation for project element that must be estimated. 4. Provide accurate cost information to project stakeholders will help to enhance the decision-making process. 5. Focus on more value adding activities in estimating (identifying construction assemblies, generating pricing and factoring risks) 6. Exploring different design options and concepts within the owner's budget	1. Quality assurance system 2. Roles and responsibilities 3. Standards 4. BIM vision 5. BIM champion	1. OIR 2. Data sharing method 3. BIM vision 4. Physical space 5. Validation process 6. Management support 7. Organisation hierarchy 8. Organisation mission 9. Quality assurance system 10. Education 11. Standardisation 12. Software 13. Training 14. BIM champion

7.5.2.3 Summary

Based on the above analysis, the most significant correlation has been found between the benefits and the technical competencies, such as software, hardware, physical space, and network. Moreover, some benefits show a significant correlation with other competencies, (Table 7.12). These are explained as follows:

1. To estimate material quantities accurately, improve project element visualisation, and enhance the decision-making process would require the enhancement of OIR, data sharing methods, BIM vision, and physical space.

2. To stay within budget constraints while the design progresses would require an improvement in data sharing method, standardisation, validation process, and BIM vision.
3. To focus on more value adding activities in estimating, and exploring different design options and concepts within the owner's budget would require the enhancement of BIM vision, physical space, and organisation hierarchy.
4. To generally gather the benefits from using BIM in cost estimating would require an increase in maturity level in the competencies that show a significant correlation with these benefits. In addition, the continuous improvement of these competencies would, consequently, generate significant value through using BIM within Cost Estimate.

To summarise, it can be seen (Table 7.13) that the main competencies that influence BIM implementation in cost estimating, and that support clients to achieve their desired benefits are; OIR, data sharing, BIM vision, physical space, validation process, management support, and organisation hierarchy.

7.5.3 Phase Planning

Using BIM in Phase Planning can be defined as a process in which a 4D model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site. Only 20 of the 26 organisations participating in this study are currently using BIM in Phase Planning. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and identify the relationship between BIM use benefits and the maturity competencies.

7.5.3.1 Descriptive analysis

Figure 7.10 shows the average assurance level for all benefits, and reveals that only three benefits, 1, 3, and 4 reach the expected level (level three), which means the client organisations' current BIM maturity level only enables them to predict this benefit. These benefits are to: produce a full understanding of the phasing schedule (benefit 1); identify a schedule, sequencing or phasing issues (benefit 3); be a more readily constructible, operable and maintainable project (benefit 4). While the other four benefits still fall below the expected benefits, which means that the current client BIM abilities are not sufficient to support their prediction of these benefits. These benefits are to produce a dynamic project plan, be more readily constructible (benefit 2); providing operable and maintainable projects , monitor the procurement status of project materials (benefit 5); increase productivity and decrease waste on job sites by creating an optimum project construction plan (benefit 6); and explore different design options and concepts within the owner's expected handover time (benefit 7). The mean, median and standard deviation for these benefits are shown in Table 7.14 in which it can be seen that benefits 2, 3, 4, and 5 show a lower than median than the mean. This means a positive skew in their distribution, with a long tail of high scores pulling the mean up more than the median. In this case, the median could be more useful in representing the actual assurance level for benefits 2, 3, 4, and 5. Meanwhile, for benefit 1 the median and the mean are approximately equal which indicate that the distribution is symmetrical and will have zero skewness. However, benefit 6 shows that their median is bigger than the mean, which means a negative skew in their distribution with a long tail of low scores pulling down the mean more than the median. This suggests that the mean can be more useful representing the current situation regarding assurance for benefit 6. This shows that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen (Table 7.14) that each benefit has a different standard deviation that can give an indication as to where most of the data are located.

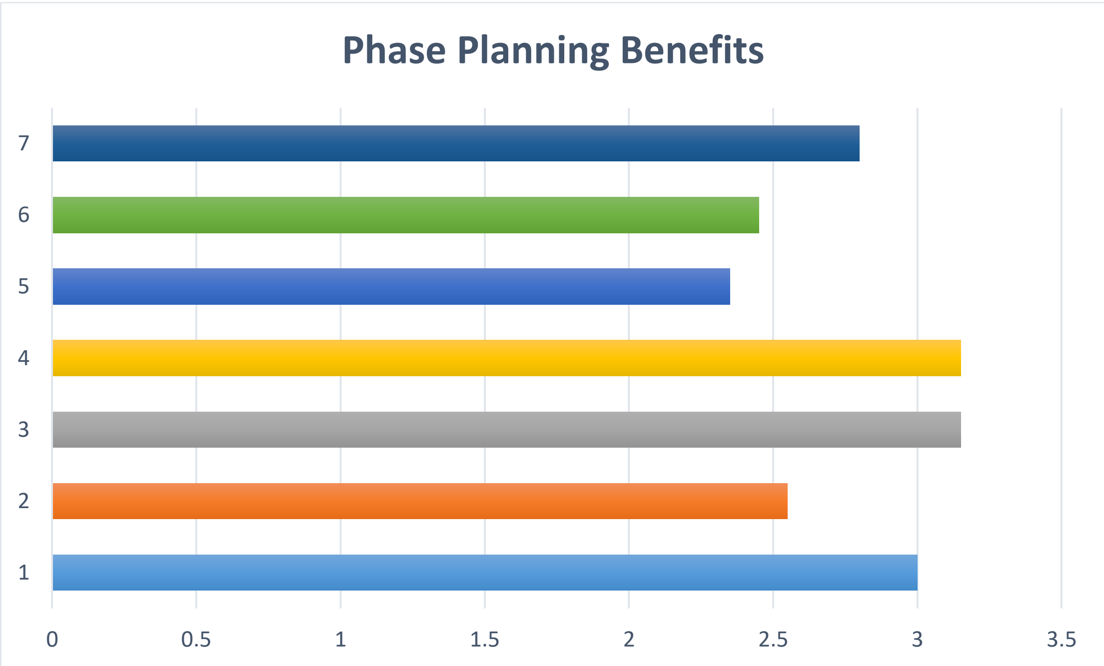


Figure 7.10: Benefit assurance evaluation for Phase Planning

Table 7.14: Descriptive analysis of Phase Planning benefits

	Mean	Median	SD
Benefit 1	3.00	3	1.41
Benefit 2	2.55	2	1.23
Benefit 3	3.15	3	1.18
Benefit 4	3.15	3	1.23
Benefit 5	2.35	2	1.27
Benefit 6	2.45	2.5	1.43
Benefit 7	2.80	3	1.47

7.5.3.2 Inferential analysis

A Spearman's correlation was implemented to judge the relationship between BIM use benefits in Phase Planning and the BIM maturity competencies. A sample of 20 participants from client organisations is currently using BIM in this area. The correlation analysis was carried in three stages. Firstly, the degree of correlation was determined between BIM uses benefits and BIM maturity competencies. Secondly, the relationships were summarised by listing all the related competencies with their correlation degree. Finally, a comparative table was drawn to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.15 shows that each benefit displays a different level of positive correlation with some BIM maturity competencies, and that these ranged from a significant correlation, where the ρ-value was less than 0.01, to a moderate correlation, where the ρ-value was equal to 0.045. Based on the analysis, benefit 1 shows a significant correlation with the data sharing method, BIM skills and all technical competencies. In addition, it displays a positive correlation with standardisation, BIM vision, management support, training, role and responsibilities, OIR, and validation process. Benefit 2 shows a significant correlation with training, BIM skills, software, hardware, and physical space, and a positive correlation with organisation mission, BIM vision, data sharing, role and responsibilities and network. Benefit 3 only shows a significant correlation with software and hardware but displays a positive correlation with the level of readiness, physical space, and network. Benefit 4 indicates a significant correlation with data sharing, BIM skills, data sharing, and all technical competencies, and expresses a positive correlation with organisation mission, BIM champion, management support, and standardisation. Benefit 5 shows a significant correlation with BIM vision, hardware only, but expresses a positive correlation with data sharing and physical space. Benefit 6 only indicates a significant correlation with the level of readiness, and expresses a positive correlation with management support and BIM vision. Benefit 7 only shows a significant correlation with the level of readiness, whilst it expresses a positive correlation with BIM champion, BIM committee, role and responsibilities, software, and hardware.

Table 7.15: Spearman correlation results for Phase Planning

			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5	Benefit 6	Benefit 7
Spearman's rho	Organisation Mission	Correlation Coefficient	.413	**.502***	.248	**.485***	.224	.407	.351
		Sig. (2-tailed)	.071	.024	.292	.030	.343	.075	.129
		N	20	20	20	20	20	20	20
	BIM Vision	Correlation Coefficient	**.480***	**.522***	.357	**.542***	.327	**.547***	.405
		Sig. (2-tailed)	.032	.018	.122	.014	.159	.013	.076
		N	20	20	20	20	20	20	20
	BIM Champion	Correlation Coefficient	.331	.389	.227	.414	.319	.322	**.458***
		Sig. (2-tailed)	.154	.090	.337	.069	.170	.167	.042
		N	20	20	20	20	20	20	20
	Management Support	Correlation Coefficient	**.458***	.441	.254	**.567****	.265	**.524***	.390
		Sig. (2-tailed)	.042	.052	.280	.009	.259	.018	.089
		N	20	20	20	20	20	20	20
	Data Sharing Method	Correlation Coefficient	**.722****	**.517***	.399	**.696****	**.453***	.255	.240
		Sig. (2-tailed)	.000	.020	.081	.001	.045	.277	.308
		N	20	20	20	20	20	20	20
	Standardisation	Correlation Coefficient	**.478***	.337	.173	**.518***	.284	.235	.377
		Sig. (2-tailed)	.033	.146	.466	.019	.225	.318	.102
		N	20	20	20	20	20	20	20
	Organisation Hierarchy	Correlation Coefficient	.285	.423	.189	.317	.145	.249	.395
		Sig. (2-tailed)	.223	.063	.424	.173	.541	.289	.085
		N	20	20	20	20	20	20	20
	BIM committee	Correlation	.117	.215	.159	.211	.400	.344	**.498***

		Coefficient							
		Sig. (2-tailed)	.625	.363	.503	.372	.081	.137	.026
		N	20	20	20	20	20	20	20
	Training	Correlation Coefficient	.540*	.563**	.280	.528*	.159	.247	.370
		Sig. (2-tailed)	.014	.010	.231	.017	.502	.295	.108
		N	20	20	20	20	20	20	20
	Education	Correlation Coefficient	.330	.277	.353	.345	.130	.183	.327
		Sig. (2-tailed)	.155	.237	.127	.136	.586	.441	.160
		N	20	20	20	20	20	20	20
	Roles and Responsibilities	Correlation Coefficient	.516*	.459*	.319	.442	.225	.230	.464*
		Sig. (2-tailed)	.020	.042	.170	.051	.341	.329	.040
		N	20	20	20	20	20	20	20
	Level of Readiness	Correlation Coefficient	.288	.388	.500*	.397	.409	.563**	.578**
		Sig. (2-tailed)	.218	.091	.025	.083	.074	.010	.008
		N	20	20	20	20	20	20	20
	BIM Skills	Correlation Coefficient	.682**	.622**	.404	.629**	.113	.235	.310
		Sig. (2-tailed)	.001	.003	.077	.003	.637	.318	.183
		N	20	20	20	20	20	20	20
	Organisation information requirements (OIR)	Correlation Coefficient	.464*	.398	.293	.506*	.218	.425	.159
		Sig. (2-tailed)	.039	.082	.210	.023	.357	.062	.503
		N	20	20	20	20	20	20	20
	Validation Process	Correlation Coefficient	.489*	.315	.125	.481*	.197	.161	.209
		Sig. (2-tailed)	.029	.176	.598	.032	.406	.499	.377
		N	20	20	20	20	20	20	20
	Quality Assurance System	Correlation Coefficient	.207	.071	.132	.183	.164	.076	.186
		Sig. (2-tailed)	.382	.766	.579	.441	.490	.749	.431
		N	20	20	20	20	20	20	20
	Software	Correlation	.713**	.650**	.564**	.674**	.438	.355	.497*

		Coefficient							
		Sig. (2-tailed)	.000	.002	.010	.001	.054	.125	.026
		N	20	20	20	20	20	20	20
	Hardware	Correlation Coefficient	.671**	.638**	.571**	.652**	.564**	.347	.495*
		Sig. (2-tailed)	.001	.002	.009	.002	.010	.134	.027
		N	20	20	20	20	20	20	20
	Physical Space	Correlation Coefficient	.764**	.655**	.531*	.659**	.479*	.415	.340
		Sig. (2-tailed)	.000	.002	.016	.002	.033	.069	.142
		N	20	20	20	20	20	20	20
	Network	Correlation Coefficient	.633**	.530*	.452*	.664**	.398	.129	.314
		Sig. (2-tailed)	.003	.016	.045	.001	.083	.588	.178
		N	20	20	20	20	20	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

Table 7.16 summarises the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen that all benefits show a significant correlation with almost the same competencies, which are technical competencies, data sharing and level of readiness.

Table 7.16: Spearman correlation summary of Phase Planning

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Produce full understanding of the phasing schedule to all project stakeholders.	1. Physical space 2. Data sharing 3. Software 4. BIM skills 5. Hardware 6. Network 7. Training 8. Role and responsibilities 9. Validation process 10. BIM vision 11. Standardisation 12. OIR 13. Management support
2	Produce dynamic project plan which will be affected by any change happened in the project during any phase through project life cycle.	1. Physical space 2. Software 3. Hardware 4. Training

		5. Network 6. BIM vision 7. Data sharing 8. Organisation mission 9. Role and responsibilities
3	Identification of schedule, sequencing or phasing issues	1. Hardware 2. Software 3. Physical space 4. Level of readiness 5. network
4	More readily constructible, operable and maintainable project	1. Data sharing method 2. Software 3. Network 4. Physical space 5. Hardware 6. BIM skills 7. Management support 8. BIM vision 9. Training 10. Standardisation 11. OIR 12. Organisation mission 13. Validation process
5	Monitor procurement status of project materials	1. Hardware 2. Physical space 3. Data sharing
6	Increased productivity and decreased waste on job sites by creating optimum project construction plan.	1. Level of readiness 2. BIM vision 3. Management support
7	Exploring different design options and concepts	1. Level of readiness 2. BIM committee 3. Software 4. Hardware 5. Role and responsibilities 6. BIM champion

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use in the Phase Planning area, a comparative table has been drawn to show the requirements, benefits, and correlated BIM maturity competencies for this particular BIM use (Table 7.17). It can be concluded that there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if the client organisations aim to achieve the desired benefits from using BIM in Phase Planning, they have to develop all correlated maturity competencies. However, if client organisations have limited time and budget for development they can use a correlation ranking to decide which competency they first need to develop.

Table 7.17: Related maturity competencies of Phase Planning

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. Project planning team must be familiar with construction project scheduling and general construction process. 2. Project planning team are able to manipulate navigate, and review a 3D model and all 4D software. 3. Hardware and all 4D software.	1. Produce full understanding of the phasing schedule to all project stakeholders. 2. Produce dynamic project plan which will be affected by any change happened in the project during any phase through project life cycle. 3. Identification of schedule, sequencing or phasing issues 4. More readily constructible, operable and maintainable project 5. Monitor procurement status of project materials 6. Increased productivity and decreased waste on job sites by creating optimum project construction plan. 7. Exploring different design options and concepts within the owner's expected handover time.	1. BIM skills 2. Software 3. Hardware 4. Training 5. BIM vision	1. Physical space 2. Data sharing 3. Software 4. Hardware 5. Network 6. Level of readiness 7. Training 8. BIM skills 9. Role and responsibilities 10. Validation process 11. BIM vision 12. Standardisation 13. OIR 14. Management support 15. BIM champion 16. BIM committee 17. Level of readiness 18. Organisation mission

7.5.3.3 Summary

Based on aforementioned correlation analyses, the most significant outcome has been found between the benefits and the software, hardware, physical space, network, data sharing, and level of readiness competencies. Moreover, some benefits show a significant correlation with other competencies, as shown in Table 7.16, which will be explained as follows:

1. To produce a full understanding of the phasing schedule to all project stakeholders would require to the enhancement of physical space, data sharing, software, and BIM skills.
2. To produce a dynamic project plan, which will be affected by any change in the project during any phase throughout project lifecycle, would require the augmentation of physical space, software, hardware, and training.
3. The identification of a schedule, sequencing or phasing issues would require an enhancement of the client's technical competencies and level of readiness.
4. A more readily constructible, operable and maintainable project would require the enhancement of data sharing methods and technical competencies.
5. To monitor the procurement status of project materials would require the enhancement of data sharing methods and some technical competencies.
6. An increase in productivity and decrease in waste on job sites through creating an optimum project construction plan would require the enhancement of a client's level of readiness, and their BIM vision, and management support.
7. Exploring different design options and concepts would require an improvement in the level of readiness and technical competencies, and the BIM committee.
8. Generally, gathering the benefits from using BIM in Phase Planning will require an increase in maturity level in the competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would, consequently, generate a significant value through using BIM in Phase Planning.

In summary, it can be seen (Table 7.17) that the main competencies that influence BIM implementations in the Phase Planning and that support the client to achieve their desired benefits are technical competencies, data sharing, and their level of readiness.

7.5.4 Design Authority

Using BIM in Design Authority can be described as a process in which 3D software is used to develop a Building Information Model based on criteria that is important to the translation of the building's design. Only 20 of 26 organisations who agreed to contribute to this study are currently using BIM in phase planning. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and to explore the relationship between BIM use benefits and maturity competencies.

7.5.4.1 Descriptive analysis

Figure 7.11 illustrates the average assurance level for all benefits and confirms that all benefits have reached the expected level, which means the client organisations' current BIM maturity level enables them to predict this benefit. These benefits are: to provide real and accurate information for all project stakeholders (benefit 1); that the powerful visualisation tool in this application will help to speed up the decision-making process (benefit 2); efficient collaboration between project stakeholders (benefit 3); and improved quality control and assurance systems (benefit 4). The mean, median and standard deviation for these benefits are shown in Table 7.18 in which it can be seen that benefits 2, 3, and 4 show that the median is lower than the mean; this means a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. As such, the median in this case could be more useful in representing the actual assurance level for benefits 2, 3 and 4. However, benefit 1 shows a median that is bigger than the mean, which means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean could be more useful in representing the current assurance situation for benefit 1. This directs that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation that can give an indication as to where most of the data are located.

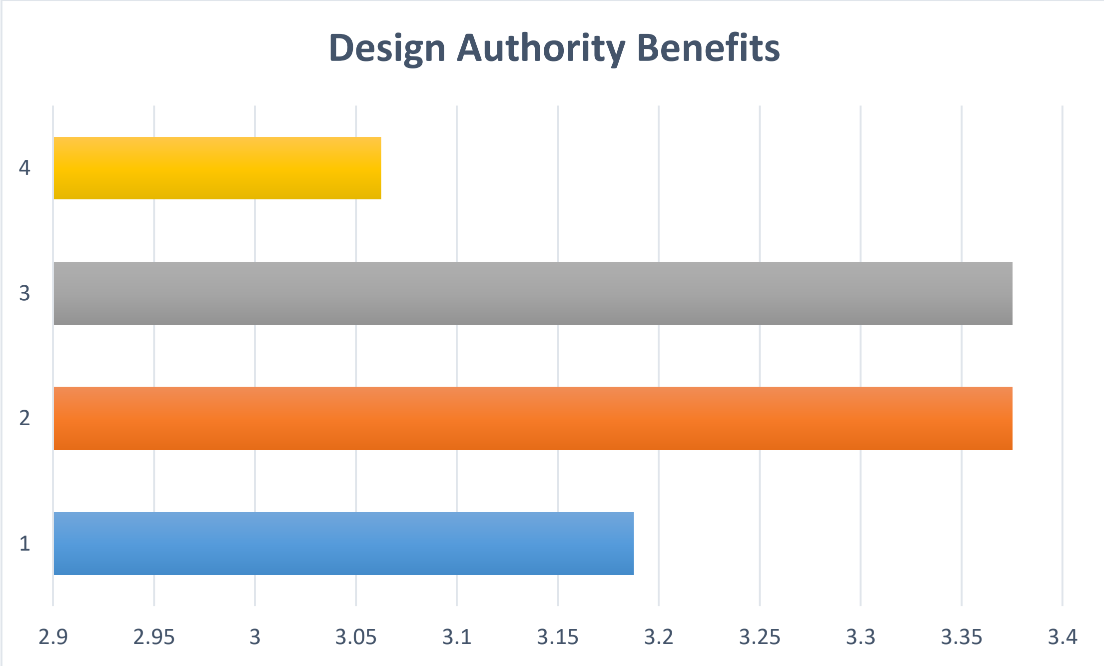


Figure 7.11: Benefit assurance evaluation for Design Authority

Table 7.18: Descriptive analysis of Design Authority benefits

	Mean	Median	SD
Benefit 1	3.19	3.5	1.56
Benefit 2	3.38	3	1.41
Benefit 3	3.38	3	1.20
Benefit 4	3.06	3	1.12

7.5.4.2 Inferential analysis

A Spearman's correlation has been calculated to analyse the relationship between BIM use benefits in Design Authority and the BIM maturity competencies. A sample of 20 participants contributed from the client organisations who are currently using BIM in this area. The correlation analysis has been carried in three stages. First, the degree of correlation between BIM uses benefits and BIM maturity competencies is shown. Second, the relationship is summarised by detailing all the related competencies regarding their correlation degree. Finally, a comparative table was developed to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.19 shows that each benefit displays a different level of positive correlation with the BIM maturity competencies, where the maximum ρ-value equals 0.044. Grounded within the analysis, benefit 1 did not show any significant correlation with any BIM maturity competencies, but indicated a positive correlation with BIM skills and network. Benefit 2 did not display any significant correlation with any BIM maturity competencies but identified a positive correlation with BIM skills, data sharing and network. Benefit 3 did not show any significant correlation with any of the BIM maturity competencies and only identified a positive correlation with physical space. Benefit 4 did not express any significant correlation with any of the BIM maturity competencies, but revealed a positive correlation with BIM skills and the organisation mission.

Table 7.19: Spearman correlation results for Design Authority

			Benefit 1	**Benefit 2**	**Benefit 3**	**Benefit 4**
Spearman's rho	Organisation Mission	Correlation Coefficient	.429	.227	.430	**.524***
		Sig. (2-tailed)	.097	.398	.096	.037
		N	16	16	16	16
	BIM Vision	Correlation Coefficient	.390	.338	.489	.306
		Sig. (2-tailed)	.135	.201	.055	.248
		N	16	16	16	16
	BIM Champion	Correlation Coefficient	.088	.249	.133	.164
		Sig. (2-tailed)	.745	.352	.623	.543
		N	16	16	16	16
	Management Support	Correlation Coefficient	.150	.266	.294	.215
		Sig. (2-tailed)	.579	.319	.269	.424
		N	16	16	16	16
	Data Sharing Method	Correlation Coefficient	.464	**.519***	.339	.188
		Sig. (2-tailed)	.070	.039	.199	.485
		N	16	16	16	16
	Standardisation	Correlation Coefficient	.206	.184	.447	.269
		Sig. (2-tailed)	.444	.495	.082	.314
		N	16	16	16	16
	Organisation Hierarchy	Correlation Coefficient	.117	.064	.247	.093
		Sig. (2-tailed)	.665	.814	.357	.732
		N	16	16	16	16
	BIM committee	Correlation Coefficient	0.000	-.002	.237	.090
		Sig. (2-tailed)	1.000	.993	.376	.739
		N	16	16	16	16
	Training	Correlation Coefficient	.248	.276	.335	.338
		Sig. (2-tailed)	.354	.302	.205	.201
		N	16	16	16	16
	Education	Correlation Coefficient	.313	.194	.407	.477
		Sig. (2-tailed)	.238	.472	.118	.062
		N	16	16	16	16
	Roles and Responsibilities	Correlation Coefficient	.302	.291	.358	.330

		Sig. (2-tailed)	.255	.274	.173	.212
		N	16	16	16	16
	Level of Readiness	Correlation Coefficient	.217	.318	.024	.324
		Sig. (2-tailed)	.420	.230	.929	.221
		N	16	16	16	16
	BIM Skills	Correlation Coefficient	**.601***	**.578***	.432	**.509***
		Sig. (2-tailed)	.014	.019	.094	.044
		N	16	16	16	16
	Organisation information requirements (OIR)	Correlation Coefficient	.363	.304	.267	.160
		Sig. (2-tailed)	.167	.253	.317	.553
		N	16	16	16	16
	Validation Process	Correlation Coefficient	.422	.443	.489	.367
		Sig. (2-tailed)	.103	.086	.054	.162
		N	16	16	16	16
	Quality Assurance System	Correlation Coefficient	.178	.141	.428	.181
		Sig. (2-tailed)	.510	.602	.098	.502
		N	16	16	16	16
	Software	Correlation Coefficient	.256	.383	.284	.308
		Sig. (2-tailed)	.339	.143	.286	.246
		N	16	16	16	16
	Hardware	Correlation Coefficient	.353	.464	.264	.411
		Sig. (2-tailed)	.180	.070	.323	.114
		N	16	16	16	16
	Physical Space	Correlation Coefficient	.491	.464	**.537***	.402
		Sig. (2-tailed)	.053	.070	.032	.122
		N	16	16	16	16
	Network	Correlation Coefficient	**.529***	**.619***	.189	.361
		Sig. (2-tailed)	.035	.010	.483	.170
		N	16	16	16	16

Table 7.20 shows the correlation results by indicating the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. All the benefits show a significant correlation with almost the same competencies, which are BIM skills and network.

Table 7.20: Spearman correlation summary of Design Authority

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Provide real and accurate information for all project stakeholders.	1. BIM Skills 2. Network
2	The powerful visualisation tool in this application will help to speed up the decision-making process.	1. Network 2. BIM skills 3. Data sharing
3	Efficient collaboration between project stakeholders.	1. Physical space
4	Improved quality control and assurance systems.	1. Organisation mission 2. BIM skills

b) Overall relationship

In order to acknowledge the BIM maturity competencies that affect BIM use in the Design Authority area, a comparative table has been developed to show the requirements, benefits, and correlated BIM maturity competencies for this particular BIM use (Table 7.21). From these results, it can be concluded that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if the client organisations aim to achieve the desired benefits from using BIM in their Design Authority, they have to develop all the correlated maturity competencies. However, if the client organisations have limited time and budget for development they can use a correlation ranking to decide which competency needs to be developed first.

Table 7.21: Related maturity competencies of the Design Authority

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. The staff are able to manipulate navigate, and review a 3D model. 2. The staff have good experience in design	1. Provide real and accurate information for all project stakeholders.	1. BIM skills 2. Training 3. Quality assurance system 4. BIM Vision	1. BIM skills 2. Network 3. Data sharing 4. Physical space 5. Organisation mission

and construction means and methods. 3. Quality assurance program to check the design deliverables. 4. Collaboration between the project stakeholders. 5. Hardware and software have the ability to support all above requirements.	2. The powerful visualisation tool in this application will help to speed up the decision-making process. 3. Efficient collaboration between project stakeholders. 4. Improved quality control and assurance systems.	5. Software 6. Hardware	

7.5.4.3 Summary

Based on above analysis, the most significant correlation has been found between the benefits and some competencies, such as BIM skills and network. Moreover, some benefits show a significant correlation with other competencies, as shown in Table 7.20. These are explained as follows:

1. Providing real and accurate information for all project stakeholders would require the enhancement of BIM skills and networks.
2. A powerful visualisation tool in this application would help to speed up the decision-making process but would require an improvement in networks, BIM skill, data sharing.
3. Efficient collaboration between project stakeholders would require the enhancement of physical space.
4. Improved quality control and assurance systems would require the development of organisation mission and BIM skills.
5. Generally, gathering the benefits from using BIM in a Design Authority would require an increase in maturity level in those competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would, consequently, generate significant value through using BIM in a Design Authority.

In summary, it can be seen (Table 7.21) that the main competencies that influence BIM implementation within Design Authority, and that support clients to achieve their desired benefits are data sharing and physical space.

7.5.5 Design Review

Using BIM in Design Review can be explained as a process in which clients view a 3D model and provide their feedbacks to validate multiple design aspects. All 26 organisations who have participated in this study are currently using BIM in their Design Reviews. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and to explore the relationship between BIM use benefits and the maturity competencies.

7.5.5.1 Descriptive analysis

Figure 7.12 displays the average assurance level for all benefits. It can be and seen that only four benefits, 2, 3, 5, and 6, reached the expected level; this indicates that the current BIM maturity levels amongst the client's organisations, suggests they are only able to predict these benefits. These benefits are; stakeholder feedback for the client in in real time during the checking process (benefit 2); an increase in the Design Review process efficiency (benefit 3); an increase in the communication and collaboration between the project stakeholders (benefit 5); and a validation of the component constructability (benefit 6). Meanwhile the other benefits, 1 and 4, which are reduced cost and time spent on checking process (benefit 1) and enhancing the project safety plan (benefit 4) are still below the expected benefits which means that the current client BIM abilities are not sufficient to support them to predict these benefits. The mean, median and standard deviation for these benefits are shown in Table 7.22, in which it can be seen that benefits 2 and 6 indicate that the median is lower than the mean; this shows a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. This suggests that the median could be more useful in representing the current assurance situation for benefits 2 and 6. However, the other benefits show that their medians are bigger than the means, which means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean could be more useful in representing the current assurance situation for benefits 1, 3, 4, and 5. This indicates that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, the table shows that each benefit has a different standard deviation that could indicate where most of the data are located.

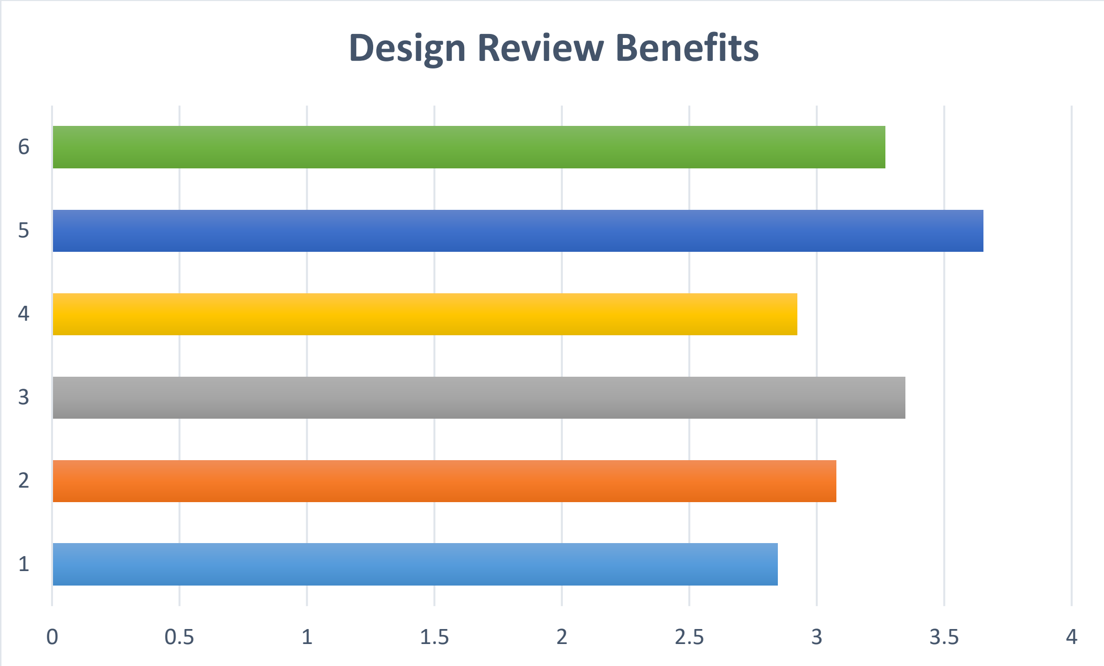


Figure 7.12: Benefit assurance evaluation for Design Review

Table 7.22: Descriptive analysis of Design Review benefits

	Mean	Median	SD
Benefit 1	2.85	3	1.52
Benefit 2	3.08	3	1.26
Benefit 3	3.35	3.5	1.52
Benefit 4	2.92	3	1.38
Benefit 5	3.65	4	1.52
Benefit 6	3.27	3	1.46

7.5.5.2 Inferential analysis

A Spearman's correlation was run to assess the relationship between BIM use benefits in the Design Review and the BIM maturity competencies. In total, 26 participants from client organisations are currently using BIM in this area. As before, the correlation analysis has been developed in three stages. The first stage displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies with their correlation degree. Finally, a comparative table was developed to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.23 shows that each benefit has a different level of positive correlation with some of the BIM maturity competencies, and that these ranged from a significant correlation, where the ρ-value was less than 0.01, to a moderate correlation, where the ρ-value equalled 0.046. Built on the correlation analysis, benefit 1 only shows a significant correlation with physical space, and a positive correlation with standardisation, BIM vision, management support, role and responsibilities, the level of readiness, BIM skills, software, hardware, and network. Benefit 2 expresses a significant correlation with the level of readiness and hardware, and a positive correlation with BIM vision, management support, role and responsibilities, physical space, and network. Benefit 3 only indicates a significant correlation with BIM vision and management support, and shows a positive correlation with the level of readiness, physical space, role and responsibilities, organisation hierarchy, and software. Benefit 4 only shows a significant correlation with BIM vision, whilst benefit 5 only displays a significant correlation with BIM committee. However, benefit 5 expresses a positive correlation with BIM vision, management support, the level of readiness, role and responsibilities, and software. Benefit 6 only shows a significant correlation with the level of readiness, but expresses a positive correlation with management support, role and responsibilities, software, hardware, and physical space.

Table 7.23: Spearman correlation results for Design Review

			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5	Benefit 6
Spearman's rho	Organisation Mission	Correlation Coefficient	.145	.104	.282	.193	.350	.273
		Sig. (2-tailed)	.481	.615	.163	.346	.080	.177
		N	26	26	26	26	26	26
	BIM Vision	Correlation Coefficient	.448*	.397*	.559**	.503**	.457*	.346
		Sig. (2-tailed)	.022	.045	.003	.009	.019	.083
		N	26	26	26	26	26	26
	BIM Champion	Correlation Coefficient	.249	.201	.247	.038	.202	.304
		Sig. (2-tailed)	.220	.325	.224	.855	.322	.131
		N	26	26	26	26	26	26
	Management Support	Correlation Coefficient	.468*	.397*	.578**	.301	.406*	.408*
		Sig. (2-tailed)	.016	.045	.002	.135	.040	.039
		N	26	26	26	26	26	26
	Data Sharing Method	Correlation Coefficient	.367	.307	.335	.338	.318	.362
		Sig. (2-tailed)	.065	.127	.095	.092	.113	.069
		N	26	26	26	26	26	26
	Standardisation	Correlation Coefficient	.272	.197	.419*	.228	.338	.264
		Sig. (2-tailed)	.180	.334	.033	.263	.091	.193
		N	26	26	26	26	26	26
	Organisation Hierarchy	Correlation Coefficient	.332	.169	.411*	.032	.346	.226

		Sig. (2-tailed)	.097	.410	.037	.878	.084	.267
		N	26	26	26	26	26	26
	BIM committee	Correlation Coefficient	.296	.271	.323	.195	**.512****	.261
		Sig. (2-tailed)	.142	.180	.108	.341	.008	.197
		N	26	26	26	26	26	26
	Training	Correlation Coefficient	.317	.264	.284	.223	.387	.208
		Sig. (2-tailed)	.115	.192	.159	.273	.051	.309
		N	26	26	26	26	26	26
	Education	Correlation Coefficient	.068	.173	.180	.083	.147	-.076
		Sig. (2-tailed)	.742	.399	.380	.688	.474	.714
		N	26	26	26	26	26	26
	Roles and Responsibilities	Correlation Coefficient	**.466***	**.417***	**.403***	.117	**.444***	**.403***
		Sig. (2-tailed)	.017	.034	.041	.570	.023	.041
		N	26	26	26	26	26	26
	Level of Readiness	Correlation Coefficient	**.420***	**.524****	**.389***	.337	**.438***	**.597****
		Sig. (2-tailed)	.033	.006	.050	.092	.025	.001
		N	26	26	26	26	26	26
	BIM Skills	Correlation Coefficient	**.430***	.275	.383	.144	.328	**.439***
		Sig. (2-tailed)	.029	.174	.054	.484	.102	.025
		N	26	26	26	26	26	26
	Organisation information requirements (OIR)	Correlation Coefficient	.155	.044	.321	.122	.129	.285
		Sig. (2-tailed)	.450	.831	.110	.554	.531	.158
		N	26	26	26	26	26	26
	Validation Process	Correlation Coefficient	.061	-.090	.025	.095	.018	.122
		Sig. (2-tailed)	.768	.660	.902	.644	.930	.553
		N	26	26	26	26	26	26
	Quality Assurance System	Correlation Coefficient	.052	.140	.107	.080	.001	-.045
		Sig. (2-tailed)	.801	.496	.603	.699	.994	.829
		N	26	26	26	26	26	26
	Software	Correlation Coefficient	**.455***	.364	**.395***	.228	**.418***	**.456***
		Sig. (2-tailed)	.019	.067	.046	.262	.034	.019
		N	26	26	26	26	26	26
	Hardware	Correlation Coefficient	**.396***	**.523****	.307	.320	.375	**.442***
		Sig. (2-tailed)	.045	.006	.128	.111	.059	.024
		N	26	26	26	26	26	26
	Physical Space	Correlation Coefficient	**.498****	**.434***	**.479***	.295	.244	**.460***

		Sig. (2-tailed)	.010	.027	.013	.143	.231	.018
		N	26	26	26	26	26	26
	Network	Correlation Coefficient	.400*	.410*	.212	.180	.333	.256
		Sig. (2-tailed)	.043	.038	.299	.378	.097	.207
		N	26	26	26	26	26	26
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Table 7.24 summarises the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. As can be seen, all benefits show a significant correlation with almost the same competencies, which are management support, role and responsibilities, the level of readiness, and physical space.

Table 7.24: Spearman correlation summary of Design Review

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Reduce the cost and time were spent on checking process.	1. Physical space 2. Management support 3. Role and responsibilities 4. Software 5. BIM vision 6. BIM skills 7. Level of readiness 8. Network 9. Hardware
2	The stakeholder feedbacks, a client, in particular, could be considered in real time during the checking process.	1. Level of readiness 2. Hardware 3. Physical space 4. Role and responsibilities 5. Network 6. BIM vision 7. Management support
3	Increase the design review process efficiency.	1. Management support 2. BIM vision 3. Physical space 4. Organisation hierarchy 5. Role and responsibilities 6. Software 7. Level of readiness
4	Enhance the project safety plan.	1. BIM vision

5	Increase the communication and collaboration between the project stakeholders.	1. BIM committee 2. BIM vision 3. Role and responsibilities 4. Level of readiness 5. Software 6. Management support
6	Validate the component constructability.	1. Level of readiness 2. Physical space 3. Software 4. Hardware 5. BIM skills 6. Role and responsibilities 7. Management support

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use in the Design Review area, a comparative table has been developed to display the requirements, benefits and correlated BIM maturity competencies (Table 7.25). It can be concluded that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits from using BIM in the Design Review they have to develop all the correlated maturity competencies. However, if client organisations have limited time and budget for development they can use the correlation ranking to decide which competency needs to be developing first.

Table 7.25: Related maturity competencies of the Design Review

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. The staff are able to manipulate navigate, and review a 3D model. 2. Team roles and responsibilities. 3. The reviewer must have a good understanding of the integration between building systems.	1. Reduce the cost and time were spent on checking process. 2. The stakeholder feedbacks, a client, in particular, could be considered in real time during the checking process. 3. Increase the design review process efficiency.	1. BIM Skills 2. Training 3. Role and responsibilities 4. Software 5. Hardware	1. Management support 2. Role and responsibilities 3. Software 4. BIM vision 5. Hardware 6. Physical space 7. BIM skills

4. Hardware and software have the ability to support all above requirements.	4. Enhance the project safety plan. 5. Increase the communication and collaboration between the project stakeholders. 6. Validate the component constructability.		8. Level of readiness 9. Network 10. Level of readiness 11. Organisation hierarchy 12. BIM vision 13. BIM committee

7.5.5.3 Summary

Constructed on above analysis, the most significant correlation has been found between the benefits and those competencies that include software, hardware, management support, role and responsibilities, and BIM vision. Moreover, some benefits show a significant correlation with other competencies (Table 7.24). These are explained as follows:

1. To reduce the cost and time spent on the checking process would require the enhancement of physical space, management support, role and responsibilities, and software.

2. The benefit regarding stakeholder feedback, where a client could receive feedback in real time during the checking process, would require a level of readiness, hardware, physical space, and role and responsibilities.

3. An improvement in the Design Review process efficiency would require management support, BIM vision, physical space, and organisation hierarchy.

4. To enhance the project safety plan would require to development in the client's BIM vision.

5. Increasing communication and collaboration between the project stakeholders would require to a development in terms of; the BIM committee, BIM vision, role and responsibilities, and the level of readiness

6. To validate the component constructability would require improvements in the level of readiness, physical space, software, and hardware

7. Generally, gathering the benefits from using BIM in the Design Review will require an increase in maturity level in certain competencies that show a significant correlation with

the benefits. In addition, the continuous improvement of these competencies would, consequently, generate significant value through using BIM in the Design Review.

In summary, it can be seen (Table 7.25) that the main competencies that influence BIM implementation in the Design Review, and that support clients to achieve their desired benefits are software, hardware, management support, role and responsibilities, and BIM vision.

7.5.6 Engineering Analysis

Using BIM in this area means a process in which intelligent modelling software uses the BIM model to determine the most effective engineering method based on design specifications. Fifteen of the 26 contributing organisations are currently using BIM in their Engineering Analysis. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and to examine the relationship between BIM use benefits and the maturity competencies.

7.5.6.1 Descriptive analysis

Figure 7.13 shows the average assurance level for all benefits, in which it can be seen that all benefits help to save time and cost due to the automation of the analysis process. This application helps to save time and cost due to the automation of the analysis process (benefit 1); increase the accuracy and efficiency of the outcomes (benefit 2); has the ability to produce different design solutions (benefit 3); and reduces the design stage period with high-quality outcomes that reach the expectation level (benefit 4). This means the client organisation's current BIM maturity level only enable them to predict this benefit. The mean, median and standard deviation for these benefits are shown in Table 7.26, which shows that benefits 1, 2, and 4 have a lower median than the mean. This shows a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. This suggests that the median could be more useful in representing the current assurances for benefits 1,2, and 4. However, benefit 3 shows a bigger median than the mean, which means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean could be more useful in representing the current assurance for benefit 3. This indicates that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation, which can indicate where most of the data are located.

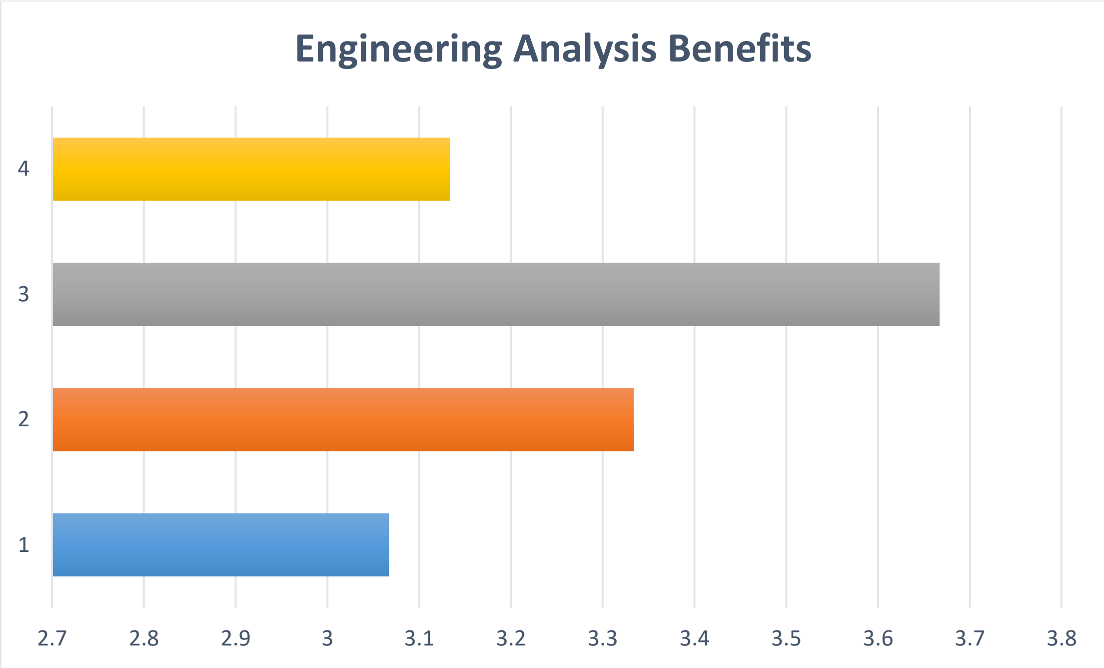


Figure 7.13: Benefit assurance evaluation for Engineering Analysis

Table 7.26: Descriptive analysis of Engineering Analysis benefits

	Mean	Median	SD
Benefit 1	3.07	3	1.16
Benefit 2	3.33	3	1.23
Benefit 3	3.67	4	1.11
Benefit 4	3.13	3	1.25

7.5.6.2 Inferential analysis

A Spearman's correlation has been calculated to judge the relationship between BIM use benefits in the Engineering Analysis and the BIM maturity competencies. A sample of 15 participants from client organisations is currently using BIM in this area. As before, the correlation analysis has been carried via three stages, where the first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies regarding their correlation degree. Finally, a comparative table was developed to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.27 specifies that each benefit displays a different level of positive correlation with some BIM maturity competencies which ranged from a significant correlation, where the ρ-value was less than 0.01, to a moderate correlation, where the ρ-value equals 0.05. Based on the correlation analysis, benefit 1 did not show significant correlation but suggested a positive correlation with training, BIM skills, and software. Benefit 2 did not express any significant correlation although showed a positive correlation with training and software. Benefit 3 only indicated a significant correlation with software, and displayed a positive correlation with data sharing, standardisation, organisation hierarchy, the BIM champion, role and responsibilities, physical space, and networks. Benefit 4 did not show any significant correlation but identified a positive correlation with training and BIM skills.

Table 7.27: Spearman correlation results for Engineering Analysis

			Benefit 1	Benefit 2	Benefit 3	Benefit 4
Spearman's rho	Organisation Mission	Correlation Coefficient	.065	-.039	.127	.158
		Sig. (2-tailed)	.819	.889	.652	.574
		N	15	15	15	15
	BIM Vision	Correlation Coefficient	.315	.387	.371	.255
		Sig. (2-tailed)	.253	.154	.174	.359
		N	15	15	15	15
	BIM Champion	Correlation Coefficient	.365	.215	**.534***	.359
		Sig. (2-tailed)	.181	.442	.040	.188
		N	15	15	15	15
	Management Support	Correlation Coefficient	.423	.415	.487	.372
		Sig. (2-tailed)	.117	.124	.066	.172
		N	15	15	15	15
	Data Sharing Method	Correlation Coefficient	.209	.291	**.524***	.163
		Sig. (2-tailed)	.455	.292	.045	.560
		N	15	15	15	15
	Standardisation	Correlation Coefficient	.095	.319	**.556***	.094
		Sig. (2-tailed)	.737	.246	.032	.740
		N	15	15	15	15
	Organisation Hierarchy	Correlation Coefficient	.299	.218	**.525***	.298
		Sig. (2-tailed)	.279	.436	.044	.280
		N	15	15	15	15
	BIM committee	Correlation Coefficient	.116	.426	**.549***	.281
		Sig. (2-tailed)	.680	.113	.034	.310
		N	15	15	15	15
	Training	Correlation Coefficient	**.526***	**.525***	.399	**.515***
		Sig. (2-tailed)	.044	.044	.141	.050
		N	15	15	15	15
	Education	Correlation Coefficient	.081	.324	.332	.311
		Sig. (2-tailed)	.775	.239	.226	.259
		N	15	15	15	15

	Roles and Responsibilities	Correlation Coefficient	.431	.395	**.544***	.500
		Sig. (2-tailed)	.109	.145	.036	.058
		N	15	15	15	15
	Level of Readiness	Correlation Coefficient	.297	.054	.326	.318
		Sig. (2-tailed)	.283	.848	.235	.247
		N	15	15	15	15
	BIM Skills	Correlation Coefficient	**.599***	.217	.495	**.582***
		Sig. (2-tailed)	.018	.437	.061	.023
		N	15	15	15	15
	Organisation information requirements (OIR)	Correlation Coefficient	.136	-.068	.372	.207
		Sig. (2-tailed)	.628	.811	.172	.459
		N	15	15	15	15
	Validation Process	Correlation Coefficient	.276	.180	.300	.261
		Sig. (2-tailed)	.320	.521	.277	.347
		N	15	15	15	15
	Quality Assurance System	Correlation Coefficient	-.094	.148	.214	-.116
		Sig. (2-tailed)	.739	.599	.444	.681
		N	15	15	15	15
	Software	Correlation Coefficient	**.556***	**.558***	**.660****	.442
		Sig. (2-tailed)	.031	.031	.007	.099
		N	15	15	15	15
	Hardware	Correlation Coefficient	.295	.276	.473	.207
		Sig. (2-tailed)	.285	.320	.075	.460
		N	15	15	15	15
	Physical Space	Correlation Coefficient	.416	.447	**.601***	.406
		Sig. (2-tailed)	.123	.095	.018	.134
		N	15	15	15	15
	Network	Correlation Coefficient	.347	.275	**.605***	.419
		Sig. (2-tailed)	.205	.321	.017	.120
		N	15	15	15	15
*. Correlation is significant at the 0.05 level (2-tailed).						
**. Correlation is significant at the 0.01 level (2-tailed).						

Table 7.28 presents the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low, and it can be seen that all benefits show a significant correlation with almost the same competencies, which are BIM skills, training, and software.

Table 7.28: Spearman correlation summary of Engineering Analysis

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Saving time and cost due to the automation of the analysis process.	1. BIM Skills 2. Software 3. Training
2	This application will help to increase the accuracy and efficiency of the outcomes.	1. Software 2. Training
3	The ability to produce different design solution.	1. Software 2. Network 3. Physical space 4. Standardisation 5. BIM committee 6. Role and responsibilities 7. Organisation hierarchy 8. Data sharing
4	Reduce the design stage period with high-quality outcomes.	1. BIM skills 2. Training

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use in the Engineering Analysis area, a comparative table (Table 7.29) has been developed to show the requirements, benefits, and correlated BIM maturity competencies for this particular BIM use. It can be concluded that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits from using BIM in their Engineering Analysis, they have to develop all correlated maturity competencies. However, if client organisations have limited time and budget for development they can use a correlation ranking to decide which competency to prioritise for development.

Table 7.29: Related maturity competencies of the Engineering Analysis

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. The staff are able to manipulate navigate, and review a 3D model. 2. The staff are able to assess a model through engineering analysis tools. 3. Knowledge of construction means and methods. 4. Design and construction experience. 5. Code checking.	1. Saving time and cost due to the automation of the analysis process. 2. This application will help to increase the accuracy and efficiency of the outcomes. 3. The ability to produce different design solution. 4. Reduce the design stage period with high-quality outcomes.	1. BIM Skills 2. Training 3. Standards 4. BIM champion	1. Software 2. Training 3. BIM skills 4. Network 5. Physical space 6. Standardisation 7. BIM committee 8. Role and responsibilities 9. Organisation hierarchy 10. Data sharing

7.5.6.3 Summary

From the above analysis, the most significant correlation has been found between the benefits and particular competencies, such as the software and training. Moreover, some benefits show a significant correlation with other competencies (Table 7.28), which can be explained as follows:

1. Saving time and cost due to the automation of the analysis process would require the enhancement of BIM skills, software, and training.

2. This application will help to increase the accuracy and efficiency of the outcomes. It would require an improvement in the level of readiness, hardware, physical space, and role and responsibilities.

3. The ability to produce different design solutions would require software, networks, physical space, and standardisation.

4. To reduce the design stage period with high-quality outcomes would require to the enhancement of BIM skills and training.

5. In general, gathering the benefits from using BIM in the Engineering Analysis would require an increase in maturity level within those competencies that show a significant correlation with the benefits. In addition, continuous improvement of these

competencies would, consequently, generate significant value through using BIM in the Engineering Analysis.

In summary, it can be seen that the main competencies that influence BIM implementation in the Engineering Analysis, and that support the client to achieve their desired benefits, are software and training (Table 7.29).

7.5.7 Energy Analysis

The BIM use of Facility Energy Analysis is a process in the facility design phase which one or more asset energy simulation programs use a properly adjusted BIM model to conduct energy assessments for the current asset design. Only 9 of the 26 organisations within this study are currently using BIM in their Energy Analysis. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and identify the relationship between BIM use benefits and the maturity competencies.

7.5.7.1 Descriptive analysis

Figure 7.14 shows the average assurance level for all benefits, and it can be seen that all are still below the expected level; this suggests that the current client BIM abilities are not sufficient to support the prediction of these benefits. These benefits are; savings in time and costs due to the automation in obtaining building and system information from BIM models (benefit 1); improvements in the accuracy of the Energy Analysis outcomes (benefit 2); auto checking through codes (benefit 3); and displaying different energy scenarios in order to produce the optimum energy saving and reduce the costs in general (benefits 4).

The mean, median and standard deviations for these benefits are displayed (Table 7.30) and it can be seen that all benefits show that their median is greater than the mean. This indicates a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This suggests that the mean could be more useful in representing the current assurance situation for these benefits. It can also be seen that each benefit has a different standard deviation and this can indicate where most of the data are located.

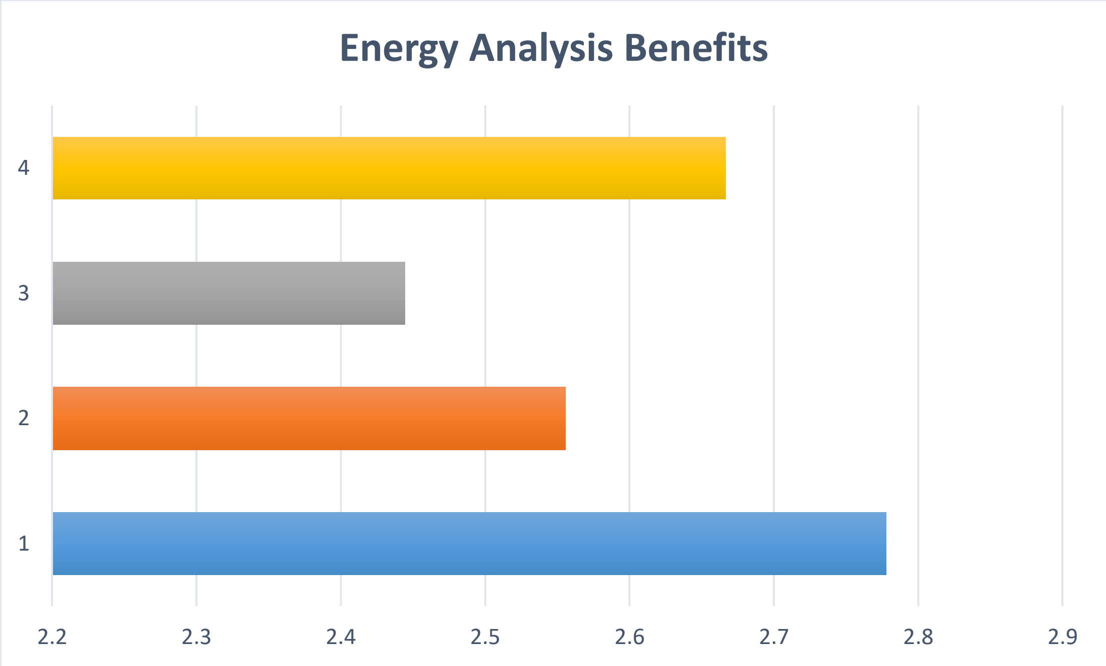


Figure 7.14: Benefit assurance evaluation for Energy Analysis

Table 7.30: Descriptive analysis of Energy Analysis benefits

	Mean	Median	SD
Benefit 1	2.78	3	1.48
Benefit 2	2.56	3	1.01
Benefit 3	2.44	3	1.42
Benefit 4	2.67	3	1.12

7.5.7.2 Inferential analysis

A Spearman's correlation was run to judge the relationship between BIM use benefits in Energy Analysis and the BIM maturity competencies. Nine participants from the client organisations are currently using BIM in this area. The correlation analysis was again carried in three stages. Firstly, the degree of correlation between BIM uses benefits and BIM maturity competencies was determined. Secondly, the relationship was summarised by listing all the related competencies under their correlation degree. Finally, a comparative table was developed to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.31 illustrates that only benefit 1 displays a different level of positive correlation with some BIM maturity competencies; these ranged from a significant correlation, where the ρ-value was less than 0.01, to a moderate correlation, where the ρ-value equalled 0.045. Based on the correlation analysis, benefit 1 shows a significant correlation with management support. The same benefit indicates a positive correlation with software and physical space. Benefits 2, 3 and 4 did not express a correlation with any of the BIM maturity competencies. This is because the client organisations are not currently using BIM in their Energy Analysis. To achieve these benefits, it means overcoming the limitations in client organisations regarding the development of BIM maturity competencies.

Table 7.31: Spearman correlation results for Engineering Analysis

			Benefit 1	Benefit 2	Benefit 3	Benefit 4
Spearman's rho	Organisation Mission	Correlation Coefficient	.249	-.042	.457	.045
		Sig. (2-tailed)	.518	.914	.216	.908
		N	9	9	9	9
	BIM Vision	Correlation Coefficient	.591	.381	.640	.410
		Sig. (2-tailed)	.094	.311	.063	.273
		N	9	9	9	9
	BIM Champion	Correlation Coefficient	.393	-.058	.305	.134
		Sig. (2-tailed)	.296	.882	.425	.731
		N	9	9	9	9
	Management Support	Correlation Coefficient	**.815****	.315	.588	.438
		Sig. (2-tailed)	.007	.409	.096	.238
		N	9	9	9	9
	Data Sharing Method	Correlation Coefficient	.288	-.174	.085	-.014
		Sig. (2-tailed)	.453	.654	.829	.972
		N	9	9	9	9
	Standardisation	Correlation Coefficient	.344	0.000	.427	.163
		Sig. (2-tailed)	.365	1.000	.252	.675
		N	9	9	9	9
	Organisation Hierarchy	Correlation Coefficient	.589	.284	.574	.439
		Sig. (2-tailed)	.095	.460	.106	.237
		N	9	9	9	9
	BIM committee	Correlation Coefficient	.373	-.071	.416	.041
		Sig. (2-tailed)	.322	.857	.266	.917
		N	9	9	9	9
	Training	Correlation Coefficient	.568	.030	.481	.227
		Sig. (2-tailed)	.111	.938	.190	.556

		N	9	9	9	9
	Education	Correlation Coefficient	.329	-.174	.437	.042
		Sig. (2-tailed)	.388	.654	.240	.915
		N	9	9	9	9
	Roles and Responsibilities	Correlation Coefficient	.347	-.297	.069	-.158
		Sig. (2-tailed)	.361	.438	.861	.685
		N	9	9	9	9
	Level of Readiness	Correlation Coefficient	.207	-.100	.329	.142
		Sig. (2-tailed)	.593	.798	.388	.716
		N	9	9	9	9
	BIM Skills	Correlation Coefficient	.536	-.099	.262	.005
		Sig. (2-tailed)	.137	.799	.496	.991
		N	9	9	9	9
	Organisation information requirements (OIR)	Correlation Coefficient	.324	-.157	.259	-.018
		Sig. (2-tailed)	.394	.686	.500	.963
		N	9	9	9	9
	Validation Process	Correlation Coefficient	.366	-.118	.162	.042
		Sig. (2-tailed)	.333	.763	.677	.914
		N	9	9	9	9
	Quality Assurance System	Correlation Coefficient	.263	-.161	.389	.005
		Sig. (2-tailed)	.495	.679	.301	.990
		N	9	9	9	9
	Software	Correlation Coefficient	**.774***	.264	.540	.402
		Sig. (2-tailed)	.014	.493	.133	.284
		N	9	9	9	9
	Hardware	Correlation Coefficient	.369	-.100	.496	.142
		Sig. (2-tailed)	.328	.798	.175	.716
		N	9	9	9	9
	Physical Space	Correlation Coefficient	**.685***	.087	.451	.250
		Sig. (2-tailed)	.042	.824	.223	.516
		N	9	9	9	9
	Network	Correlation Coefficient	.290	-.337	.223	-.178
		Sig. (2-tailed)	.448	.375	.565	.648
		N	9	9	9	9

Table 7.32 summarises the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed from high to low regarding the degree of correlation. It can be seen that only one benefit has a positive correlation with some maturity competencies, which are management support, software, and physical space.

Table 7.32: Spearman correlation summary of Energy Analysis

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Save time and costs due to the automation in obtaining building and system information from BIM model.	1. Management support 2. Software 3. Physical space
2	Improve the accuracy of energy analysis outcomes.	1. None
3	Auto checking through codes.	1. None
4	Display different energy scenario in order to produce the optimum energy saving and reduce the cost in general.	1. None

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use within Energy Analysis, a comparative table was developed. This shows the requirements, benefits, and correlated BIM maturity competencies for this particular BIM use (Table 7.33). It can be concluded that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if the client organisations aim to achieve benefit 1 from using BIM within their Energy Analysis, they have to develop all the correlated maturity competencies. However, if client organisations have limited time and budget for development they can use the correlation ranking to decide which competency has to be prioritised.

Table 7.33: Related maturity competencies of the Energy Analysis

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. The staff must have at least basic knowledge about building energy systems and its standards.	1. Save time and costs due to the automation in obtaining building and system information from BIM model.	1. BIM skills 2. Training 3. Software 4. Hardware 5. BIM vision 6. BIM champion	1. Management support 2. Software 3. Physical space

2. The staff have a knowledge and experience about building system design in general. 3. The staff are able to manipulate navigate, and review a 3D model. 4. The staff are able to check a model through engineering analysis tools. 5. Software and hardware (for read and store data or may be some time to check the design result). 6. Collaboration between the project stakeholders. 7. Team roles and responsibilities. 8. The level of details. 9. Quality assurance system to check the design deliverables. 10. Model breakdown element for project use. 11. Codes and standards.	2. Improve the accuracy of energy analysis outcomes. 3. Auto checking through codes. 4. Display different energy scenario in order to produce the optimum energy saving and reduce the cost in general.	7. Role and responsibilities 8. Standards 9. Quality Assurance system 10. BEP	

7.5.7.3 Summary

Grounded within the aforementioned analysis, the only significant correlation was found between the benefit 1 and the following competencies; management support, software, and physical space. However, the other benefits did not show any correlation with any competencies (Table 7.32) for several reasons, as explained:

1. Currently, client organisations are not using BIM in their Energy Analysis and thus cannot access these benefits.

2. Client organisations are not currently able to predict these benefits due to the limitations in their BIM competencies.

3. There are other competencies, aside from the proposed ones, that may affect the client's ability to predict these benefits.

In summary, it can be seen (Table 7.33) that the only competency that influences BIM implementation within their Energy Analysis and that supports the client to achieve their desired benefits is management support.

7.5.8 Lighting Analysis

Using BIM in Lighting Analysis can be defined as a process in which analytical modelling software utilizes the BIM design authoring model so to determine the behaviour of a given lighting system. Only 11 out of the 26 organisations who contributed to this study are currently using BIM in their Lighting Analysis. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and determine the relationship between BIM use benefits and the maturity competencies.

7.5.8.1 Descriptive analysis

Figure 7.15 displays the average assurance level for all benefits. It can be seen that all the benefits, are still below the expected level and this indicates that current client BIM abilities are not sufficient to support them in predicting these benefits. These benefits include; saving time and cost in order to provide additional models (benefit 1); improving the accuracy of energy analysis outcomes (benefit 2); displaying different energy scenarios in order to produce the optimum light energy savings and reduce the costs in general (benefit 3); improving the quality of the design outcomes (benefit 4); and reducing the cycle time of the design stage (benefit 5). The mean, median and standard deviations for these benefits are shown in Table 7.34, in which it can be seen that benefit 5 has a lower median than the mean and this means a positive skew in their distribution with a long tail of high scores pulling the mean up greater than the median. This means the median can be more useful in representing the current assurance for benefit 5. However, the other benefits show that their median is bigger than the mean which means a negative skew in their distribution with a long tail of low scores pulling the mean down further than the median. This implies the mean could be more useful in representing the current assurance for these benefits. This shows that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation that could indicate where most of the data are located.

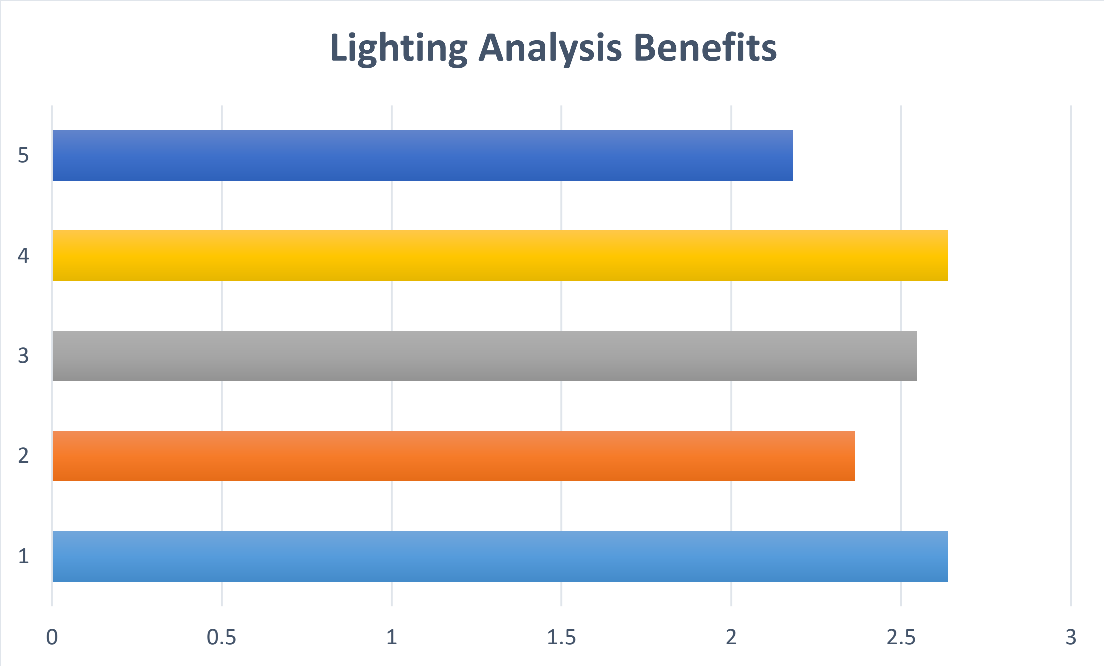


Figure 7.15: Benefit assurance evaluation for Lighting Analysis

Table 7.34: Descriptive analysis of Lighting Analysis benefits

	Mean	Median	SD
Benefit 1	2.64	3	1.36
Benefit 2	2.36	3	1.03
Benefit 3	2.55	3	0.93
Benefit 4	2.64	3	1.12
Benefit 5	2.18	2	1.17

7.5.8.2 Inferential analysis

A Spearman's correlation has been run to judge the relationship between BIM use benefits in a Lighting Analysis and the BIM maturity competencies. Eleven participants from client organisations are currently using BIM in this area. As before, the correlation analysis has been carried in three stages. Firstly, the degree of correlation, between BIM uses benefits and BIM maturity competencies, is shown. Secondly, the relationship is summarised by listing all the related competencies regarding their degree of correlation. Finally, a comparative table will compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.35 indicates that only benefit 4 displays a positive correlation with one BIM maturity competency, which is the level of readiness, where the ρ-value is equal to 0.042. Based on the correlation analysis, the other benefits did not show a correlation with any BIM maturity competencies. The main reason is due to the high level of technical skills required for such

BIM use; the current level of BIM knowledge and expertise amongst client organisations prevents them from becoming involved in this BIM use or being able to predict the benefits.

Table 7.35: Spearman correlation results for Lighting Analysis

			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5
Spearman's rho	Organisation Mission	Correlation Coefficient	.198	-.153	.075	.279	.029
		Sig. (2-tailed)	.560	.654	.827	.406	.932
		N	11	11	11	11	11
	BIM Vision	Correlation Coefficient	.359	.318	.214	.235	.401
		Sig. (2-tailed)	.278	.341	.527	.486	.222
		N	11	11	11	11	11
	BIM Champion	Correlation Coefficient	.236	.013	-.041	.107	.186
		Sig. (2-tailed)	.484	.971	.904	.755	.584
		N	11	11	11	11	11
	Management Support	Correlation Coefficient	.382	.198	-.018	.089	.452
		Sig. (2-tailed)	.247	.560	.957	.795	.163
		N	11	11	11	11	11
	Data Sharing Method	Correlation Coefficient	.005	-.387	-.310	-.072	-.142
		Sig. (2-tailed)	.989	.240	.354	.834	.677
		N	11	11	11	11	11
	Standardisation	Correlation Coefficient	.090	-.153	-.143	.046	-.019
		Sig. (2-tailed)	.791	.653	.675	.894	.955
		N	11	11	11	11	11
	Organisation Hierarchy	Correlation Coefficient	.221	.207	-.057	.019	.343
		Sig. (2-tailed)	.514	.542	.869	.955	.302
		N	11	11	11	11	11
	BIM committee	Correlation Coefficient	.492	.229	.198	.378	.419
		Sig. (2-tailed)	.125	.498	.559	.252	.199
		N	11	11	11	11	11
	Training	Correlation Coefficient	.133	-.072	-.261	-.085	.185
		Sig. (2-tailed)	.696	.834	.438	.803	.587
		N	11	11	11	11	11
	Education	Correlation Coefficient	.069	-.262	-.257	-.005	-.022
		Sig. (2-tailed)	.841	.436	.445	.989	.948
		N	11	11	11	11	11

	Roles and Responsibilities	Correlation Coefficient	.270	-.190	-.170	.066	.064
		Sig. (2-tailed)	.422	.576	.616	.848	.853
		N	11	11	11	11	11
	Level of Readiness	Correlation Coefficient	.472	.235	.460	**.619***	.330
		Sig. (2-tailed)	.142	.487	.155	.042	.322
		N	11	11	11	11	11
	BIM Skills	Correlation Coefficient	.285	-.224	-.159	.087	.107
		Sig. (2-tailed)	.395	.508	.640	.799	.754
		N	11	11	11	11	11
	Organisation information requirements (OIR)	Correlation Coefficient	.089	-.271	-.179	.029	-.056
		Sig. (2-tailed)	.794	.421	.599	.932	.869
		N	11	11	11	11	11
	Validation Process	Correlation Coefficient	.147	-.264	-.128	.091	-.057
		Sig. (2-tailed)	.667	.433	.707	.790	.868
		N	11	11	11	11	11
	Quality Assurance System	Correlation Coefficient	.247	-.223	-.056	.264	.038
		Sig. (2-tailed)	.464	.510	.871	.433	.913
		N	11	11	11	11	11
	Software	Correlation Coefficient	.455	.241	.053	.172	.469
		Sig. (2-tailed)	.160	.475	.877	.614	.146
		N	11	11	11	11	11
	Hardware	Correlation Coefficient	.432	-.095	.106	.488	.283
		Sig. (2-tailed)	.184	.781	.757	.128	.399
		N	11	11	11	11	11
	Physical Space	Correlation Coefficient	.447	.013	-.039	.210	.379
		Sig. (2-tailed)	.168	.971	.909	.535	.250
		N	11	11	11	11	11
	Network	Correlation Coefficient	-.015	-.472	-.443	-.143	-.104
		Sig. (2-tailed)	.966	.143	.173	.675	.760
		N	11	11	11	11	11

Table 7.36 summarises the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen that only benefit 4 has a positive correlation, with the level of readiness as the only correlated BIM maturity competency.

Table 7.36: Spearman correlation summary of Lighting Analysis

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Save time and cost in order to provide additional models.	1. None
2	Improve the accuracy of lighting analysis outcomes.	1. None
3	Display different energy scenario in order to produce the optimum light energy saving and reduce the cost in general.	1. None
4	Improve the quality of the design outcomes	1. Level of readiness
5	Reduce the cycle time of the design stage.	1. None

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use in Lighting Analysis, a comparative table (Table 7.37) has been drawn to show the requirements, benefits and correlated BIM maturity competencies for this particular BIM use. It can be concluded that, if the client organisations aim to achieve benefit 4 from using BIM in their Lighting Analysis, they have to develop the level of readiness amongst their organisation's employees. In addition, due to lack to identify the correlated BIM maturity competencies, the proposed related BIM maturity competencies can be used as guidance and not necessarily will lead to improve the achievement of the desired benefit of using BIM in Lighting Analysis.

Table 7.37: Related maturity competencies of the Lighting Analysis

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. The staff are able to manipulate navigate, and review a 3D Lighting Model 2. The staff are able to assess a model through engineering analysis tools	1. Save time and cost in order to provide additional models. 2. Improve the accuracy of energy analysis outcomes. 3. Display different energy scenario in order to produce the optimum light energy saving and	1. BIM skills 2. Training 3. Software 4. Hardware 5. Standards	1. Level of readiness

3. The staff must have at least basic lighting expertise. 4. The level of details.	reduce the cost in general. 4. Improve the quality of the design outcomes. 5. Reduce the cycle time of the design stage.		

7.5.8.3 Summary

Based on above analysis, the only correlation found was between benefit 4 and the level of readiness. However, the other benefits did not show a correlation with any competencies (Table 7.36) and this could be due to several reasons, as explained below:

1. Currently, client organisations are not using BIM in their Lighting Analysis to gather these benefits.
2. Client organisations presently are not able to predict these benefits due to the limitation in their BIM competencies.
3. There are other competencies aside from those proposed that may affect a client's ability to predict these benefits.

In summary, it can be seen (Table 7.37) that there is only one competency that influences BIM implementation within their Lighting Analysis, and that would support a client to achieve this benefit; this is the level of readiness.

7.5.9 Sustainability Evaluation

A process in which a BIM project is evaluated based on any sustainable criteria. This process should occur during all stages of an asset life including planning, design, construction, and operation. Only seven out of 26 organisations participating in this study are currently using BIM in their Sustainability Evaluation. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and to find the relationship between BIM use benefits and the maturity competencies.

7.5.9.1 Descriptive analysis

Figure 7.16 displays the average assurance level for all benefits. It can be seen that only four benefits, namely, 1, 2, 3, and 5, have reached the expectation level (level three) which means that client organisations' current BIM maturity levels only enable them to predict this benefit. These benefits are: to provide a good evaluation in the early design stage to increase the efficiency of the project and reduce cost and time (benefit 1); to ensure the speed and access to information help to review many of the alternatives at specific times (benefit 2); to improve the project quality (benefit 3); and to optimise building performance via improved energy management (benefit 5). While the other benefits, namely 4, 6, and 7, are still below the expected benefits, which mean that the current client BIM abilities are not enough to support him to predict these benefits. These benefits are: to reduce the documentation load after design and accelerate certification (benefit 4); pay more attention to environmentally friendly and sustainable design (benefit 6); and provide valuable information for future use (benefit 7). The mean, median and standard deviations for these benefits are shown in Table 7.38 in which it can be seen that benefit 7 shows that their median is lower than the mean which means a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. This indicates that the median can be more useful in representing the current assurance level for benefit 7. While benefits 4 and 6 show that the median and the mean are approximately equal, which indicates that the distribution is symmetric and will have zero skewness. However, the other benefits show that their median is bigger than the mean, which means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This suggests that the mean could be more useful in representing the current assurance for these benefits. This indicates that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation that can give an indication where most of the data are located.

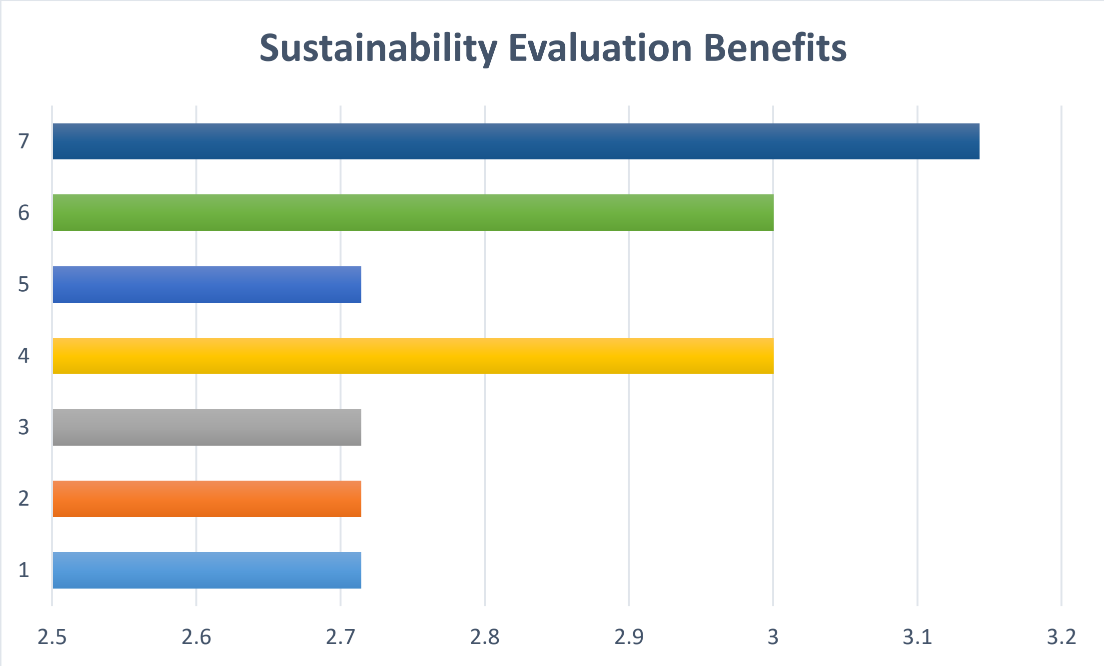


Figure 7.16: Benefit assurance evaluation for Sustainability Evaluation

Table 7.38: Descriptive analysis of Sustainability Evaluation benefits

	Mean	Median	SD
Benefit 1	2.71	3	1.25
Benefit 2	2.71	3	0.95
Benefit 3	2.71	3	1.25
Benefit 4	3.00	3	1.15
Benefit 5	2.71	3	1.25
Benefit 6	3.00	3	1.00
Benefit 7	3.14	3	1.07

7.5.9.2 Inferential analysis

A Spearman's correlation was carried out to judge the relationship between BIM use benefits in Sustainability Evaluation and the BIM maturity competencies. Seven participants from client organisations are currently using BIM in this area. Again, the correlation analysis has been carried in three stages. Firstly, the degree of correlation between BIM uses benefits and BIM maturity competencies is displayed. Secondly, the relationship is summarised by listing all the related competencies by their correlation degree. Finally, a comparative Table will be developed to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.39 specifies that some benefits have shown a different level of positive correlation with some BIM maturity competencies, which ranged from a strong correlation, where the ρ-value is less than 0.02, to a moderate correlation, where the ρ-value is equal to 0.044. Based on the correlation analysis, only benefits 1, 3, 4 and 5 show a positive correlation with BIM vision. However, benefits 2 and 6 did not show a positive correlation with any competency, and benefit 7 indicates a positive correlation with only the BIM vision, quality assurance systems, and hardware.

Table 7.39: Spearman correlation results for Sustainability Evaluation

			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5	Benefit 6	Benefit 7
Spearman's rho	Organisation Mission	Correlation Coefficient	.392	.491	.392	.369	.392	.455	.641
		Sig. (2-tailed)	.384	.264	.384	.415	.384	.305	.121
		N	7	7	7	7	7	7	7
	BIM Vision	Correlation Coefficient	**.777***	.415	**.777***	**.760***	**.777***	.522	**.773***
		Sig. (2-tailed)	.040	.354	.040	.048	.040	.229	.041
		N	7	7	7	7	7	7	7
	BIM Champion	Correlation Coefficient	.291	-.152	.291	.365	.291	.256	.496
		Sig. (2-tailed)	.526	.745	.526	.420	.526	.580	.258
		N	7	7	7	7	7	7	7
	Management Support	Correlation Coefficient	.510	.128	.510	.667	.510	.452	.625
		Sig. (2-tailed)	.242	.785	.242	.102	.242	.309	.133
		N	7	7	7	7	7	7	7
	Data Sharing Method	Correlation Coefficient	.450	.104	.450	.624	.450	.453	.633
		Sig. (2-tailed)	.311	.824	.311	.134	.311	.307	.127
		N	7	7	7	7	7	7	7
	Standardisation	Correlation Coefficient	.486	.051	.486	.558	.486	.502	.734
		Sig. (2-tailed)	.269	.914	.269	.193	.269	.251	.061
		N	7	7	7	7	7	7	7
	Organisation Hierarchy	Correlation Coefficient	.340	0.000	.340	.404	.340	.440	.674
		Sig. (2-tailed)	.456	1.000	.456	.369	.456	.323	.097
		N	7	7	7	7	7	7	7
	BIM committee	Correlation	.241	-.100	.241	.305	.241	.193	.491

		Coefficient							
		Sig. (2-tailed)	.603	.831	.603	.506	.603	.679	.263
		N	7	7	7	7	7	7	7
	Training	Correlation Coefficient	.422	-.209	.422	.459	.422	.300	.581
		Sig. (2-tailed)	.346	.653	.346	.300	.346	.513	.171
		N	7	7	7	7	7	7	7
	Education	Correlation Coefficient	.200	-.177	.200	.267	.200	.274	.531
		Sig. (2-tailed)	.667	.704	.667	.562	.667	.552	.220
		N	7	7	7	7	7	7	7
	Roles and Responsibilities	Correlation Coefficient	.096	-.191	.096	.333	.096	-.091	.177
		Sig. (2-tailed)	.837	.682	.837	.465	.837	.846	.705
		N	7	7	7	7	7	7	7
	Level of Readiness	Correlation Coefficient	.194	0.000	.194	.202	.194	.563	.674
		Sig. (2-tailed)	.676	1.000	.676	.664	.676	.188	.097
		N	7	7	7	7	7	7	7
	BIM Skills	Correlation Coefficient	.340	.203	.340	.596	.340	.195	.436
		Sig. (2-tailed)	.456	.663	.456	.158	.456	.676	.328
		N	7	7	7	7	7	7	7
	Organisation information requirements (OIR)	Correlation Coefficient	.433	.100	.433	.572	.433	.314	.609
		Sig. (2-tailed)	.332	.831	.332	.180	.332	.492	.147
		N	7	7	7	7	7	7	7
	Validation Process	Correlation Coefficient	.612	.085	.612	.728	.612	.473	.667
		Sig. (2-tailed)	.144	.856	.144	.064	.144	.283	.102
		N	7	7	7	7	7	7	7
	Quality Assurance System	Correlation Coefficient	.644	.031	.644	.657	.644	.522	**.768***
		Sig. (2-tailed)	.119	.947	.119	.109	.119	.230	.044
		N	7	7	7	7	7	7	7

	Software	Correlation Coefficient	.612	.085	.612	.728	.612	.473	.667
		Sig. (2-tailed)	.144	.856	.144	.064	.144	.283	.102
		N	7	7	7	7	7	7	7
	Hardware	Correlation Coefficient	.644	.031	.644	.608	.644	.647	**.829***
		Sig. (2-tailed)	.119	.947	.119	.148	.119	.116	.021
		N	7	7	7	7	7	7	7
	Physical Space	Correlation Coefficient	.612	.085	.612	.728	.612	.473	.667
		Sig. (2-tailed)	.144	.856	.144	.064	.144	.283	.102
		N	7	7	7	7	7	7	7
	Network	Correlation Coefficient	.297	-.072	.297	.441	.297	.146	.465
		Sig. (2-tailed)	.518	.878	.518	.322	.518	.755	.293
		N	7	7	7	7	7	7	7
*. Correlation is significant at the 0.05 level (2-tailed).									
**. Correlation is significant at the 0.01 level (2-tailed).									

Table 7.40 presents the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed under the degree of correlation, from high to low. It can be seen that benefits 2 and 6 did not have a relationship with any competency. However, the rest of the benefits show a positive correlation with BIM vision as a common competency.

Table 7.40: Spearman correlation summary of Sustainability Evaluation

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Provide good evaluation in early design stage will increase the efficiency of the project and reduce cost and time.	1. BIM vision
2	The speed and access of information help to review many of the alternatives at a specific time.	1. None
3	Improve the project quality.	1. BIM vision
4	Reduces documentation load after design and accelerates certification because concurrently prepared calculations can be used for verification.	1. BIM vision
5	It optimised building performance via improved energy management.	1. BIM vision

6	Add more attention on the environmentally friendly and sustainable design.	1. None
7	Provide valuable information for future use.	1. Hardware 2. BIM vision 3. Quality assurance system

b) Overall relationship

In order to acknowledge the BIM maturity competencies that affect BIM use within Sustainability Evaluation, a comparative table (Table 7.41) has been provided, which shows the requirements, benefits and correlated BIM maturity competencies for this particular BIM use. It can be concluded that, if client organisations aim to achieve benefit 4 from using BIM in sustainable evaluation, they have to develop their BIM vision, hardware, and quality assurance systems. In addition, there are differences between the proposed and correlated BIM maturity competencies which mean proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience.

Table 7.41: Related maturity competencies of the Sustainability Evaluation

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. The staff are able to manipulate navigate, and review a 3D model. 2. The staff must have knowledge about the most updating sustainability checking systems. 3. The staff are able to organise and manage the database. 4. The required software and hardware.	1. Provide good evaluation in early design stage will increase the efficiency of the project and reduce cost and time. 2. The speed and access of information help to review many of the alternatives at a specific time. 3. Improve the project quality. 4. Reduces documentation load and accelerates certification because concurrently prepared calculations can be used for verification. 5. It optimised building performance via improved energy management.	1. BIM skills 2. Training 3. Software 4. Hardware	1. BIM vision 2. Hardware 3. Quality assurance system

	6. Add more attention on the environmentally friendly and sustainable design. 7. Provide valuable information for future use.		

7.5.9.3 Summary

Based on the above analysis, correlations have been found between the benefits and some competencies, such as BIM vision, hardware, and quality assurance systems. Moreover, some benefits show a correlation with other competencies (Table 7.40), which will be explained as follows:

1. Benefits 1, 3, 4, and 5 would require an improvement in the level of BIM vision.
2. Providing valuable information for future use would require to an improvement in the level of hardware, BIM vision, and quality assurance system.
3. Benefits 2 and 6 did not show a correlation with any competency, which may lead to one or more of the following conclusions:

a) Currently, client organisations are not using BIM in Sustainability Evaluation to access these benefits.

b) Client organisations presently are not able to predict these benefits due to limitations in their BIM competencies.

c) There are other competencies, aside from those proposed, that may affect a client's ability to predict these benefits.

4. Generally, gathering the benefits from using BIM in Sustainability Evaluation will require an increase in maturity level in those competencies that show significant correlation with the benefits. In addition, the continuous improvement of these competencies would, consequently, generate significant value through using BIM in Sustainability Evaluation.

In summary, it can be seen (Table 7.41) that the main competencies that influence BIM implementation in Sustainability Evaluation and that would support a client to achieve their desired benefits are BIM vision, hardware, quality assurance systems.

7.5.10 Code Validation

Using BIM in Code Validation means a process in which Code Validation software is utilised to check the model parameters against project specific codes. Only seven out of the 26 organisations who contributed to this study are currently using BIM in Code Validation. For this BIM use, both descriptive and inferential analyses will be conducted to test the data and determine the relationship between BIM use benefits and the maturity competencies.

7.5.10.1 Descriptive analysis

Figure 7.17 shows the average assurance level for all benefits. It can be seen that all are still below the expected benefits, which means that current client BIM abilities are not sufficient to support them in predicting these benefits. These are: checking the building design against specific codes (benefit 1); reducing the errors and omissions due to early code checking (benefit 2); the automation process in code checking allowing time to focus on more important issues (benefit 3); saving time on multiple checking for code compliance and allowing for a more efficient design process since mistakes cost time and money (benefit 4). The mean, median and standard deviations for these benefits are shown in Table 7.42 in which it can be seen that all benefits show that their median is bigger than the mean. This means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This shows that the mean can be more useful in representing the current assurance for these benefits. This indicates that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation; this can indicate where most of the data are located.

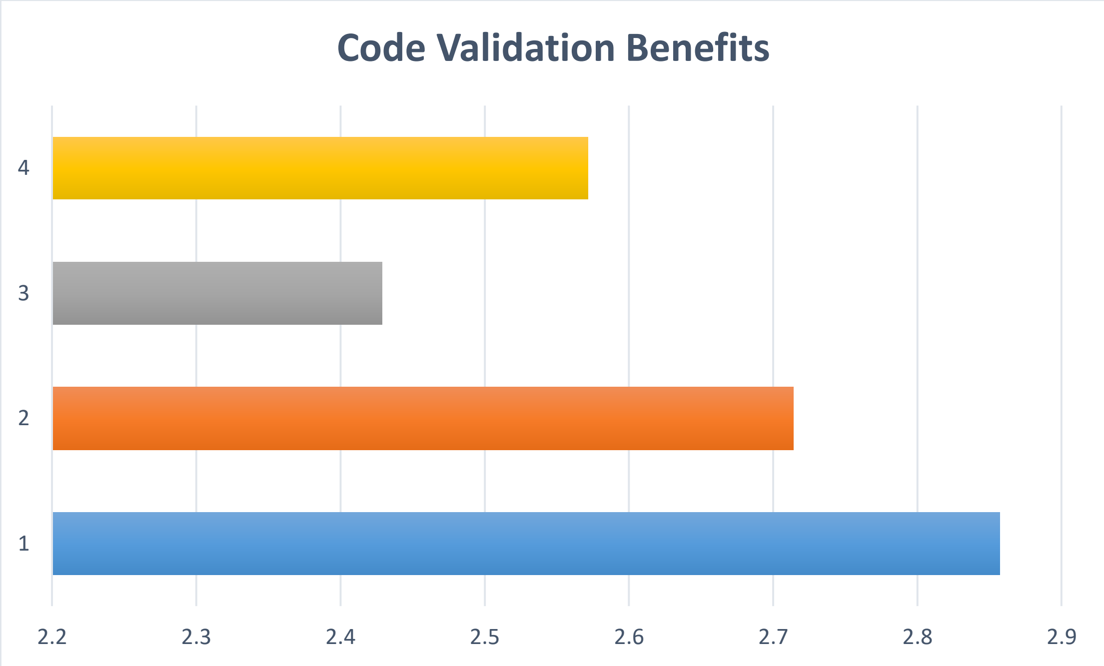


Figure 7.17: Benefit assurance evaluation for Code Validation

Table 7.42: Descriptive analysis of Code Validation benefits

	Mean	Median	SD
Benefit 1	2.86	3	1.35
Benefit 2	2.71	3	1.38
Benefit 3	2.43	3	1.40
Benefit 4	2.57	3	1.27

7.5.10.2 Inferential analysis

A Spearman's correlation has been implemented to examine the relationship between BIM use benefits in Code Validation and the BIM maturity competencies. Seven participants from client organisations are currently using BIM in this area. The correlation analysis has been carried in three stages, where the first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies by their correlation degree. Finally, a comparative table will be developed to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.43 shows that some benefits have a different level of positive correlation with some BIM maturity competencies; these ranged from a strong correlation, where the ρ-value is less than 0.018, to a moderate correlation, where the ρ-value is equal to 0.025. Based on this analysis, benefits 3 and 4 only show a positive correlation with management support. However, benefits 2 and 6 did not show a positive correlation with any competency.

Table 7.43: Spearman correlation results for Code Validation

			Benefit 1	Benefit 2	Benefit 3	Benefit 4
Spearman's rho	Organisation Mission	Correlation Coefficient	.418	.346	.631	.575
		Sig. (2-tailed)	.351	.447	.128	.176
		N	7	7	7	7
	BIM Vision	Correlation Coefficient	.712	.629	.674	.710
		Sig. (2-tailed)	.073	.130	.097	.074
		N	7	7	7	7
	BIM Champion	Correlation Coefficient	.200	.167	.559	.543
		Sig. (2-tailed)	.667	.720	.192	.208
		N	7	7	7	7
	Management Support	Correlation Coefficient	.420	.376	**.840***	**.816***
		Sig. (2-tailed)	.348	.405	.018	.025
		N	7	7	7	7
	Data Sharing Method	Correlation Coefficient	.735	.647	.367	.515
		Sig. (2-tailed)	.060	.116	.417	.236
		N	7	7	7	7
	Standardisation	Correlation Coefficient	.670	.574	.590	.670
		Sig. (2-tailed)	.100	.178	.163	.099
		N	7	7	7	7
	Organisation Hierarchy	Correlation Coefficient	.450	.347	.450	.486
		Sig. (2-tailed)	.311	.446	.311	.269
		N	7	7	7	7
	BIM committee	Correlation Coefficient	.465	.431	.426	.510
		Sig. (2-tailed)	.293	.334	.341	.243
		N	7	7	7	7
	Training	Correlation Coefficient	-.011	-.094	.295	.235
		Sig. (2-tailed)	.982	.841	.520	.611
		N	7	7	7	7
	Education	Correlation Coefficient	-.011	-.094	.295	.235
		Sig. (2-tailed)	.982	.841	.520	.611
		N	7	7	7	7
	Roles and Responsibilities	Correlation Coefficient	.031	-.021	.156	.152
		Sig. (2-tailed)	.947	.965	.738	.745

		N	7	7	7	7
	Level of Readiness	Correlation Coefficient	.407	.310	.719	.699
		Sig. (2-tailed)	.365	.499	.068	.081
		N	7	7	7	7
	BIM Skills	Correlation Coefficient	.272	.192	.340	.330
		Sig. (2-tailed)	.555	.679	.456	.470
		N	7	7	7	7
	Organisation information requirements (OIR)	Correlation Coefficient	.495	.402	.485	.519
		Sig. (2-tailed)	.259	.371	.270	.232
		N	7	7	7	7
	Validation Process	Correlation Coefficient	.450	.347	.450	.486
		Sig. (2-tailed)	.311	.446	.311	.269
		N	7	7	7	7
	Quality Assurance System	Correlation Coefficient	.450	.347	.450	.486
		Sig. (2-tailed)	.311	.446	.311	.269
		N	7	7	7	7
	Software	Correlation Coefficient	.220	.129	.590	.524
		Sig. (2-tailed)	.635	.783	.163	.227
		N	7	7	7	7
	Hardware	Correlation Coefficient	.396	.284	.406	.442
		Sig. (2-tailed)	.379	.537	.366	.320
		N	7	7	7	7
	Physical Space	Correlation Coefficient	.670	.574	.590	.670
		Sig. (2-tailed)	.100	.178	.163	.099
		N	7	7	7	7
	Network	Correlation Coefficient	.406	.333	.129	.221
		Sig. (2-tailed)	.366	.465	.783	.634
		N	7	7	7	7
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

Table 7.44 bridges the correlation results by showing the benefits with their related competencies. The BIM maturity competencies have been listed regarding the degree of correlation, from high to low. It can be seen that benefits 1 and 2 did not have a relationship with any competency. However, the remaining benefits show a positive correlation with management support, which was a common competency.

Table 7.44: Spearman correlation summary of Code Validation

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Checking the building design against specific codes.	1. None
2	Reduce the errors and omissions due to early code checking.	1. None
3	The automation process in code checking will give the team to focus on more important issues.	1. Management support
4	Saves time on multiple checking for code compliance and allows for a more efficient design process since mistakes cost time and money.	1. Management support

b) Overall relationship

In order to acknowledge the BIM maturity competencies that affect BIM use in Code Validation, a comparative table (Table 7.45) has been drawn up to show the requirements, benefits and correlated BIM maturity competencies for this particular BIM use. It can be concluded that, if client organisations aim to achieve benefits 3 and 4 from using BIM in Code Validation, they have to develop their management support. Meanwhile, the proposed related maturity competencies can be used just as guidance for any improvement related to use BIM in Coding Validation area.

Table 7.45: Related maturity competencies of the Code Validation

Requirements	Benefits	Proposed related maturity competencies	Maturity
1. Collaboration between the project stakeholders. 2. Quality Assurance to check design deliverables. 3. Standards. 4. Suitable software and hardware. 5. Teams roles and responsibilities. 6. The team are able to use code validation	1. Checking the building design against specific codes. 2. Reduce the errors and omissions due to early code checking. 3. The automation process in code checking will give the team to focus	1. BIM vision 2. Quality assurance system 3. Software 4. Hardware 5. Role and responsibilities	1. Management support

software and previous knowledge and experience with checking codes is needed.	on more important issues. 4. Saves time on multiple checking for code compliance and allows for a more efficient design process since mistakes cost time and money.		

7.5.10.3 Summary

Based on the above analysis, a correlation has been found between benefits 3 and 4 and management support. However, some benefits did not show a correlation with any competency (Table 7.44), which could be explained as follows:

1. Benefits 3 and 4 would require an improvement in the level of management support.
2. Benefits 1 and 2 did not show a correlation with any competency, which may lead to several conclusions, such as:
   a) Currently, client organisations are not using BIM in code validation to gather these benefits.
   b) Client organisations are not presently able to predict these benefits due to the limitations in their BIM competencies.
   c) There are other competencies aside from those proposed that may affect a client ability to predict these benefits.
3. Generally, gathering the benefits from using BIM in Code Validation will require an increase in maturity level in particular competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would, consequently, generate significant value through using BIM in sustainability evaluation.

In summary, it can be seen (Table 7.45) that the main competency that influences BIM implementation in Code Validation, and that supports the client to achieve their desired benefits is only management support.

7.5.11 Clash Detection

Using BIM in Clash Detection area can be described as a process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of asset’s systems. All of the 26 organisations who contributed to this study are currently using BIM in Clash Detection. For this BIM use, both descriptive and inferential analyses will be conducted to test the data and to determine the relationship between BIM use benefits and the maturity competencies.

7.5.11.1 Descriptive analysis

Figure 7.18 shows the average assurance level for all benefits. It can be seen that all benefits have reached the expected level, which means the client organisation’s current BIM maturity level only enables them to predict this benefit. These benefits are to: coordinate building projects through a model (benefit 1); reduce the Requests For Information (RFI) in the construction stage (benefit 2); increase productivity for the project in general (benefit 3); reduce the budget cost (benefit 4); improve and step up the construction process (benefit 5); and increase the as-built model accuracy (benefit 6). The mean, median and standard deviations for these benefits are shown in Table 7.46 from which it can be seen that benefits 2, 3, and 4 indicate that their median is lower than the mean, which means a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. This suggests that the median could be more useful in representing the current assurance for benefits 2, 3, and 4. However, benefits 1, 5, and 6 show a bigger median than the mean, which means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean can be more useful in representing the current assurance for benefits 1, 5, and 6. This indicates that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, each benefit has a different standard deviation that can give an indication where most of the data are located.

Figure 7.18: Benefit assurance evaluation for Clash Detection

Table 7.46: Descriptive analysis of Clash Detection benefits

	Mean	Median	SD
Benefit 1	3.92	4	1.16
Benefit 2	3.62	3.5	1.27
Benefit 3	3.46	3	1.27
Benefit 4	3.54	3	1.27
Benefit 5	3.88	4	1.18
Benefit 6	3.77	4	1.50

7.5.11.2 Inferential analysis

A Spearman's correlation was run to evaluate the relationship between BIM use benefits in Clash Detection and the BIM maturity competencies. Twenty-six participants from client organisations are currently using BIM in this area. The correlation analysis has been carried in three stages. The first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies with regard to their correlation degree. Finally, a comparative table will be developed to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.47 indicates that each benefit has a different level of positive correlation with some BIM maturity competencies, and that these ranged from a significant correlation, where the ρ-value is less than 0.01, to a moderate correlation, where the ρ-value is equal to 0.049. Based on the correlation analysis, benefit 1 shows a significant correlation with BIM vision, BIM champion, management support, data sharing, standardisation, training, role and responsibilities, the level of readiness, BIM skills, and all technical competencies. In addition, it displays a positive correlation with OIR, validation process, and quality assurance system. Benefit 2 shows a significant correlation with data sharing, training, role and responsibilities, the level of readiness, BIM skills, and all technical competencies, and a positive correlation with BIM vision, management support, organisation mission, BIM champion, OIR, and validation process. Benefit 3 only indicates a significant correlation with BIM vision, training, software, hardware, physical space, and management support, but displays a positive correlation with the BIM champion and role and responsibilities. Benefit 4 only shows a significant correlation with BIM vision, training, software, hardware, physical space, and management support, but displays a positive correlation with BIM champion, BIM skills and role and responsibilities. Benefit 5 only indicates a significant correlation with validation process and hardware, although expresses a positive correlation with BIM vision, BIM skills, OIR, and the rest of the technical competencies. Benefit 6 shows a significant correlation with BIM vision, management support, standardisation, OIR, hardware, and physical space. In addition, it expresses a positive correlation with organisation mission, BIM champion, data sharing, BIM committee, training, education, role and responsibilities, validation process, and quality assurance system.

Table 7.47: Spearman correlation results for Clash Detection

			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5	Benefit 6
Spearman's rho	Organisation Mission	Correlation Coefficient	.263	**.432***	.122	.149	.254	**.468***
		Sig. (2-tailed)	.194	.028	.553	.467	.210	.016
		N	26	26	26	26	26	26
	BIM Vision	Correlation Coefficient	**.502****	**.397***	**.552****	**.568****	**.407***	**.690****
		Sig. (2-tailed)	.009	.045	.003	.002	.039	.000
		N	26	26	26	26	26	26
	BIM Champion	Correlation Coefficient	**.564****	**.484***	**.454***	**.453***	.349	**.409***
		Sig. (2-tailed)	.003	.012	.020	.020	.080	.038
		N	26	26	26	26	26	26
	Management Support	Correlation Coefficient	**.612****	**.491***	**.569****	**.663****	.371	**.553****
		Sig. (2-tailed)	.001	.011	.002	.000	.062	.003

		N	26	26	26	26	26	26
	Data Sharing Method	Correlation Coefficient	**.727****	**.556****	.287	.302	.338	**.465***
		Sig. (2-tailed)	.000	.003	.155	.134	.092	.017
		N	26	26	26	26	26	26
	Standardisation	Correlation Coefficient	**.558****	.322	.259	.325	.350	**.558****
		Sig. (2-tailed)	.003	.109	.202	.105	.080	.003
		N	26	26	26	26	26	26
	Organisation Hierarchy	Correlation Coefficient	.324	.070	.215	.348	.147	.346
		Sig. (2-tailed)	.107	.732	.292	.082	.474	.084
		N	26	26	26	26	26	26
	BIM committee	Correlation Coefficient	.251	.271	.341	.316	.311	**.390***
		Sig. (2-tailed)	.216	.181	.089	.115	.122	.049
		N	26	26	26	26	26	26
	Training	Correlation Coefficient	**.578****	**.500****	**.504****	**.593****	.376	**.441***
		Sig. (2-tailed)	.002	.009	.009	.001	.058	.024
		N	26	26	26	26	26	26
	Education	Correlation Coefficient	.320	.104	.235	.254	.198	**.486***
		Sig. (2-tailed)	.111	.612	.249	.211	.332	.012
		N	26	26	26	26	26	26
	Roles and Responsibilities	Correlation Coefficient	**.634****	**.525****	**.457***	**.446***	.349	**.478***
		Sig. (2-tailed)	.001	.006	.019	.022	.081	.013
		N	26	26	26	26	26	26
	Level of Readiness	Correlation Coefficient	**.552****	**.535****	.344	.337	.277	.277
		Sig. (2-tailed)	.003	.005	.086	.092	.171	.170
		N	26	26	26	26	26	26
	BIM Skills	Correlation Coefficient	**.565****	**.525****	.326	**.420***	**.409***	.338
		Sig. (2-tailed)	.003	.006	.105	.033	.038	.091
		N	26	26	26	26	26	26
	Organisation information requirements (OIR)	Correlation Coefficient	**.429***	**.435***	.221	.272	**.438***	**.669****
		Sig. (2-tailed)	.029	.026	.277	.179	.025	.000
		N	26	26	26	26	26	26
	Validation Process	Correlation Coefficient	**.418***	**.450***	.216	.308	**.496****	**.456***
		Sig. (2-tailed)	.034	.021	.289	.126	.010	.019
		N	26	26	26	26	26	26
		Correlation Coefficient	**.420***	.081	.046	.025	.041	**.474***

	Quality Assurance System	Sig. (2-tailed)	.033	.693	.822	.904	.842	.014
		N	26	26	26	26	26	26
	Software	Correlation Coefficient	.747**	.610**	.645**	.650**	.466*	.302
		Sig. (2-tailed)	.000	.001	.000	.000	.017	.133
		N	26	26	26	26	26	26
	Hardware	Correlation Coefficient	.856**	.655**	.551**	.542**	.524**	.516**
		Sig. (2-tailed)	.000	.000	.004	.004	.006	.007
		N	26	26	26	26	26	26
	Physical Space	Correlation Coefficient	.764**	.551**	.509**	.533**	.468*	.584**
		Sig. (2-tailed)	.000	.004	.008	.005	.016	.002
		N	26	26	26	26	26	26
	Network	Correlation Coefficient	.667**	.506**	.375	.381	.434*	.369
		Sig. (2-tailed)	.000	.008	.059	.055	.027	.063
		N	26	26	26	26	26	26
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Table 7.48 summarises the correlation results by showing the benefits with their related competencies. The BIM maturity competencies have been listed regarding the degree of correlation, from high to low. It can be seen that all benefits show a significant correlation with almost the same competencies, which are technical competencies, role and responsibilities, OIR, and data sharing.

Table 7.48: Spearman correlation summary of Clash Detection

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Coordinate building project through a model	1. Hardware 2. Physical space 3. Software 4. Data share 5. Network 6. Role and responsibilities 7. Management support 8. Training 9. BIM skills 10. BIM champion 11. Standardisation 12. Level of readiness 13. BIM vision 14. OIR

		15. Quality assurance system 16. Validation process
2	Reduce the requests for information (RFI) in the construction stage.	1. Hardware 2. Software 3. Data sharing 4. Physical space 5. Level of readiness 6. Role and responsibilities 7. BIM skills 8. Network 9. Training 10. Management support 11. BIM champion 12. Validation process 13. OIR 14. Organisation mission 15. BIM vision
3	Increase productivity for the project in general.	1. Software 2. Management support 3. BIM vision 4. Hardware 5. Physical space 6. Training 7. Role and responsibilities 8. BIM champion
4	Reduce budget cost.	1. Management support 2. Software 3. Training 4. BIM vision 5. Hardware 6. Physical space 7. BIM champion 8. Role and responsibilities 9. BIM skills
5	Improve and speed up the construction process.	1. Hardware 2. Validation process 3. Physical space 4. Software 5. OIR 6. Network 7. BIM skills 8. BIM vision
6	Increase the as-built model accuracy.	1. BIM vision 2. OIR 3. Physical space 4. Standardisation 5. Management support

		6. Hardware 7. Education 8. Role and responsibilities 9. Quality assurance system 10. Organisation mission 11. Data sharing method 12. Validation process 13. Training 14. BIM champion 15. BIM committee

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use in Clash Detection, a comparative table has been established to show the requirements, benefits and correlated BIM maturity competencies (Table 7.49). It can be determined that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits from using BIM in Clash Detection, they have to develop all correlated maturity competencies. However, if they have limited time and budget for development they can use correlation ranking to decide which competency has to be developed first.

Table 7.49: Related maturity competencies of the Clash Detection

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. Suitable software and hardware. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff have at least basic knowledge about BIM model applications for facility updates. 4. The staff have at least a basic	1. Coordinate building project through a model 2. Reduce the Requests For Information (RFI) in the construction stage. 3. Increase productivity for the project in general. 4. Reduce budget cost. 5. Improve and speed up the construction process.	1. BIM skills 2. Training 3. Software 4. Hardware 5. BIM vision 6. BIM champion 7. Standards	1. Hardware 2. Physical space 3. Software 4. OIR 5. Data share 6. Network 7. Role and responsibilities 8. Management support 9. Training 10. BIM skills 11. BIM vision 12. Standardisation 13. Level of readiness 14. BIM champion 15. Quality assurance system 16. Validation process 17. BIM committee

knowledge of building systems. 5. Collaboration between the project stakeholders. 6. The level of Details.	6. Increase the as-built model accuracy.		18. Organisation mission

7.5.11.3 Summary

Based on above analysis, the most significant correlation has been found between the benefits and hardware, physical space, software, OIR, data sharing, network, role and responsibilities, management support, training, BIM skills, BIM vision, and standardisation. Moreover, it can be seen that all the benefits show a correlation with almost all the proposed maturity competencies (Table 7.48), which may lead to the following two conclusions:

1. All benefits show a significant correlation with the technical competencies, which means that the client organisation can gather the desired benefits by improving their technical competencies.
2. Showing a correlation with almost all proposed BIM competencies means that improving all these competencies may improve a client's ability to move from Clash Detection to clash avoidance.

In summary, it can be seen (Table 7.49) that most of the proposed competencies influence BIM implementation in Clash Detection and support the client to achieve their desired benefits. However, the technical competencies represent a high correlation among the proposed competencies.

7.5.12 Construction System Design

A process in which 3D System Design Software is used to design and analyse the construction of a complex asset system (e.g. form work, glazing, tie-backs, etc.) in order to emphasise planning. Sixteen of the 26 organisations who contributed to this study are currently using BIM in their Construction System Design. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and determine the relationship between BIM use benefits and the maturity competencies.

7.5.12.1 Descriptive analysis

Figure 7.19 shows the average assurance level for all benefits. It can be seen that all benefits have reached their expected level, which means the client organisation's current BIM maturity level enables them only to predict this benefit. These benefits are; to increase the constructability and safety of a complex building system (benefit 1); increase productivity at the construction stage (benefit 2); increase safety awareness of a complex building system (benefit 3); improve the collaboration between project stakeholders (benefit 4); reduce the change order in the construction stage (benefit 5); and improve cost estimation and time scheduling (benefit 6).

The mean, median and standard deviations for these benefits are shown in Table 7.50 in which it can be seen that the median for benefits 2 and 3 is lower than the mean, which means a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. This suggests that the median could be more useful in representing the current assurance for benefits 2 and 3. However, the other benefits show that their median is bigger than the mean, which means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This implies that the mean could be more useful in representing the current assurance for these benefits. This shows that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation; this could indicate where most of the data are located.

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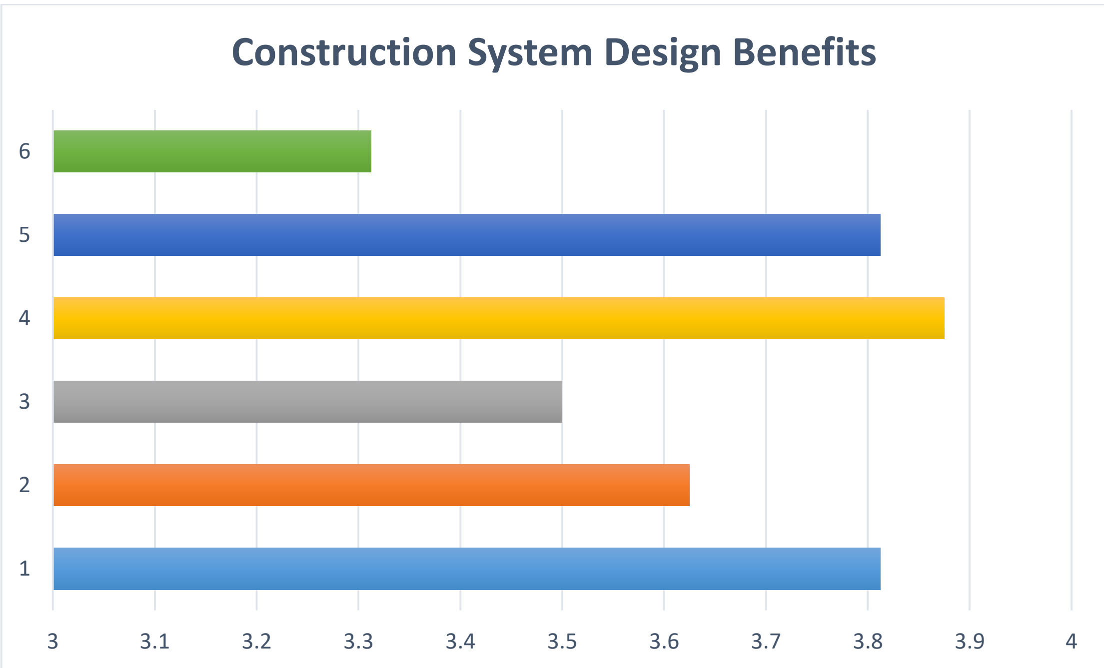

Figure 7.19: Benefit assurance evaluation for Construction System Design

Table 7.50: Descriptive analysis of Construction System Design benefits

	Mean	Median	SD
Benefit 1	3.81	4	1.22
Benefit 2	3.63	3.5	1.20
Benefit 3	3.50	3	1.03
Benefit 4	3.88	4	1.09
Benefit 5	3.81	4	1.22
Benefit 6	3.31	3.5	1.30

7.5.12.2 Inferential analysis

A Spearman's correlation has been carried out to judge the relationship between BIM use benefits in the Construction System Design and the BIM maturity competencies. Sixteen participants from client organisations are currently using BIM in this area. Again, the correlation analysis has been carried in three stages. Firstly, the degree of correlation between BIM uses benefits and BIM maturity competencies is displayed. Secondly, the relationship is summarised by listing all the related competencies by their correlation degree. Finally, a comparative table is developed to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.51 specifies that each benefit displays a different level of positive correlation with some BIM maturity competencies, which ranged from a significant correlation, where the ρ-value is less than 0.01, to a moderate correlation, where the ρ-value is equal to 0.041. Built on the correlation analysis, benefit 1 shows only a positive correlation with hardware. Benefit 2 expresses a significant correlation with training and education and demonstrates a positive correlation with BIM vision. Benefit 3 expresses a significant correlation with only BIM vision, and a positive correlation with organisation hierarchy, training, BIM skills, software, and hardware. Benefit 4 shows a significant correlation with only training and education, and a positive correlation with BIM vision and software. Benefit 5 only shows a significant correlation with education, whilst benefit 6 shows a significant correlation with just BIM vision and education.

Table 7.51: Spearman correlation results for Construction System Design

			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5	Benefit 6
Spearman's rho	Organisation Mission	Correlation Coefficient	.486	.260	**.539***	.243	.373	.267
		Sig. (2-tailed)	.056	.330	.031	.365	.154	.317
		N	16	16	16	16	16	16
	BIM Vision	Correlation Coefficient	.444	**.619***	**.632****	**.578***	.479	**.721****
		Sig. (2-tailed)	.085	.011	.009	.019	.060	.002
		N	16	16	16	16	16	16
	BIM Champion	Correlation Coefficient	.052	.121	.246	.206	.004	.065
		Sig. (2-tailed)	.849	.656	.358	.445	.989	.810
		N	16	16	16	16	16	16
	Management Support	Correlation Coefficient	.140	.327	.364	.380	.041	.378
		Sig. (2-tailed)	.605	.217	.166	.147	.879	.149
		N	16	16	16	16	16	16
	Data Sharing Method	Correlation Coefficient	.400	.220	.368	.270	.253	-.039
		Sig. (2-tailed)	.125	.413	.160	.312	.344	.885
		N	16	16	16	16	16	16
	Standardisation	Correlation Coefficient	.300	.236	.253	.347	.211	.292
		Sig. (2-tailed)	.259	.380	.344	.188	.433	.272
		N	16	16	16	16	16	16
	Organisation Hierarchy	Correlation Coefficient	.291	.331	**.590***	.455	.152	.335
		Sig. (2-tailed)	.275	.210	.016	.076	.574	.204
		N	16	16	16	16	16	16
	BIM committee	Correlation Coefficient	-.027	-.041	-.127	.024	-.055	.102
		Sig. (2-tailed)	.920	.881	.640	.928	.840	.707
		N	16	16	16	16	16	16
	Training	Correlation Coefficient	.414	**.627****	**.598***	**.646****	.458	.410
		Sig. (2-tailed)	.111	.009	.014	.007	.074	.114
		N	16	16	16	16	16	16
	Education	Correlation Coefficient	.486	**.630****	.491	**.628****	**.651****	**.687****
		Sig. (2-tailed)	.056	.009	.053	.009	.006	.003
		N	16	16	16	16	16	16
	Roles and Responsibilities	Correlation Coefficient	.166	.193	.154	.224	.166	.022
		Sig. (2-tailed)	.540	.474	.568	.405	.540	.935
		N	16	16	16	16	16	16

	Level of Readiness	Correlation Coefficient	.414	.294	.514*	.314	.280	-.063
		Sig. (2-tailed)	.111	.270	.041	.236	.293	.818
		N	16	16	16	16	16	16
	BIM Skills	Correlation Coefficient	.415	.409	**.539***	.446	.415	.110
		Sig. (2-tailed)	.110	.116	.031	.084	.110	.684
		N	16	16	16	16	16	16
	Organisation information requirements (OIR)	Correlation Coefficient	.339	.207	.480	.194	.339	.303
		Sig. (2-tailed)	.198	.442	.060	.471	.198	.253
		N	16	16	16	16	16	16
	Validation Process	Correlation Coefficient	.138	.110	.093	.100	.252	.122
		Sig. (2-tailed)	.611	.685	.733	.713	.347	.654
		N	16	16	16	16	16	16
	Quality Assurance System	Correlation Coefficient	.234	.098	.053	.092	.238	.156
		Sig. (2-tailed)	.383	.719	.846	.736	.374	.565
		N	16	16	16	16	16	16
	Software	Correlation Coefficient	.410	.489	**.527***	**.516***	.264	.064
		Sig. (2-tailed)	.115	.055	.036	.041	.323	.813
		N	16	16	16	16	16	16
	Hardware	Correlation Coefficient	**.603***	.461	**.542***	.444	.451	-.099
		Sig. (2-tailed)	.013	.072	.030	.085	.080	.714
		N	16	16	16	16	16	16
	Physical Space	Correlation Coefficient	.352	.440	.435	.388	.401	.275
		Sig. (2-tailed)	.182	.088	.092	.138	.123	.302
		N	16	16	16	16	16	16
	Network	Correlation Coefficient	.350	.340	.321	.393	.443	-.002
		Sig. (2-tailed)	.183	.198	.226	.132	.086	.993
		N	16	16	16	16	16	16

Table 7.52 displays the correlation results by showing the benefits with their related competencies. The BIM maturity competencies have been listed regarding the degree of correlation from high to low, and it can be seen that all benefits show a significant correlation which almost the same competencies, which are BIM vision, education, and training.

Table 7.52: Spearman correlation summary of Construction System Design

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Increase constructability and safety of a complex building system.	1. Hardware
2	Increase productivity at the construction stage.	1. Education 2. Training 3. BIM vision
3	Increase safety awareness of a complex building system	1. BIM vision 2. Training 3. Organisation mission 4. Hardware 5. BIM skills 6. Software
4	Improve the collaboration between project stakeholders.	1. Training 2. Education 3. BIM vision 4. Software
5	Reduce the change order in the construction stage.	1. Education
6	Improve cost estimation and time scheduling.	1. BIM vision 2. Education

b) Overall relationship

In order to acknowledge the BIM maturity competencies that affect BIM use in the Construction System Design area, a comparative table was developed (Table 7.53); it shows the requirements, benefits and correlated BIM maturity competencies for this particular BIM use. It can be noted that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits from using BIM in clash Construction System Design, they have to develop all correlated maturity competencies.

However, if client organisations have limited time and budget for development they can use correlation ranking to decide which competency they need to develop first.

Table 7.53: Related maturity competencies of the Construction System Design

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. Suitable software and hardware. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff are able to make appropriate construction decisions supported by a 3D System Design Software. 4. The staff have at least a basic knowledge of construction practices for each component.	1. Increase constructability and safety of a complex building system. 2. Increase productivity at the construction stage. 3. Increase safety awareness of a complex building system 4. Improve the collaboration between project stakeholders. 5. Reduce the change order in the construction stage. 6. Improve cost estimation and time scheduling.	1. BIM skills 2. Training 3. Software 4. Hardware	1. Education 2. BIM vision 3. Training 4. Hardware 5. Software 6. Organisation mission 7. BIM skills

7.5.12.3 Summary

From the above analysis, the most significant correlation has been found between the benefits and the following competencies; education, BIM vision, and training. Moreover, some benefits show a correlation with other competencies (Table 7.52), which can be explained as follows:

1. Increasing the constructability and safety of a complex building system would require the enhancement of BIM education.
2. Increasing the productivity at the construction stage would require improvements in education, training, and BIM vision.
3. Increasing safety awareness of a complex building system would require the development of BIM vision, training, organisation mission, hardware, BIM skills, and software.
4. Improving collaboration between project stakeholders would require the enhancement of training, education, BIM vision, and software.

5. Reducing the change order in the construction stage would require developments in BIM education.
6. Improving cost estimation and time scheduling would require improvements in BIM vision and education.
7. Generally, gathering the benefits from using BIM in Construction System Design will require an increase in maturity level in particular competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would, consequently, generate significant value through using BIM in engineering analysis.

In summary, it can be seen (Table 7.53) that the main competencies that influence BIM implementation in Construction System Design, and that support client to achieve these desired benefits are education, BIM vision, and training.

7.5.13 Site Planning

BIM can be used in Site Planning to simulate all the existing facilities during different project phase in order to optimise the project construction process. In total, 18 of the 26 organisations that participated in this study are currently using BIM in Site Planning. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and find the relationship between BIM use benefits and the maturity competencies.

7.5.13.1 Descriptive analysis

Figure 7.20 illustrates the average assurance level for all benefits. It can be seen that only three benefits, namely 1, 2, and 4, attain the expected level; this means that the current BIM maturity level amongst client organisations only enables them to predict these benefits. These benefits are; an enhanced decision-making process through providing all the required information that may be needed to choose in order to choose a suitable site for the project (benefit 1); decreased costs in all additional work that may be needed to prepare the site before starting the project (benefit 2); and increased safety (benefit 4). Benefit 3, namely the increase in energy efficiency, is still below the expected benefits; this means that the current client BIM abilities are not sufficient to support them in predicting this benefit.

The mean, median and standard deviations for these benefits are shown in Table 7.54 in which it can be seen that benefits 1 and 2 show a median lower than the mean. This means a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. This indicates that the median could be more useful in representing the current assurance for benefits 1 and 2. However, the other benefits show a bigger median than the mean, which means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This suggests that the mean could be more useful in representing the current assurance for these benefits. This indicates that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation, which can give an indication as to where most of the data are located.

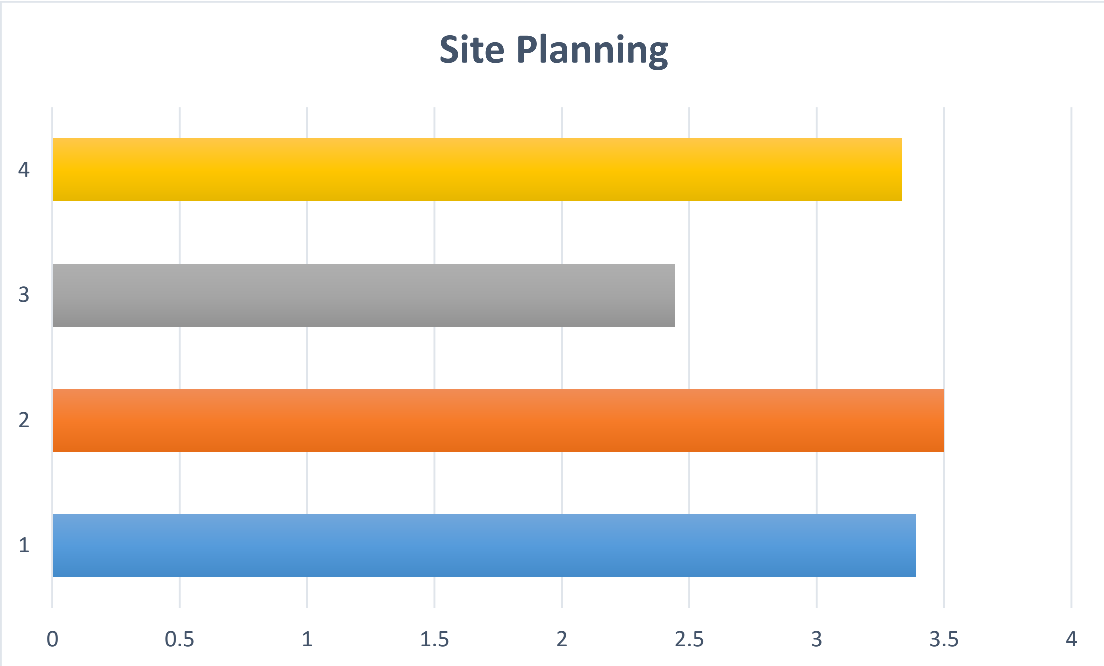

Figure 7.20: Benefit assurance evaluation for Site Planning

Table 7.54: Descriptive analysis of Site Planning benefits

	Mean	Median	SD
Benefit 1	3.39	3	1.04
Benefit 2	3.50	3	1.10
Benefit 3	2.44	3	1.10
Benefit 4	3.33	4	1.19

7.5.13.2 Inferential analysis

A Spearman's correlation was run to judge the relationship between BIM use benefits in Site Planning and the BIM maturity competencies. Eighteen participants from client organisations are currently using BIM in this area. The correlation analysis has been carried in three stages, where the first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies regarding their correlation degree. The final stage sees a comparative table established to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.55 specifies that each benefit displays a different level of positive correlation with some BIM maturity competencies; these range from a significant correlation, where the ρ-value is less than 0.01, to a moderate correlation, where the ρ-value is equal to 0.05. Based on this correlation analysis, benefit 1 shows a positive correlation with only BIM vision. Benefit 2 indicates a positive correlation with just education, whilst benefit 3 did not express a positive correlation with any competency. Benefit 4 only shows a significant correlation with training and BIM skills; however, the same benefit displays a positive correlation with role and responsibilities.

Table 7.55: Spearman correlation results for Site Planning

			Benefit 1	Benefit 2	Benefit 3	Benefit 4
Spearman's rho	Organisation Mission	Correlation Coefficient	.274	.434	.263	.172
		Sig. (2-tailed)	.271	.072	.292	.495
		N	18	18	18	18
	BIM Vision	Correlation Coefficient	**.469***	.255	.387	.439
		Sig. (2-tailed)	.050	.306	.113	.069
		N	18	18	18	18
	BIM Champion	Correlation Coefficient	.170	-.056	.049	.349
		Sig. (2-tailed)	.500	.825	.848	.155
		N	18	18	18	18
	Management Support	Correlation Coefficient	.143	-.209	.076	.461
		Sig. (2-tailed)	.572	.405	.763	.054
		N	18	18	18	18
	Data Sharing Method	Correlation Coefficient	.076	.020	-.308	.003
		Sig. (2-tailed)	.763	.938	.214	.989
		N	18	18	18	18
	Standardisation	Correlation Coefficient	.226	.185	-.029	.172
		Sig. (2-tailed)	.368	.462	.909	.495
		N	18	18	18	18
	Organisation Hierarchy	Correlation Coefficient	.300	-.028	.329	.317
		Sig. (2-tailed)	.227	.912	.182	.200
		N	18	18	18	18
	BIM committee	Correlation Coefficient	.360	.131	.112	.248

		Sig. (2-tailed)	.142	.605	.658	.320
		N	18	18	18	18
	Training	Correlation Coefficient	.384	.153	.235	**.593****
		Sig. (2-tailed)	.115	.545	.349	.009
		N	18	18	18	18
	Education	Correlation Coefficient	.277	**.550***	.357	.235
		Sig. (2-tailed)	.266	.018	.146	.348
		N	18	18	18	18
	Roles and Responsibilities	Correlation Coefficient	.358	.166	.005	**.522***
		Sig. (2-tailed)	.144	.510	.986	.026
		N	18	18	18	18
	Level of Readiness	Correlation Coefficient	.338	.199	.238	.433
		Sig. (2-tailed)	.169	.428	.341	.072
		N	18	18	18	18
	BIM Skills	Correlation Coefficient	.361	.240	-.001	**.591****
		Sig. (2-tailed)	.141	.338	.996	.010
		N	18	18	18	18
	Organisation information requirements (OIR)	Correlation Coefficient	.197	.211	.008	.129
		Sig. (2-tailed)	.433	.400	.975	.610
		N	18	18	18	18
	Validation Process	Correlation Coefficient	.192	.232	-.111	.318
		Sig. (2-tailed)	.446	.354	.661	.198
		N	18	18	18	18
	Quality Assurance System	Correlation Coefficient	.024	.236	.060	-.192
		Sig. (2-tailed)	.926	.345	.812	.445
		N	18	18	18	18
	Software	Correlation Coefficient	.437	.089	.137	.428
		Sig. (2-tailed)	.070	.726	.588	.076
		N	18	18	18	18
	Hardware	Correlation Coefficient	.327	.289	.024	.143
		Sig. (2-tailed)	.186	.244	.925	.571
		N	18	18	18	18
	Physical Space	Correlation Coefficient	.343	.198	.005	.311
		Sig. (2-tailed)	.164	.432	.985	.209
		N	18	18	18	18
	Network	Correlation Coefficient	.214	.273	-.184	.248
		Sig. (2-tailed)	.393	.274	.465	.322
		N	18	18	18	18
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

Table 7.56 shows the benefits with their related competencies; the BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen that each benefit displays a correlation with different competencies, which suggests that each benefit may need to be treated individually.

Table 7.56: Spearman correlation summary of Site Planning

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Enhance the decision-making process through providing all the require information that may need it to choose the suitable site for the project.	1. BIM vision
2	Decrease costs of all additional work may need it to prepare the site before stat the project.	1. Education
3	Increase energy efficiency.	None
4	Increase safety.	1. Training 2. BIM skills 3. Role and responsibilities

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use in Site Planning, a comparative table (Table 7.57) has been developed to show the requirements, benefits, and correlated BIM maturities. It can be noted that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits from using BIM in Site Planning, they have to develop all correlated maturity competencies. However, if client organisations have a limited time and budget for development they can use a correlation ranking to decide which competency they need to first develop.

Table 7.57: Related maturity competencies of the Site Planning

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. The staff are able to manipulate navigate, and review a 3D model. 2. The familiarity of local authority's system (GIS, database information). 3. Suitable software and hardware.	1. Enhance the decision-making process through providing all the require information that may need it to choose the suitable site for the project. 2. Decrease costs of all additional work may need it to prepare the site before stat the project. 3. Increase energy efficiency. 4. Increase safety.	1. BIM skills 2. Training 3. Software 4. Hardware	1. Training 2. BIM skills 3. BIM vision 4. Education 5. Role and responsibilities

7.5.13.3 Summary

Based on above analysis, the most significant correlation has been found between the benefits and the training and BIM skills competencies. Moreover, some benefits show a correlation with other competencies (Table 7.56), which can be explained as follows:

1. To enhance the decision-making process would require the development of BIM vision.
2. Decreasing the costs of additional work that may be needed to prepare the site before the start of the project, would require an improvement in BIM education.
3. Increasing the energy efficiency did not show a correlation with any competency, which may be due to one or more of the following several reasons:
   a) Currently, client organisations are not using BIM in Site Planning to access this benefit.
   b) Client organisations presently are not able to predict this benefit due to limitations in their BIM competencies.
   c) There are other competencies aside from those proposed that may affect a client’s ability to predict this benefit.

4. Increasing safety would require the enhancement of training, BIM skills, and role and responsibilities.
5. In general, accessing the benefits from using BIM in Site Planning would require an increase in maturity level in those competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would generate significant value through using BIM in Site Planning.

To summarise, it can be seen (Table 7.57) that the main competencies that influence BIM implementation in Site Planning, and that support the client to achieve the desired benefits are BIM training and BIM skills.

7.5.14 Digital Fabrication

A process that uses digitised information to facilitate the fabrication of construction materials or assemblies. Eleven of the 26 participating organisations are currently using BIM in Digital Fabrication. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and determine the relationship between BIM use benefits and the maturity competencies.

7.5.14.1 Descriptive analysis

Figure 7.21 shows the average assurance level for all benefits and indicates that all benefits have reached the expected level, which means the client organisations' current BIM maturity levels only enable them to predict this benefit. These benefits are to; increase the information quality (benefit 1); improve the design outcomes (benefit 2); and increase fabrication productivity and safety (benefit 3). The mean, median and standard deviations for these benefits are shown in Table 7.58 in which, it can be seen that all benefits show a bigger median than the mean. This means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean could be more useful in representing the current assurance for these benefits. This shows that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation to suggest where most of the data are located.

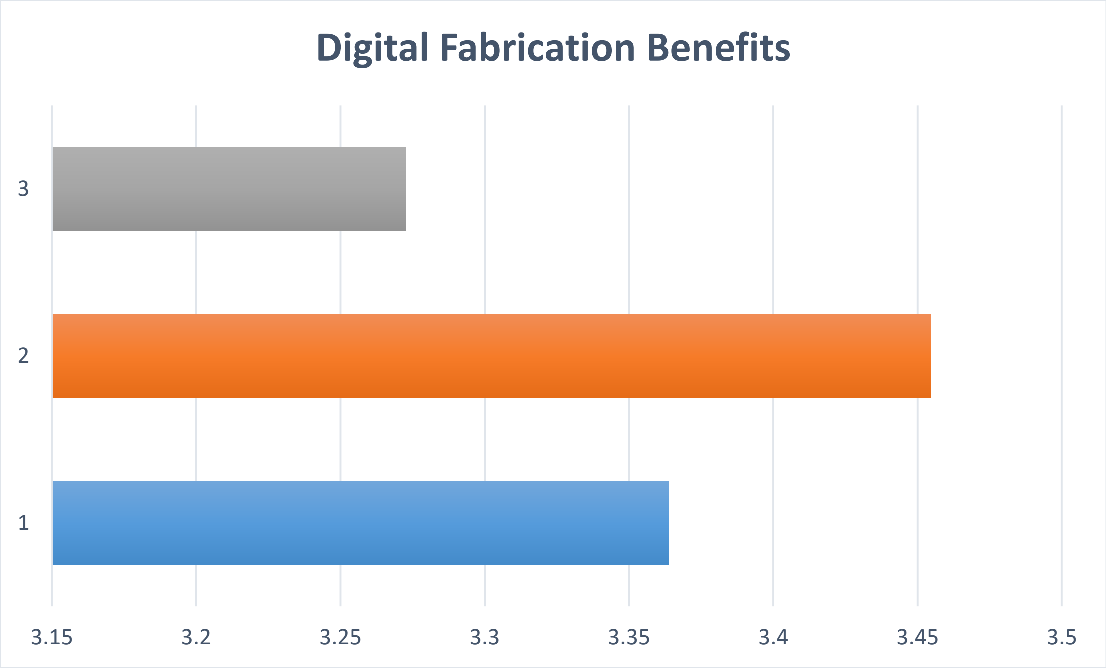

Figure 7.21: Benefit assurance evaluation for Digital Fabrication

Table 7.58: Descriptive analysis of Digital Fabrication benefits

	Mean	Median	SD
Benefit 1	3.36	4	1.36
Benefit 2	3.45	4	1.57
Benefit 3	3.27	4	1.62

7.5.14.2 Inferential analysis

A Spearman's correlation has been adopted to evaluate the relationship between BIM use benefits in Digital Fabrication and the BIM maturity competencies. Eleven participants from client organisations are currently using BIM in this area. The correlation analysis has been carried in three stages. The first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the relevant competencies by their correlation degree. Finally, a table compares the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.59 shows that each benefit has a different level of positive correlation with some BIM maturity competencies, and that these ranged from a significant correlation, where the ρ-value is less than 0.01, to a moderate correlation, where the ρ-value equals 0.040.

Benefit 1 shows a significant correlation with only physical space and a positive correlation with hardware, software, and the level of readiness. Benefit 2 expresses a significant correlation with the level of readiness and the same benefit demonstrates a positive correlation with software and hardware. Benefit 3 only expresses a significant correlation with the level of readiness, but also displays a positive correlation with physical space, software, and hardware.

Table 7.59: Spearman correlation results for Digital Fabrication

			Benefit 1	Benefit 2	Benefit 3
Spearman's rho	Organisation Mission	Correlation Coefficient	.384	.171	.330
		Sig. (2-tailed)	.244	.615	.321
		N	11	11	11
	BIM Vision	Correlation Coefficient	.546	.270	.516
		Sig. (2-tailed)	.082	.423	.105
		N	11	11	11
	BIM Champion	Correlation Coefficient	.193	.216	.306
		Sig. (2-tailed)	.569	.523	.360
		N	11	11	11
	Management Support	Correlation Coefficient	.465	.323	.576
		Sig. (2-tailed)	.149	.333	.064
		N	11	11	11
	Data Sharing Method	Correlation Coefficient	.379	.233	.386
		Sig. (2-tailed)	.250	.490	.241
		N	11	11	11
	Standardisation	Correlation Coefficient	.047	-.012	.099
		Sig. (2-tailed)	.891	.971	.773
		N	11	11	11
	Organisation Hierarchy	Correlation Coefficient	.311	.128	.230
		Sig. (2-tailed)	.352	.707	.497
		N	11	11	11
	BIM committee	Correlation Coefficient	.235	.133	.173
		Sig. (2-tailed)	.486	.698	.610
		N	11	11	11
	Training	Correlation Coefficient	.366	.311	.402
		Sig. (2-tailed)	.268	.352	.220
		N	11	11	11
	Education	Correlation Coefficient	.208	.014	.120
		Sig. (2-tailed)	.540	.967	.725
		N	11	11	11
	Roles and Responsibilities	Correlation Coefficient	.262	.359	.299
		Sig. (2-tailed)	.437	.278	.373
		N	11	11	11

	Level of Readiness	Correlation Coefficient	**.672***	**.801****	**.740****
		Sig. (2-tailed)	.023	.003	.009
		N	11	11	11
	BIM Skills	Correlation Coefficient	.374	.492	.410
		Sig. (2-tailed)	.257	.125	.211
		N	11	11	11
	Organisation information requirements (OIR)	Correlation Coefficient	.477	.153	.447
		Sig. (2-tailed)	.138	.654	.168
		N	11	11	11
	Validation Process	Correlation Coefficient	.047	-.012	.099
		Sig. (2-tailed)	.891	.971	.773
		N	11	11	11
	Quality Assurance System	Correlation Coefficient	.005	-.393	-.164
		Sig. (2-tailed)	.988	.232	.629
		N	11	11	11
	Software	Correlation Coefficient	**.628***	**.729***	**.624***
		Sig. (2-tailed)	.039	.011	.040
		N	11	11	11
	Hardware	Correlation Coefficient	**.660***	**.733***	**.636***
		Sig. (2-tailed)	.027	.010	.035
		N	11	11	11
	Physical Space	Correlation Coefficient	**.739****	.508	**.686***
		Sig. (2-tailed)	.009	.110	.020
		N	11	11	11
	Network	Correlation Coefficient	.290	.471	.309
		Sig. (2-tailed)	.388	.144	.355
		N	11	11	11
**. Correlation is significant at the 0.01 level (2-tailed).					
*. Correlation is significant at the 0.05 level (2-tailed).					

Table 7.60 summarises the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen that most benefits display a correlation with almost the same competencies.

Table 7.60: Spearman correlation summary of Digital Fabrication

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Increase the information quality.	1. Physical space 2. Level of readiness 3. Hardware 4. Software
2	Improve the design outcomes.	1. Level of readiness 2. Hardware 3. Software
3	Increase fabrication productivity and safety	1. Physical space 2. Level of readiness 3. Hardware 4. Software

b) Overall relationship

In order to recognise the BIM maturity competencies that affect BIM use within Digital Fabrication, a comparative table (Table 7.61) has been provided to show the requirements, benefits and correlated BIM maturity competencies for this particular BIM use. It can be deduced that, if client organisations aim to achieve the desired benefits from using BIM in Digital Fabrication, they have to develop all the correlated maturity competencies. However, if client organisations have limited time and budget for development they can use correlation ranking to decide which competency to develop first.

Table 7.61: Related maturity competencies benefits of the Digital Fabrication

Requirements	Benefits	Proposed related Maturity competencies	Maturity correlated competencies
1. Suitable software and hardware. 2. The staff are able to understand the fabrication models methods. 3. The staff are able to manipulate navigate, and review a 3D model. 4. Ability to extract digital information for fabrication from 3D models. 5. The level of details.	1. Increase the information quality. 2. Improve the design outcomes. 3. Increase fabrication productivity and safety.	1. BIM skills 2. Training 3. Software 4. Hardware 5. Standards	1. Physical space 2. Level of readiness 3. Hardware 4. Software

7.5.14.3 Summary

Based on above analysis, the most significant correlation has been noted between the benefits and the physical space, the level of readiness, hardware, and software competencies. Generally, gathering the benefits from using BIM in Digital Fabrication will require an increase in maturity level within those competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would help to generate significant value through using BIM within Digital Fabrication.

7.5.15 3D Control and Planning

Using BIM in this area can be defined as a process that utilises an information model to layout facility assemblies or automate control of equipment's movement and location. Fifteen of the 26 participating organisations are currently using BIM in 3D Control and Planning. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and determine the relationship between BIM use benefits and the maturity competencies.

7.5.15.1 Descriptive analysis

Figure 7.22 shows the average assurance level for all benefits, from which it can be seen that all benefits reach the expected level, which means the client organisations' current BIM maturity level only enables them to predict these benefits. These benefits are to: improve information accuracy (benefit 1); increase efficiency and productivity at the construction stage (benefit 2); reduce rework (benefit 3); and improve the collaboration between project stakeholders (benefit 4). The mean, median and standard deviations for these benefits are shown in Table 7.62 in which it can be seen that the median is bigger than the mean for all benefits; this means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean could be more useful in representing the current assurance for these benefits. This directs that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation that can indicate where most of the data are located.

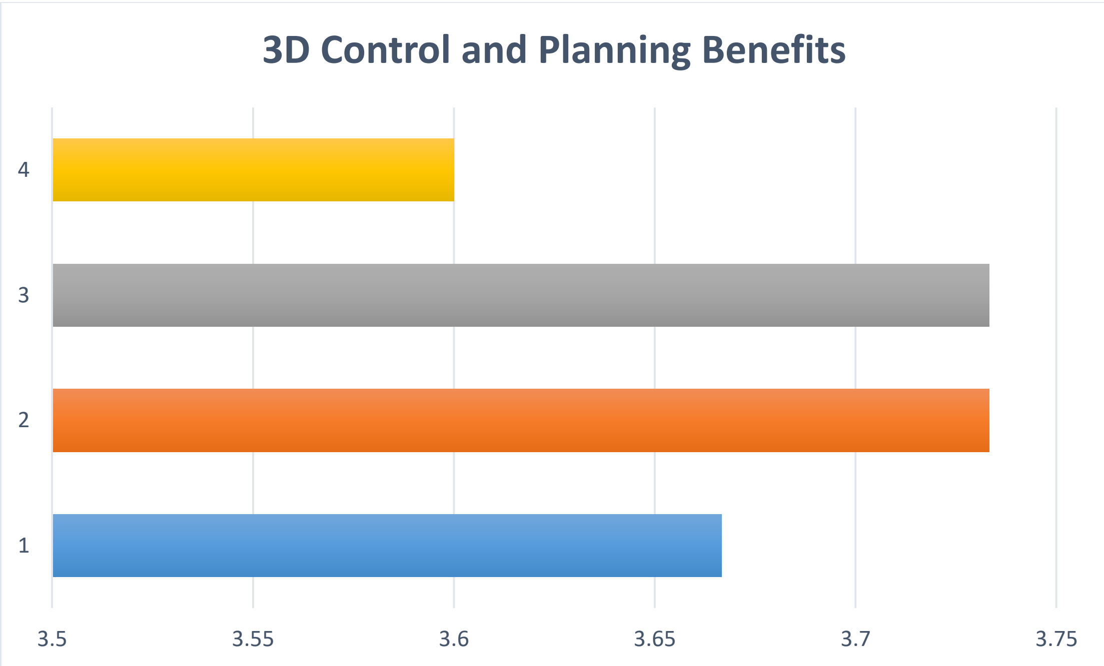

Figure 7.22: Benefit assurance evaluation for 3D Control and Planning

Table 7.62: Descriptive analysis of 3D Control and Planning benefits

	Mean	Median	SD
Benefit 1	3.67	4	1.29
Benefit 2	3.73	4	1.22
Benefit 3	3.73	4	1.22
Benefit 4	3.60	4	1.30

7.5.15.2 Inferential analysis

A Spearman's correlation was run to judge the relationship between BIM use benefits in 3D Control and Planning and the BIM maturity competencies. Fifteen participants from client organisations are currently using BIM in this area. The correlation analysis has been carried via three stages; firstly, the degree of correlation between BIM uses benefits and BIM maturity competencies are displayed. Secondly, the relationship is summarised by listing all the relevant competencies by their degree of correlation. Finally, a comparative table is developed to compare the BIM uses requirements, benefits, and related maturity competencies.

a) Correlation factors

Table 7.63 indicates that each benefit has a different level of positive correlation with some BIM maturity competencies; these ranged from a significant correlation, where the ρ-value is less than 0.01, to a moderate correlation, when the ρ-value is equal to 0.05. Based on the correlation analysis, benefit 1 only shows a positive correlation with software, hardware, BIM skills, and training. Benefit 2 only expresses a positive correlation with software, BIM skills, and training; whilst benefit 3 indicates a positive correlation with training, education, and BIM skills. Finally, benefit 4 only shows a significant correlation with organisation mission and OIR, and a positive correlation with BIM skills and education.

Table 7.63: Spearman correlation results for 3D Control and Planning

			Benefit 1	Benefit 2	Benefit 3	Benefit 4
Spearman's rho	Organisation Mission	Correlation Coefficient	.222	.289	.215	**.683******
		Sig. (2-tailed)	.427	.297	.441	.005
		N	15	15	15	15
	BIM Vision	Correlation Coefficient	.501	.485	.485	.464
		Sig. (2-tailed)	.057	.067	.067	.081
		N	15	15	15	15
	BIM Champion	Correlation Coefficient	.304	.289	.113	0.000
		Sig. (2-tailed)	.270	.297	.688	1.000
		N	15	15	15	15
	Management Support	Correlation Coefficient	.429	.409	.247	.076
		Sig. (2-tailed)	.110	.130	.375	.788
		N	15	15	15	15
	Data Sharing Method	Correlation Coefficient	.319	.299	.103	.026
		Sig. (2-tailed)	.247	.279	.716	.926
		N	15	15	15	15
	Standardisation	Correlation Coefficient	.128	.112	-.016	.034
		Sig. (2-tailed)	.650	.691	.954	.903
		N	15	15	15	15
	Organisation Hierarchy	Correlation Coefficient	.187	.218	.046	.389
		Sig. (2-tailed)	.505	.435	.871	.152
		N	15	15	15	15
	BIM committee	Correlation Coefficient	-.249	-.230	-.263	.077

		Sig. (2-tailed)	.371	.409	.343	.786
		N	15	15	15	15
	Training	Correlation Coefficient	**.611***	**.585***	**.585***	.375
		Sig. (2-tailed)	.016	.022	.022	.168
		N	15	15	15	15
	Education	Correlation Coefficient	.382	.386	**.603***	**.576***
		Sig. (2-tailed)	.160	.156	.017	.025
		N	15	15	15	15
	Roles and Responsibilities	Correlation Coefficient	.286	.290	.290	.220
		Sig. (2-tailed)	.301	.295	.295	.432
		N	15	15	15	15
	Level of Readiness	Correlation Coefficient	.375	.396	.279	.050
		Sig. (2-tailed)	.169	.144	.315	.860
		N	15	15	15	15
	BIM Skills	Correlation Coefficient	**.615***	**.630***	**.630***	**.558***
		Sig. (2-tailed)	.015	.012	.012	.031
		N	15	15	15	15
	Organisation information requirements (OIR)	Correlation Coefficient	.411	.446	.380	**.690****
		Sig. (2-tailed)	.128	.096	.163	.004
		N	15	15	15	15
	Validation Process	Correlation Coefficient	.338	.304	.302	.204
		Sig. (2-tailed)	.218	.271	.274	.466
		N	15	15	15	15
	Quality Assurance System	Correlation Coefficient	-.091	-.130	-.178	-.119
		Sig. (2-tailed)	.746	.643	.526	.673
		N	15	15	15	15
	Software	Correlation Coefficient	**.560***	**.544***	.319	.109
		Sig. (2-tailed)	.030	.036	.247	.699
		N	15	15	15	15
	Hardware	Correlation Coefficient	**.515***	.498	.270	.058
		Sig. (2-tailed)	.050	.059	.330	.837
		N	15	15	15	15
	Physical Space	Correlation Coefficient	.484	.454	.454	.280
		Sig. (2-tailed)	.068	.089	.089	.313
		N	15	15	15	15
	Network	Correlation Coefficient	.377	.371	.432	.338
		Sig. (2-tailed)	.166	.174	.108	.218
		N	15	15	15	15

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 7.64 summarises the correlation results by showing the benefits with their related competencies. The BIM maturity competencies have been listed regarding their degree of correlation from high to low. It can be seen that most of the benefits displayed a correlation with almost the same competencies.

Table 7.64: Spearman correlation summary of 3D Control and Planning

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Improve the information accuracy.	1. BIM Skills 2. Training 3. Software 4. Hardware
2	Increase efficiency and productivity at construction stage.	1. BIM skills 2. Training 3. Software
3	Reduce rework.	1. BIM skills 2. Education 3. Training
4	Improve the collaboration between project stakeholders.	1. OIR 2. Organisation mission 3. Education 4. BIM skills

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM using in the 3D control and planning area, a comparative table (Table 7.65) has been developed to show the requirements, benefits, and correlated BIM maturity competencies. It can be concluded that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits from using BIM in 3D Control and Planning, they have to develop all correlated maturity competencies. However, if client organisations have limited time and budgets, they can use the correlation ranking to decide which competency to develop first.

Table 7.65: Related maturity competencies of the 3D Control and Planning

Requirements	Benefits	Proposed related maturity competencies	Maturity
1. Suitable software, hardware and equipment. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff are able to interpret if model data is appropriate for layout and equipment control.	1. Improve the information accuracy. 2. Increase efficiency and productivity at construction stage. 3. Reduce rework. 4. Improve the collaboration between project stakeholders.	1. BIM skills 2. Training 3. Software 4. Hardware	1. BIM Skills 2. Training 3. Software 4. OIR 5. Education 6. Hardware 7. Organisation mission

7.5.15.3 Summary

Based on above analyses, the most significant correlation has been found between the benefits and the BIM skills and training competencies. Moreover, some benefits show a significant correlation with other competencies (Table 7.64), which can be explained as follows:

1. To improve the information accuracy would require the enhancement of BIM skills, training, software and hardware.
2. To increase efficiency and productivity at the construction stage would require the development of BIM skills, training, and software.
3. To reduce the rework would require the improvement of BIM skills, education, and training.
4. To improve the collaboration between project stakeholders would require the enhancement of the OIR, organisation mission, education, and BIM skills.
5. Generally, gathering the benefits from using BIM in 3D Control and Planning would require an increase in maturity level in those competencies that show a significant correlation with the benefits. In addition, the continuous improvement of such

competencies would generate significant value through using BIM in 3D control and planning.

In summary, it can be seen (Table 7.65) that the main competencies that influence BIM implementation in 3D Control and Planning, and that support the client to achieve their desired benefits are BIM skills and training.

7.5.16 Record Model

Record Model is the process used to depict an accurate representation of the physical conditions, environment, and assets of an asset. In total, 24 of the 26 contributing organisations are currently using BIM in Record Model. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and determine the relationship between the BIM use benefits and maturity competencies.

7.5.16.1 Descriptive analysis

Figure 7.23 displays the average assurance level for all benefits. It can be seen that only three benefits, namely 1, 2, and 4, reach the expected level; this means the client organisations' current BIM maturity level only enables them to predict these benefits. These benefits are: help within future operation and maintenance (benefit 1); improving the accuracy and availability of information for future use (benefit 2); and optimising project information and its storage space (benefit 4). Meanwhile, the other benefit, which is to minimise dispute between project stakeholders, is still below the expected level; this means that the current client BIM abilities are not sufficient to support them in predicting these benefits.

The mean, median and standard deviations for these benefits are shown in Table 7.66 and it can be seen that the median is lower than the mean for benefits 1, 2, and 4. This means a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. This suggests that the median could be more appropriate in representing the current assurance for benefits 1,2, and 4. However, for benefit 3 the median is bigger than the mean; this means a negative skew in its distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean can be more useful in representing the current assurance for this benefit. This specifies that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level Also, it can be seen that each benefit has a different standard deviation; this could give an indication as to where most of the data are located.

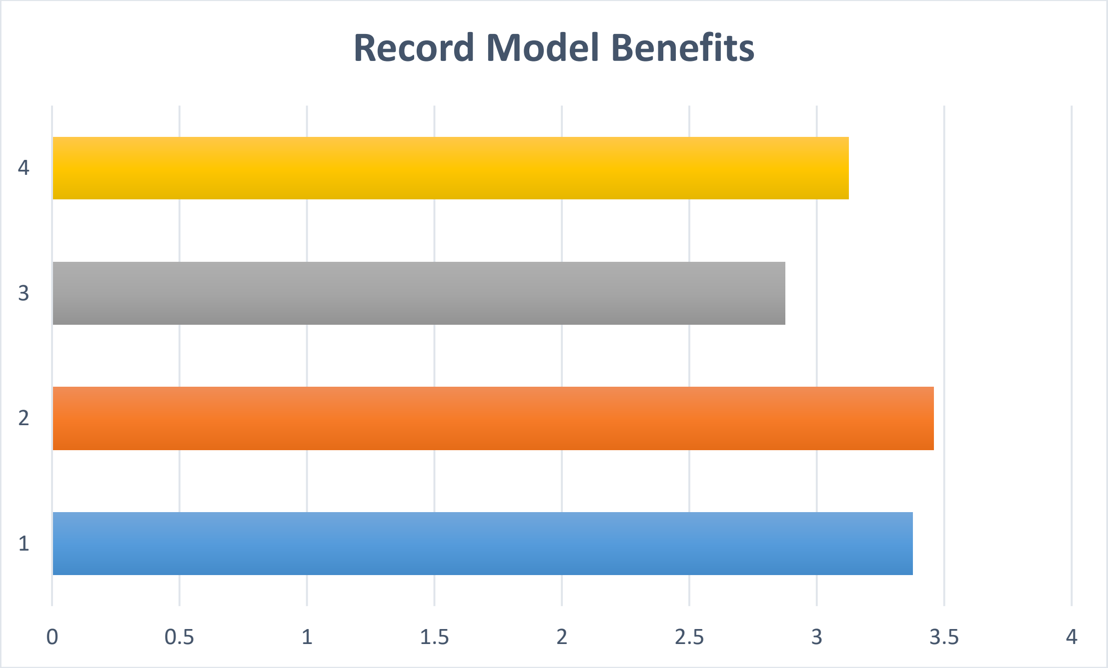

Figure 7.23: Benefit assurance evaluation for Record Model

Table 7.66: Descriptive analysis of Record Model benefits

	Mean	Median	SD
Benefit 1	3.38	3	1.21
Benefit 2	3.46	3	1.25
Benefit 3	2.88	3	1.19
Benefit 4	3.13	3	1.33

7.5.16.2 Inferential analysis

A Spearman's correlation has been adopted to assess the relationship between BIM use benefits in Record Model and the BIM maturity competencies. Twenty-two participants from client organisations are currently using BIM in this area. As before, the correlation analysis has been carried out in three stages; firstly, the degree of correlation between BIM uses benefits and BIM maturity competencies is shown. Secondly, the relationship is summarised by listing all competencies by their correlation degree. Finally, a comparative table is shown to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.67 shows that only benefit 3 shows a positive correlation with BIM vision where the significant ratio is equal to 0.028. This could have resulted for several reasons; for example, the client organisation is currently not using BIM in Record Model to achieve these benefits, or the clients' current abilities prevent them from predicting these benefits.

Table 7.67: Spearman correlation results for Record Model

			Benefit 1	Benefit 2	Benefit 3	Benefit 4
Spearman's rho	Organisation Mission	Correlation Coefficient	-.031	-.033	.010	.149
		Sig. (2-tailed)	.885	.879	.964	.488
		N	24	24	24	24
	BIM Vision	Correlation Coefficient	.249	.318	**.449***	.402
		Sig. (2-tailed)	.241	.130	.028	.052
		N	24	24	24	24
	BIM Champion	Correlation Coefficient	-.230	-.160	-.036	-.145
		Sig. (2-tailed)	.279	.454	.868	.499
		N	24	24	24	24
	Management Support	Correlation Coefficient	.126	.210	.227	.156
		Sig. (2-tailed)	.557	.324	.286	.467
		N	24	24	24	24
	Data Sharing Method	Correlation Coefficient	-.055	-.015	.045	-.166
		Sig. (2-tailed)	.798	.943	.833	.438
		N	24	24	24	24
	Standardisation	Correlation Coefficient	.004	.020	.118	.049
		Sig. (2-tailed)	.985	.927	.583	.821
		N	24	24	24	24
	Organisation Hierarchy	Correlation Coefficient	.001	-.006	.056	.130
		Sig. (2-tailed)	.996	.977	.794	.546
		N	24	24	24	24
	BIM committee	Correlation Coefficient	-.007	-.021	.174	.233

		Sig. (2-tailed)	.975	.924	.417	.272
		N	24	24	24	24
	Training	Correlation Coefficient	.104	.156	.149	.042
		Sig. (2-tailed)	.628	.467	.487	.846
		N	24	24	24	24
	Education	Correlation Coefficient	-.079	.000	.116	.062
		Sig. (2-tailed)	.712	.999	.590	.772
		N	24	24	24	24
	Roles and Responsibilities	Correlation Coefficient	-.186	-.122	-.005	-.144
		Sig. (2-tailed)	.383	.570	.981	.502
		N	24	24	24	24
	Level of Readiness	Correlation Coefficient	.153	.314	.201	.031
		Sig. (2-tailed)	.476	.135	.347	.886
		N	24	24	24	24
	BIM Skills	Correlation Coefficient	-.097	-.118	-.088	-.195
		Sig. (2-tailed)	.651	.581	.684	.360
		N	24	24	24	24
	Organisation information requirements (OIR)	Correlation Coefficient	-.169	-.229	.022	.109
		Sig. (2-tailed)	.430	.283	.917	.612
		N	24	24	24	24
	Validation Process	Correlation Coefficient	-.188	-.299	-.176	-.102
		Sig. (2-tailed)	.379	.156	.411	.636
		N	24	24	24	24
	Quality Assurance System	Correlation Coefficient	-.104	-.075	-.055	-.011

		Sig. (2-tailed)	.628	.727	.800	.958
		N	24	24	24	24
	Software	Correlation Coefficient	.294	.265	.332	.006
		Sig. (2-tailed)	.163	.210	.113	.979
		N	24	24	24	24
	Hardware	Correlation Coefficient	.056	.162	.341	-.003
		Sig. (2-tailed)	.796	.451	.103	.989
		N	24	24	24	24
	Physical Space	Correlation Coefficient	-.087	-.125	.233	-.123
		Sig. (2-tailed)	.687	.562	.274	.568
		N	24	24	24	24
	Network	Correlation Coefficient	-.362	-.318	-.020	-.313
		Sig. (2-tailed)	.083	.130	.927	.136
		N	24	24	24	24
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

Table 7.68 provides the correlation results by showing the benefits with their related competencies. The BIM maturity competencies have been listed regarding the degree of correlation from high to low and only benefit 3 has a positive correlation with BIM vision.

Table 7.68: Spearman correlation summary of Record Model

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Help in future operation and maintenance.	2. None
2	Improve the accuracy and availability of information for future use.	2. None
3	Minimize dispute between project stakeholders.	3. BIM vision

4	Optimise project information and its storage space.	4. None

b) Overall relationship

In order to acknowledge the BIM maturity competencies that affect BIM use in Record Model, a comparative table is shown to detail the requirements, benefits, and correlated BIM maturity competencies for this particular BIM use (Table 7.69). It can be concluded that, identifying BIM vision as only correlated competency means that the current clients knowledge and experience regarding this BIM use is not enough to establish the relationship between BIM maturity competencies and BIM uses benefits. Therefore, currently clients can use the proposed related competencies as guidance without any guarantee that improving these competencies will improve BIM benefits achievements.

Table 7.69: Related maturity competencies of the Record Model

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. The staff are able to manipulate navigate, and review a 3D model. 2. The staff are able to use BIM modelling application to update building information. 3. The staff have at least basic knowledge about building operation and ambience in order to check the input information. 4. Effective collaboration between the project stakeholders. 5. Suitable software, hardware and equipment. 6. The level of Details. 7. Quality Assurance system.	1. Help in future operation and maintenance. 2. Improve the accuracy and availability of information for future use. 3. Minimize dispute between project stakeholders. 4. Optimise project information and its storage space.	1. BIM skills 2. Training 3. Software 4. Hardware 5. BIM Vision 6. BIM champion 7. BIM committee 8. Standards 9. Quality assurance system	1. BIM vision

7.5.16.3 Summary

Based on the above analysis, the only correlation that has been found is between benefit 3 and BIM vision. However, the other benefits did not show any correlation with any competencies, which may lead to several conclusions, such as:

1. Currently, client organisations are not using BIM in Record Model to gather these benefits.
2. Client organisations are not presently able to predict these benefits due to the limitations in their BIM competencies.
3. There are other competencies aside from those proposed that may affect the client's ability to predict these benefits.

7.5.17 Asset Maintenance Scheduling

Using BIM in this area can be described as a process in which the functionality of an asset structure (walls, floors, roof, etc) and equipment serving the asset (mechanical, electrical, plumbing, etc) are maintained over the operational life of an asset. In total, 14 of the 26 participating organisations are currently using BIM in Asset Maintenance Scheduling. For this use, both descriptive and inferential analyses will be carried out to test the data and to determine the relationship between BIM use benefits and the maturity competencies.

7.5.17.1 Descriptive analysis

Figure 7.24 displays the average assurance level for all benefits. It can be seen that all benefits have reached the expected level, which means that the client organisations' current BIM maturity level enables them to predict these benefits only. These benefits are: to help to adapt a proactive maintenance plan (benefit 1); to ensure optimum maintenance staff distribution (benefit 2); to record and track maintenance history (benefit 3); to reduce unexpected maintenance (benefit 4); and to select the cost effective maintenance approach (benefit 5). The mean, median and standard deviation for these benefits are shown in Table 7.70 where it can be seen that all benefits show a bigger median than the mean. This shows a negative skew in their distribution, with a long tail of low scores pulling the mean down more than the median. This indicates that the mean could be more useful in representing the current benefits assurance. It can also be seen that each benefit has a different standard deviation, which can indicate where most of the data are located.

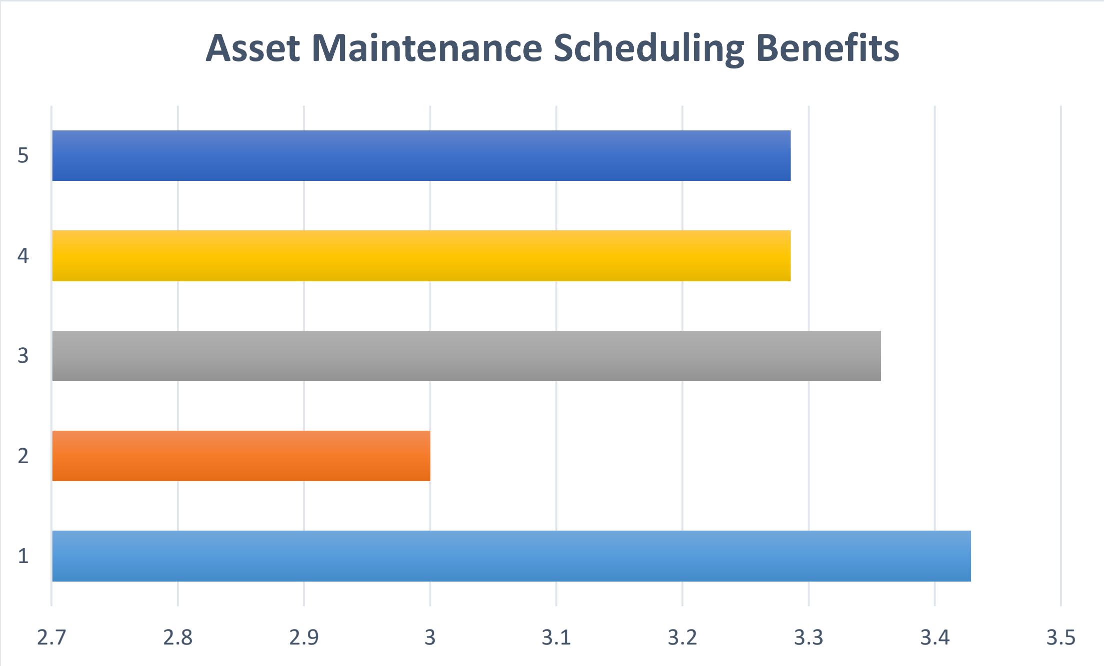

Figure 7.24: Benefit assurance evaluation for Asset Maintenance Scheduling

Table 7.70: Descriptive analysis of Asset Maintenance Scheduling benefits

	Mean	Median	SD
Benefit 1	3.43	4	1.22
Benefit 2	3.00	3.5	1.36
Benefit 3	3.36	3.5	1.22
Benefit 4	3.29	4	1.20
Benefit 5	3.29	4	1.20

7.5.17.2 Inferential analysis

A Spearman's correlation has been used to judge the relationship between BIM use benefits in Asset Maintenance Scheduling and the BIM maturity competencies. Fourteen participants from client organisations are currently using BIM in this area. As before, the correlation analysis has been carried via three stages, by firstly, displaying the degree of correlation between BIM uses benefits and BIM maturity competencies; secondly, summarising the relationship by listing all the related competencies by their correlation degree; and finally, providing a table to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.71 shows that each benefit has a different level of positive correlation with some BIM maturity competencies; these ranged from a significant correlation, where the ρ-value is less than 0.01, to a moderate correlation, where the ρ-value equals 0.047. Based on the correlation analysis, benefit 1 shows a significant correlation with organisation hierarchy, and a positive correlation with standardisation and BIM skill. Benefit 2 expresses a positive correlation with only organisation hierarchy. Benefit 3 indicates a significant correlation with organisation hierarchy, and a positive correlation with BIM vision and standardisation. Benefit 4 shows a significant correlation with organisation hierarchy, and a positive correlation with only BIM vision. Benefit 5 shows a significant correlation with organisation hierarchy, and a positive correlation with only BIM vision.

Table 7.71: Spearman correlation results for Asset Maintenance Scheduling

			Benefit 1	Benefit 2	Benefit 3	Benefit 4	Benefit 5
Spearman's rho	Organisation Mission	Correlation Coefficient	.266	.240	.351	.316	.316
		Sig. (2-tailed)	.357	.409	.218	.271	.271
		N	14	14	14	14	14
	BIM Vision	Correlation Coefficient	.512	.435	**.636***	**.540***	**.540***
		Sig. (2-tailed)	.062	.120	.014	.046	.046
		N	14	14	14	14	14
	BIM Champion	Correlation Coefficient	.105	-.126	.236	-.045	-.045
		Sig. (2-tailed)	.720	.667	.417	.879	.879
		N	14	14	14	14	14
	Management Support	Correlation Coefficient	.510	.353	.640*	.396	.396
		Sig. (2-tailed)	.063	.215	.014	.161	.161
		N	14	14	14	14	14
	Data Sharing Method	Correlation Coefficient	.200	-.092	.123	.092	.092
		Sig. (2-tailed)	.493	.754	.675	.754	.754
		N	14	14	14	14	14
	Standardisation	Correlation Coefficient	**.581***	.407	**.601***	.524	.524
		Sig. (2-tailed)	.029	.148	.023	.054	.054
		N	14	14	14	14	14
	Organisation Hierarchy	Correlation Coefficient	**.729****	**.556***	**.824****	**.673****	**.673****
		Sig. (2-tailed)	.003	.039	.000	.008	.008
		N	14	14	14	14	14
	BIM committee	Correlation Coefficient	-.123	-.257	.001	-.128	-.128
		Sig. (2-tailed)	.675	.374	.997	.664	.664
		N	14	14	14	14	14

	Training	Correlation Coefficient	.460	.337	.450	.461	.461
		Sig. (2-tailed)	.098	.239	.106	.097	.097
		N	14	14	14	14	14
	Education	Correlation Coefficient	.127	.306	.220	.253	.253
		Sig. (2-tailed)	.664	.288	.450	.382	.382
		N	14	14	14	14	14
	Roles and Responsibilities	Correlation Coefficient	.071	-.076	.164	-.003	-.003
		Sig. (2-tailed)	.809	.797	.575	.993	.993
		N	14	14	14	14	14
	Level of Readiness	Correlation Coefficient	.136	-.137	.238	-.016	-.016
		Sig. (2-tailed)	.644	.641	.413	.957	.957
		N	14	14	14	14	14
	BIM Skills	Correlation Coefficient	**.538***	.500	.482	.494	.494
		Sig. (2-tailed)	.047	.069	.081	.073	.073
		N	14	14	14	14	14
	Organisation information requirements (OIR)	Correlation Coefficient	.380	.320	.483	.333	.333
		Sig. (2-tailed)	.180	.264	.080	.244	.244
		N	14	14	14	14	14
	Validation Process	Correlation Coefficient	.232	.274	.149	.270	.270
		Sig. (2-tailed)	.425	.344	.612	.350	.350
		N	14	14	14	14	14
	Quality Assurance System	Correlation Coefficient	.186	.049	.186	.172	.172
		Sig. (2-tailed)	.524	.867	.524	.556	.556
		N	14	14	14	14	14
	Software	Correlation Coefficient	.403	.157	.263	.276	.276
		Sig. (2-tailed)	.153	.592	.363	.340	.340
		N	14	14	14	14	14
	Hardware	Correlation Coefficient	.037	-.303	.118	-.099	-.099
		Sig. (2-tailed)	.899	.292	.688	.736	.736
		N	14	14	14	14	14
	Physical Space	Correlation Coefficient	.257	.265	.197	.188	.188
		Sig. (2-tailed)	.374	.359	.500	.521	.521
		N	14	14	14	14	14

	Network	Correlation Coefficient	-.195	-.343	-.197	-.212	-.212
		Sig. (2-tailed)	.503	.230	.501	.466	.466
		N	14	14	14	14	14
**. Correlation is significant at the 0.01 level (2-tailed).							
*. Correlation is significant at the 0.05 level (2-tailed).							

Table 7.72 displays the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen that most of the benefits show a correlation with almost the same competencies.

Table 7.72: Spearman correlation summary of Asset Maintenance Scheduling

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Help to adapt a proactively maintenance plan.	1. Organisation hierarchy 2. Standardisation 3. BIM skills
2	Optimum maintenance staff distribution.	1. Organisation hierarchy
3	Record and track maintenance history.	1. Organisation hierarchy 2. BIM vision 3. Standardisation
4	Reduce the unexpected maintenance.	1. Organisation hierarchy 2. BIM vision
5	Selection the cost effective maintenance approach	1. Organisation hierarchy 2. BIM vision

b) Overall relationship

In order to demonstrate the BIM maturity competencies that affect BIM use within Asset Maintenance Scheduling, a comparative table has been developed to show the requirements, benefits, and correlated BIM maturity competencies for this particular BIM use (Table 7.73). It can be deduced that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits by using BIM in Asset

Maintenance Scheduling, they have to develop all correlated maturity competencies. However, if client organisations have a limited time and budget for development they can use a correlation ranking to decide which competency they will develop first.

Table 7.73: Related maturity competencies of the Asset Maintenance Scheduling

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. Suitable software and hardware like Building Automation System (BAS) and Computerized Maintenance Management System (CMMS), this software need to be connected to the record model 2. The staff are able to understand all the required software, hardware and typical equipment. 3. The staff are able to manipulate navigate, and review a 3D model. 4. Quality Assurance system.	1. Help to adapt a proactively maintenance plan. 2. Optimum maintenance staff distribution. 3. Record and track maintenance history. 4. Reduce the unexpected maintenance. 5. Selection the cost effective maintenance approach.	1. BIM skills 2. Training 3. Software 4. Hardware 5. Quality assurance system	1. Organisation hierarchy 2. Standardisation 3. BIM vision 4. BIM skills

7.5.17.3 Summary

Based on above analysis, the most significant correlation has been found between the benefits and organisation hierarchy. However, some benefits show a significant correlation with other competencies (Table 7.72), which can be explained as follows:

1. To help to adapt a proactive maintenance plan would require the enhancement of the organisation hierarchy, standardisation, and BIM skills.
2. To achieve optimum maintenance staff distribution would require the development of the organisation hierarchy.

3. To record and track maintenance history would require improvments in the organisation hierarchy, BIM vision, and standardisation.
4. To reduce unexpected maintenance and ensure the selection of the cost effective maintenance approach would require the development of organisation hierarchy and BIM vision.
5. Generally, gathering the benefits from using BIM in Asset Maintenance Scheduling would require an increase in the maturity level in those competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would, consequently, generate significant value through using BIM in Asset Maintenance Scheduling.

In summary, it can be seen (Table 7.73) that the only competency that influences the BIM implementation in Asset Maintenance Scheduling, and to support a client to achieve the desired benefits would be the organisation hierarchy.

7.5.18 Asset System Analysis

A process that measures how an asset's performance compares to the specified design. This includes how the mechanical system operates and how much energy an asset uses. In total, 14 of the 26 organisations in this study are currently using BIM in Asset System Analysis. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and to determine the relationship between BIM use benefits and the maturity competencies.

7.5.18.1 Descriptive analysis

Figure 7.25 shows the average assurance level for all benefits. It can be seen that only two benefits, namely 1 and 2, reach the expected level; this means that the client organisations' current BIM maturity levels only enable them to predict these benefits. These benefits are: to ensure that the building is operating according to the specified standards (benefit 1); and to help to identify opportunities to modify system operations to improve the overall building performance (benefit 2). Meanwhile, benefit 3, which develops different scenarios to improve building performance, is still below the expected benefits; this means that the current client BIM abilities are not sufficient to support them to predict this benefit. The mean, median and standard deviations for these benefits are shown in Table 7.74 in which it can be seen that benefit 2 has a lower median than the mean. This means a positive skew in their distribution with a long tail of high scores pulling the mean up more than the median. This suggests that the median could be more useful in representing the current assurance for benefits 2 However, the other benefits show that their median is bigger than the mean, which means a negative skew in their distribution with a long tail of low scores pulling the mean down more than the median. This indicates that the mean could be more useful in representing the current assurance for these benefits. This shows that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, it can be seen that each benefit has a different standard deviation and this can give an indication where most of the data are located.

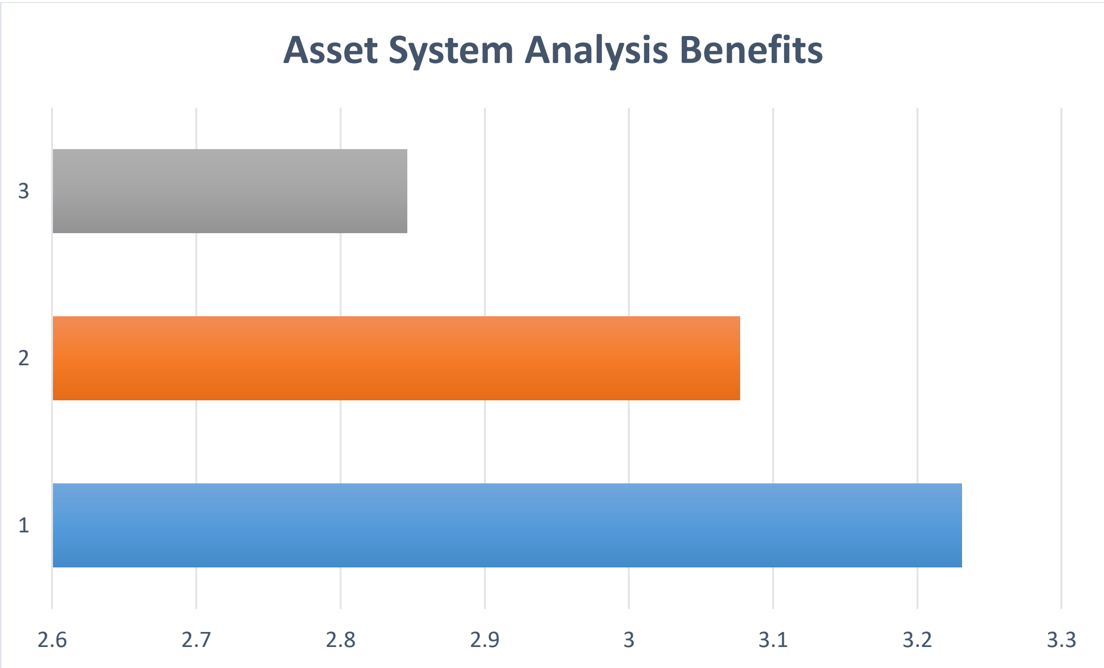

Figure 7.25: Benefit assurance evaluation for Asset System Analysis

Table 7.74: Descriptive analysis of Asset System Analysis benefits

	Mean	Median	SD
Benefit 1	3.23	4	1.36
Benefit 2	3.08	3	1.32
Benefit 3	2.85	3	1.41

7.5.18.2 Inferential analysis

A Spearman's correlation was run to judge the relationship between BIM use benefits in Asset System Analysis and the BIM maturity competencies. Fourteen participants from client organisations are currently using BIM in this area. The correlation analysis has been carried in three stages where the first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies by their correlation degree. The final step provides a comparative table to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.75 indicates that each benefit displays a different level of positive correlation with some BIM maturity competencies, where the maximum significant ratio shows the ρ-value equal to 0.028. Based on the correlation analysis, benefit 1 did not show any correlation with any maturity competencies. Benefits 2 and 3 display a positive correlation with only organisation hierarchy.

Table 7.75: Spearman correlation results for Asset System Analysis

			Benefit 1	Benefit 2	Benefit 3
Spearman's rho	Organisation Mission	Correlation Coefficient	.204	.142	.224
		Sig. (2-tailed)	.503	.643	.462
		N	13	13	13
	BIM Vision	Correlation Coefficient	.481	.377	.443
		Sig. (2-tailed)	.096	.204	.129
		N	13	13	13
	BIM Champion	Correlation Coefficient	.012	-.069	.042
		Sig. (2-tailed)	.969	.824	.892
		N	13	13	13
	Management Support	Correlation Coefficient	.382	.305	.419
		Sig. (2-tailed)	.197	.311	.154
		N	13	13	13
	Data Sharing Method	Correlation Coefficient	.215	-.046	.281
		Sig. (2-tailed)	.480	.882	.352
		N	13	13	13
	Standardisation	Correlation Coefficient	.419	.307	.530
		Sig. (2-tailed)	.154	.307	.062
		N	13	13	13
	Organisation Hierarchy	Correlation Coefficient	.504	**.606***	**.617***
		Sig. (2-tailed)	.079	.028	.025

		N	13	13	13
	BIM committee	Correlation Coefficient	-.071	-.078	-.059
		Sig. (2-tailed)	.817	.800	.849
		N	13	13	13
	Training	Correlation Coefficient	.442	.182	.358
		Sig. (2-tailed)	.130	.551	.229
		N	13	13	13
	Education	Correlation Coefficient	-.107	-.086	-.222
		Sig. (2-tailed)	.728	.781	.466
		N	13	13	13
	Roles and Responsibilities	Correlation Coefficient	-.079	-.180	-.154
		Sig. (2-tailed)	.798	.556	.615
		N	13	13	13
	Level of Readiness	Correlation Coefficient	.178	.066	.124
		Sig. (2-tailed)	.560	.831	.687
		N	13	13	13
	BIM Skills	Correlation Coefficient	.384	.235	.429
		Sig. (2-tailed)	.195	.440	.144
		N	13	13	13
	Organisation information requirements (OIR)	Correlation Coefficient	.103	.128	.287
		Sig. (2-tailed)	.739	.676	.341
		N	13	13	13
	Validation Process	Correlation Coefficient	.069	-.117	.227
		Sig. (2-tailed)	.824	.703	.456
		N	13	13	13
	Quality Assurance System	Correlation Coefficient	-.165	-.130	-.163
		Sig. (2-tailed)	.590	.673	.594
		N	13	13	13
	Software	Correlation Coefficient	.299	.051	.427

		Sig. (2-tailed)	.321	.870	.146
		N	13	13	13
	Hardware	Correlation Coefficient	.053	-.106	.021
		Sig. (2-tailed)	.864	.731	.944
		N	13	13	13
	Physical Space	Correlation Coefficient	-.142	-.205	.247
		Sig. (2-tailed)	.644	.503	.415
		N	13	13	13
	Network	Correlation Coefficient	-.122	-.398	-.146
		Sig. (2-tailed)	.693	.178	.633
		N	13	13	13
**. Correlation is significant at the 0.01 level (2-tailed).					
*. Correlation is significant at the 0.05 level (2-tailed).					

Table 7.76 summarises the correlation results by showing the benefits with their related competencies. The BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen that only benefits 2 and 3 show a correlation with organisation hierarchy.

Table 7.76: Spearman correlation summary of Asset System Analysis

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Make sure that the building is operating according to the specified standards.	1. None
2	Help to identify opportunities to modify system operations to improve the overall building performance.	1. Organisation hierarchy
3	Develop different scenarios to improve building performance	1. Organisation hierarchy

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use in Asset System Analysis, a comparative table has been provided to show the requirements, benefits and correlated BIM maturity competencies for this particular use (Table 7.77). It can be concluded that, identifying organisation hierarchy as only correlated competency means that the current clients knowledge and experience regarding this BIM use is not enough to establish the relationship between BIM maturity competencies and BIM uses benefits. Therefore, currently clients can use the proposed related competencies as guidance without any guarantee that improving these competencies will improve BIM benefits achievements.

Table 7.77: Related maturity competencies of the Asset System Analysis

Requirements	Benefits	Proposed related maturity competencies	Maturity correlated competencies
1. Suitable software and hardware. 2. The staff have at least basic knowledge about CMMS and building control systems with Record Model 3. The staff are able to understand typical equipment operation and maintenance practices 4. The staff are able to manipulate navigate, and review a 3D model. 5. Quality Assurance system.	1. Make sure that the building is operating according to the specified standards. 2. Help to identify opportunities to modify system operations to improve the overall building performance. 3. Develop different scenarios to improve building performance.	1. BIM skills 2. Training 3. Software 4. Hardware 5. Quality assurance system	1. Organisation hierarchy

7.5.18.3 Summary

Based on the above analysis, the only significant correlation has been found between benefits 2 and 3 and the organisation hierarchy. However, benefit 1 did not show any correlation with any competencies, which could lead to the following conclusions:

a) Currently, client organisations are not using BIM in Asset System Analysis to access this benefit.

b) Client organisations are not presently able to predict this benefit due to the limitations in their BIM competencies.

c) There are other competencies aside from those proposed that may affect a client's ability to predict this benefit.

Generally, accessing the benefits from using BIM within Asset System Analysis will require an increase in maturity level in those competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would generate significant value through using BIM within Asset System Analysis.

7.5.19 Asset Management

A process in which an organised management system is bi-directionally linked to a record model to efficiently aid in the maintenance and operation of a facility and its assets. Fourteen of the 26 organisations that contributed to this study are currently using BIM in Asset Management. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and to determine the relationship between BIM use benefits and the maturity competencies.

7.5.19.1 Descriptive analysis

Figure 7.26 expresses the average assurance level for all benefits, in which it can be seen that only two benefits, 1 and 4, reach the expected level, which means the client organisations' current BIM maturity level only enables them to predict this benefit. These benefits are: providing quick access to the operations; maintenance owner user manuals (benefit 1) and updating the existing record models (benefit 4). Meanwhile, benefits 2 and 3 are still below the expected benefits, which means that current client BIM abilities are not sufficient to support them in predicting these benefits. These benefits are: equipment specifications and providing real-time information about the facility performance and equipment conditions (benefit 2) and producing accurate quantity take-offs for different future uses (benefit 3). The mean, median and standard deviations for these benefits are shown in Table 7.78 in which it can be seen that benefits 1, 2, and 4 show a lower median than the mean, which means a positive skew in their distribution and a long tail of high scores pulling the mean more than the median. This indicates that the median could be more useful in representing the current assurance for these benefits. However, benefit 3 shows a bigger median than the mean, which means a negative skew in its distribution with a long tail of low scores pulling the mean down more than the median. This suggests that the mean could be more useful in representing the current assurance for this benefit. This indicates that using mean in most of existing BIM maturity models will not necessarily reflects the real situation regarding maturity level. Also, each benefit has a different standard deviation that could indicate where most of the data are located.

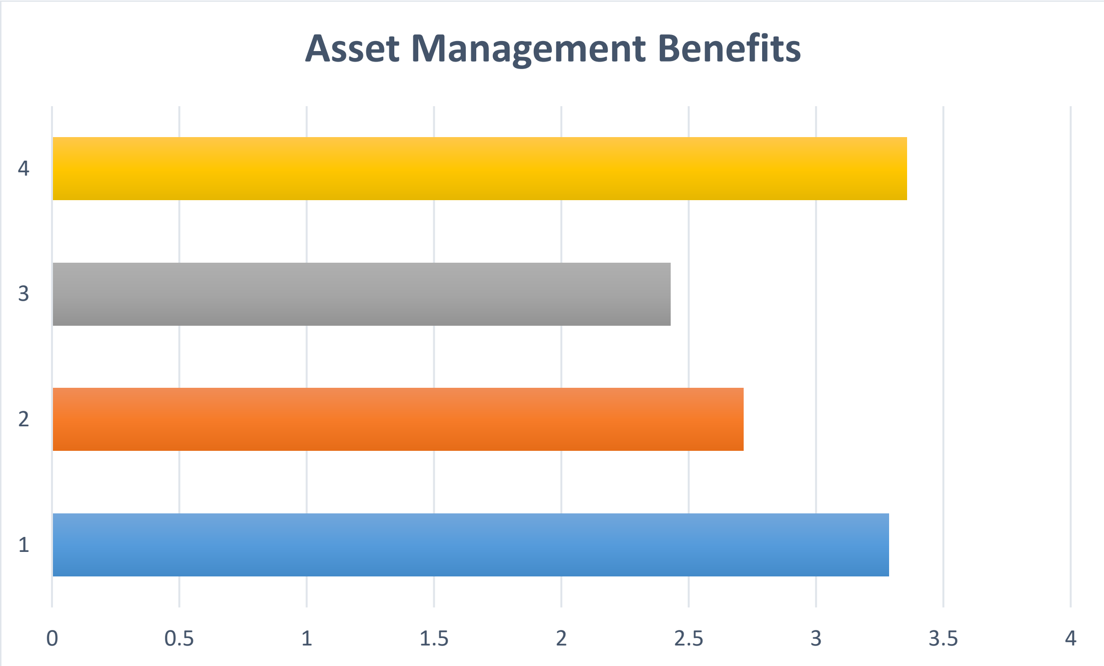

Figure 7.26: Benefit assurance evaluation for Asset Management

Table 7.78: Descriptive analysis of Asset Management benefits

	Mean	Median	SD
Benefit 1	3.29	3	1.33
Benefit 2	2.71	2.5	1.27
Benefit 3	2.43	2.5	1.22
Benefit 4	3.36	3	1.01

7.5.19.2 Inferential analysis

A Spearman's correlation has been adopted to judge the relationship between BIM use benefits in Asset Management and the BIM maturity competencies. Fourteen participants from client organisations are currently using BIM in this area. The correlation analysis has been carried via three stages, where the first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies by their correlation degree. The final stage establishes a comparative table to compare the BIM uses requirements, benefits, and related maturity competencies.

a) Correlation factors

Table 7.79 shows that each benefit has a different level of positive correlation with some BIM maturity competencies, and these ranged from a significant correlation, where the ρ-value is less than 0.01, to a moderate correlation, where the ρ-value equals 0.048. Based on the correlation analysis, benefit 1 shows a significant correlation with organisation mission and BIM vision, and a positive correlation with management support and the level of readiness. Benefit 2 expresses only a positive correlation with standardisation and OIR, whilst benefit 3 does not express a correlation with any maturity competency. Benefit 4 shows a positive correlation with only standardisation.

Table 7.79: Spearman correlation results for Asset Management

			Benefit 1	Benefit 2	Benefit 3	Benefit 4
Spearman's rho	Organisation Mission	Correlation Coefficient	**.720****	.442	.342	.531
		Sig. (2-tailed)	.004	.113	.231	.051
		N	14	14	14	14
	BIM Vision	Correlation Coefficient	**.690****	.450	.254	.482
		Sig. (2-tailed)	.006	.107	.381	.081
		N	14	14	14	14
	BIM Champion	Correlation Coefficient	.257	.287	-.273	-.075
		Sig. (2-tailed)	.375	.320	.345	.800
		N	14	14	14	14
	Management Support	Correlation Coefficient	**.537***	.340	.057	.150
		Sig. (2-tailed)	.048	.234	.846	.608
		N	14	14	14	14
	Data Sharing Method	Correlation Coefficient	.044	.135	.132	.495
		Sig. (2-tailed)	.880	.646	.654	.072
		N	14	14	14	14
	Standardisation	Correlation Coefficient	.524	**.567***	.444	**.614***
		Sig. (2-tailed)	.054	.034	.112	.019
		N	14	14	14	14
	Organisation Hierarchy	Correlation Coefficient	.395	.411	.321	.152
		Sig. (2-tailed)	.162	.144	.263	.605
		N	14	14	14	14
	BIM committee	Correlation Coefficient	.185	-.046	-.077	-.157

		Sig. (2-tailed)	.527	.877	.794	.592
		N	14	14	14	14
	Training	Correlation Coefficient	.464	.094	-.071	.327
		Sig. (2-tailed)	.095	.750	.808	.254
		N	14	14	14	14
	Education	Correlation Coefficient	.288	.066	-.044	-.008
		Sig. (2-tailed)	.318	.823	.880	.979
		N	14	14	14	14
	Roles and Responsibilities	Correlation Coefficient	.272	-.043	-.335	-.119
		Sig. (2-tailed)	.348	.883	.241	.686
		N	14	14	14	14
	Level of Readiness	Correlation Coefficient	**.586***	.280	-.179	.199
		Sig. (2-tailed)	.028	.332	.540	.496
		N	14	14	14	14
	BIM Skills	Correlation Coefficient	.333	.199	.242	.339
		Sig. (2-tailed)	.244	.495	.405	.236
		N	14	14	14	14
	Organisation information requirements (OIR)	Correlation Coefficient	.315	**.584***	.363	.205
		Sig. (2-tailed)	.273	.028	.202	.482
		N	14	14	14	14
	Validation Process	Correlation Coefficient	-.012	.177	.196	.235
		Sig. (2-tailed)	.968	.545	.501	.419
		N	14	14	14	14
	Quality Assurance System	Correlation Coefficient	.307	.082	.179	.328
		Sig. (2-tailed)	.286	.782	.540	.252
		N	14	14	14	14
	Software	Correlation Coefficient	.141	.204	.171	.503
		Sig. (2-tailed)	.630	.485	.558	.066
		N	14	14	14	14
	Hardware	Correlation Coefficient	.305	.125	.065	.370
		Sig. (2-tailed)	.289	.671	.825	.193
		N	14	14	14	14
	Physical Space	Correlation Coefficient	-.328	.182	.399	.057
		Sig. (2-tailed)	.252	.533	.158	.846

		N	14	14	14	14
	Network	Correlation Coefficient	-.137	-.105	-.312	.034
		Sig. (2-tailed)	.640	.721	.277	.909
		N	14	14	14	14
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

Table 7.80 summarises the correlation results by showing the benefits with their related competencies. The BIM maturity competencies have been listed by their degree of correlation, from high to low. It can be seen that most of the benefits show a correlation with almost the same competencies.

Table 7.80: Spearman correlation summary of Asset Management

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Provide quick access to the operations, maintenance owner user manuals, and equipment specifications.	1. Organisation mission 2. BIM vision 3. Level of readiness 4. Management support
2	Provide real-time information about the facility performance and equipment condition.	1. OIR 2. Standardisation
3	Produce accurate quantity take-offs for different future use.	None
4	Update the existing record model.	1. Standardisation

b) Overall relationship

In order to identify the BIM maturity competencies that affect BIM use in Asset Management, a comparative table has been developed to show the requirements, benefits, and correlated BIM maturity competencies (Table 7.81). It can be concluded that, there are differences between the proposed and correlated BIM maturity competencies which means proposing the related BIM maturity competencies from requirements understanding only will not reflects the real practices and experience. In addition, if client organisations aim to achieve the desired benefits from using BIM in Asset Management, they have to develop all correlated maturity competencies, which in this area is basically organisation hierarchy.

Table 7.81: Related maturity competencies of the Asset Management

Requirements	Benefits	Proposed related maturity competencies	Maturity
1. Suitable software and hardware. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff are able to manipulate an asset management system 4. The staff have at least basic information about building operation system. 5. Quality Assurance system.	6. Provide quick access to the operations, maintenance owner user manuals, and equipment specifications. 7. Provide real-time information about the facility performance and equipment condition. 8. Produce accurate quantity take-offs for different future use. 9. Update the existing record model.	1. BIM skills 2. Training 3. Software 4. Hardware 5. Quality assurance system	1. Organisation mission 2. BIM vision 3. Standardisation 4. OIR 5. Level of readiness 6. Management support

7.5.19.3 Summary

Based on above analysis, the most significant correlation has been found between the benefits and the organisation mission and BIM vision competencies. Moreover, some benefits show a significant correlation with other competencies, as shown in Table 7.80. These are explained as follows:

1. To provide quick access to the operations, maintenance owner user manuals, and equipment specifications would require the enhancement of the organisation mission, BIM vision, level of readiness, and management support.

2. To provide real-time information about facility performance and equipment conditions would require an improvement in OIR and standardisation.

3. The production of accurate quantity take-offs for different future use did not show a correlation with any BIM maturity competencies, and this may be due to the following reasons:

    a) Currently, client organisations are not using BIM in Asset Management analysis to access this benefit.

   b) Client organisations presently are not able to predict this benefit due to limitations in their BIM competencies.

   c) There are other competencies, aside from those proposed, that may affect the client's ability to predict this benefit.

4. To update the existing record model would require an enhancement in standardisation.
5. Generally, gathering the benefits from using BIM in Asset Management will require an increase in maturity level within those competencies that show a significant correlation with the benefits. In addition, the continuous improvement of these competencies would, consequently, generate significant value through using BIM within Asset Management.

To summarise, it can be seen (Table 7.81) that the main competencies that influence BIM implementation in Asset Management and that support clients to achieve these desired benefits are organisation mission and BIM vision.

7.5.20 Space Tracking

A process in which BIM is utilised to effectively distribute, manage, and track appropriate spaces and related resources within a facility. Only 8 of the 26 organisations that participated are currently using BIM in Space Tracking. Both descriptive and inferential analyses will be carried out to test the data and determine the relationship between BIM use benefits and the maturity competencies.

7.5.20.1 Descriptive analysis

Figure 7.27 illustrates the average assurance level for all benefits and it can be seen that all benefits reached the expected level, which means the client organisations' current BIM maturity level only enables them to predict this benefit. These benefits are: the time and cost saving process in identifying and allocating space for appropriate building use (benefit 1); an increase in the efficiency of transition planning and management (benefit 2); provision of accurate information about tracking the use of current space and resources (benefit 3); and help in the planning process for future space needs in the facility (benefit 4). The mean, median and standard deviations for these benefits are shown in Table 7.82 in which it can be seen that all benefits show that the median and the mean are equal. This indicates that the distribution is symmetric and will have zero skewness. Also, it can be seen that each benefit has a different standard deviation that can indicates where most of the data are located.

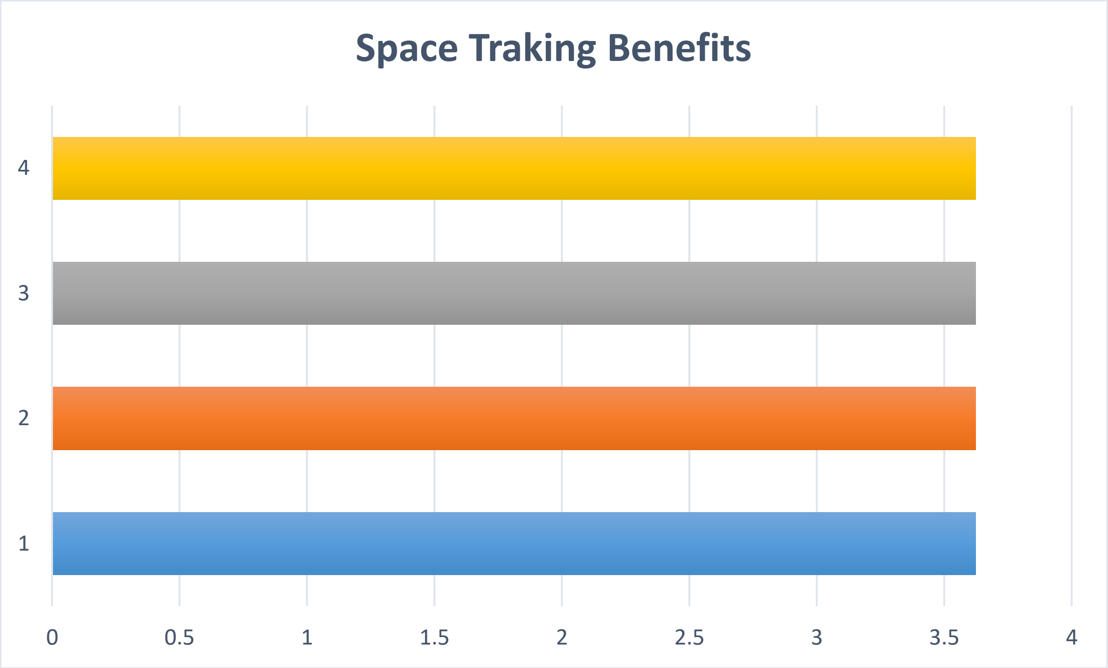

Figure 7.27: Benefit assurance evaluation for Space Tracking

Table 7.82: Descriptive analysis of Space Tracking benefits

	Mean	Median	SD
Benefit 1	3.63	3.5	1.41
Benefit 2	3.63	3.5	1.41
Benefit 3	3.63	3.5	1.41
Benefit 4	3.63	3.5	1.41

7.5.20.2 Inferential analysis

A Spearman's correlation has been calculated to analyse the relationship between BIM use benefits in Space Tracking and the BIM maturity competencies. Eight participants from client organisations are currently using BIM in this area, and the analysis has been conducted by exploring the correlation analysis results for all benefits.

a) Correlation factors

Table 7.83 shows All benefits show same correlation factor with BIM skills competency which 0.779 with significant ratio equal 0.023.

Table 7.83: Spearman correlation results for Space Tracking

			Benefit 1	Benefit 2	Benefit 3	Benefit 4
Spearman's rho	Organisation Mission	Correlation Coefficient	.494	.494	.494	.494
		Sig. (2-tailed)	.214	.214	.214	.214
		N	8	8	8	8
	BIM Vision	Correlation Coefficient	.564	.564	.564	.564
		Sig. (2-tailed)	.145	.145	.145	.145
		N	8	8	8	8
	BIM Champion	Correlation Coefficient	.213	.213	.213	.213
		Sig. (2-tailed)	.612	.612	.612	.612
		N	8	8	8	8
	Management Support	Correlation Coefficient	.609	.609	.609	.609
		Sig. (2-tailed)	.109	.109	.109	.109
		N	8	8	8	8
	Data Sharing Method	Correlation Coefficient	.408	.408	.408	.408
		Sig. (2-tailed)	.316	.316	.316	.316
		N	8	8	8	8
	Standardisation	Correlation Coefficient	.649	.649	.649	.649
		Sig. (2-tailed)	.081	.081	.081	.081
		N	8	8	8	8
	Organisation Hierarchy	Correlation Coefficient	.211	.211	.211	.211
		Sig. (2-tailed)	.617	.617	.617	.617
		N	8	8	8	8
	BIM committee	Correlation Coefficient	.408	.408	.408	.408
		Sig. (2-tailed)	.316	.316	.316	.316
		N	8	8	8	8
	Training	Correlation Coefficient	.541	.541	.541	.541
		Sig. (2-tailed)	.166	.166	.166	.166
		N	8	8	8	8

	Education	Correlation Coefficient	.644	.644	.644	.644
		Sig. (2-tailed)	.085	.085	.085	.085
		N	8	8	8	8
	Roles and Responsibilities	Correlation Coefficient	.188	.188	.188	.188
		Sig. (2-tailed)	.656	.656	.656	.656
		N	8	8	8	8
	Level of Readiness	Correlation Coefficient	.182	.182	.182	.182
		Sig. (2-tailed)	.667	.667	.667	.667
		N	8	8	8	8
	BIM Skills	Correlation Coefficient	.779*	.779*	.779*	.779*
		Sig. (2-tailed)	.023	.023	.023	.023
		N	8	8	8	8
	Organisation information requirements (OIR)	Correlation Coefficient	.594	.594	.594	.594
		Sig. (2-tailed)	.121	.121	.121	.121
		N	8	8	8	8
	Validation Process	Correlation Coefficient	.537	.537	.537	.537
		Sig. (2-tailed)	.170	.170	.170	.170
		N	8	8	8	8
	Quality Assurance System	Correlation Coefficient	.054	.054	.054	.054
		Sig. (2-tailed)	.899	.899	.899	.899
		N	8	8	8	8
	Software	Correlation Coefficient	.349	.349	.349	.349
		Sig. (2-tailed)	.397	.397	.397	.397
		N	8	8	8	8
	Hardware	Correlation Coefficient	.137	.137	.137	.137
		Sig. (2-tailed)	.746	.746	.746	.746
		N	8	8	8	8
	Physical Space	Correlation Coefficient	.211	.211	.211	.211
		Sig. (2-tailed)	.617	.617	.617	.617

		N	8	8	8	8
	Network	Correlation Coefficient	.215	.215	.215	.215
		Sig. (2-tailed)	.609	.609	.609	.609
		N	8	8	8	8
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

7.5.20.3 Summary

Based on the above analysis, the most significant correlation has been found between all benefits and BIM skills; improving this competency would help the client to achieve all the benefits by using BIM within Space Tracking. However, the behaviour of all benefits has the same attitude with all BIM maturity competencies; this means that these benefits were not affected by maturity development, and the correlation with BIM skills may happen by chance. Therefore, the correlation analysis results will be considered unreliable, and this is subsequently identified one limitation for this research. Therefore, currently clients can use the proposed related competencies as guidance without any guarantee that improving these competencies will improve BIM benefits achievements.

7.5.21 Disaster Management

A process in which emergency responders would have access to critical building information in the form of a model and information system. Only 7 out of the 26 contributing organisations are currently using BIM in Disaster Management. For this BIM use, both descriptive and inferential analyses will be carried out to test the data and to determine the relationship between BIM use benefits and the maturity competencies

7.5.21.1 Descriptive analysis

Figure 7.28 displays the average assurance level for all benefits, and it can be seen that all benefits reached the expected level which means the client organisations' current BIM maturity levels enable them to only predict this benefit. These benefits are: to provide real-time accurate information about any emergency event for different types of responders (benefit 1); like police, fire, and public safety officials (benefit 2); to improve the effectiveness of emergency responses (benefit 3); and to minimize risks to responders (benefit 4). The mean, median and standard deviations for these benefits are shown in Table 7.84 in which it can be seen that all benefits show that their median is bigger than the mean. This indicates a negative skew in their distribution, with a long tail of low scores pulling the mean down more than the median. This shows that the mean could be more useful in representing the current assurance for these benefits. Also, it can be seen that each benefit has a different standard deviation that can give an indication as to where most of the data are located.

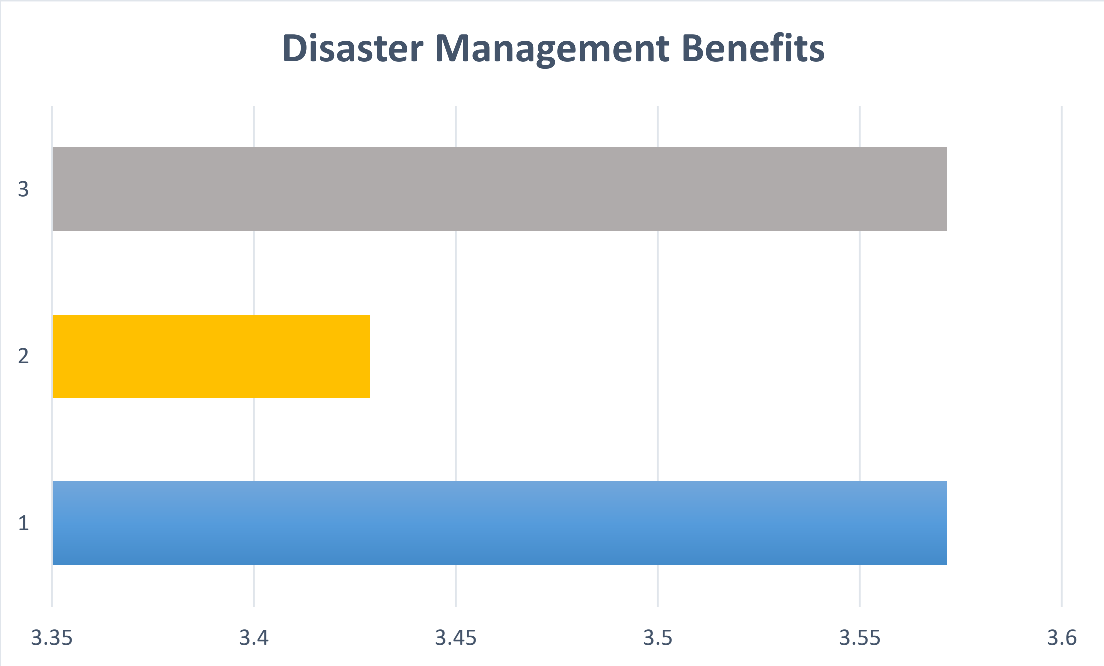

Figure 7.28: Benefit assurance evaluation for Disaster Management

Table 7.84: Descriptive analysis of Disaster Management benefits

	Mean	Median	SD
Benefit 1	3.57	4	1.62
Benefit 2	3.43	4	1.51
Benefit 3	3.57	4	1.62

7.5.21.2 Inferential analysis

A Spearman's correlation has been conducted to evaluate the relationship between BIM use benefits in Disaster Management and the BIM maturity competencies. Seven participants from client organisations are currently using BIM in this area. The correlation analysis has been carried in three stages, where the first displays the degree of correlation between BIM uses benefits and BIM maturity competencies. The second summarises the relationship by listing all the related competencies regarding their correlation degree. The final stage establishes a comparative table to compare the BIM uses requirements, benefits, and related BIM maturity competencies.

a) Correlation factors

Table 7.85 indicates that only benefits 1 and 3 show a positive correlation with BIM skills, with a significant ratio equal to 0.046.

Table 7.85: Spearman correlation results for Disaster Management

			Benefit 1	Benefit 2	Benefit 3
Spearman's rho	Organisation Mission	Correlation Coefficient	.453	.602	.453
		Sig. (2-tailed)	.307	.153	.307
		N	7	7	7
	BIM Vision	Correlation Coefficient	.252	.429	.252
		Sig. (2-tailed)	.585	.337	.585
		N	7	7	7
	BIM Champion	Correlation Coefficient	.078	-.057	.078
		Sig. (2-tailed)	.869	.903	.869
		N	7	7	7
	Management Support	Correlation Coefficient	.310	.365	.310
		Sig. (2-tailed)	.499	.421	.499
		N	7	7	7
	Data Sharing Method	Correlation Coefficient	.491	.463	.491
		Sig. (2-tailed)	.264	.295	.264
		N	7	7	7
	Standardisation	Correlation Coefficient	.571	.664	.571
		Sig. (2-tailed)	.180	.104	.180
		N	7	7	7
	Organisation Hierarchy	Correlation Coefficient	.311	.343	.311
		Sig. (2-tailed)	.498	.451	.498
		N	7	7	7
	BIM committee	Correlation Coefficient	-.495	-.673	-.495
		Sig. (2-tailed)	.258	.098	.258
		N	7	7	7
	Training	Correlation Coefficient	.388	.333	.388
		Sig. (2-tailed)	.389	.465	.389
		N	7	7	7
	Education	Correlation Coefficient	.544	.581	.544
		Sig. (2-tailed)	.207	.171	.207
		N	7	7	7
	Roles and Responsibilities	Correlation Coefficient	.155	-.048	.155
		Sig. (2-tailed)	.739	.919	.739
		N	7	7	7

	Level of Readiness	Correlation Coefficient	.038	-.140	.038
		Sig. (2-tailed)	.935	.764	.935
		N	7	7	7
	BIM Skills	Correlation Coefficient	**.762***	.645	**.762***
		Sig. (2-tailed)	.046	.118	.046
		N	7	7	7
	Organisation information requirements (OIR)	Correlation Coefficient	.308	.491	.308
		Sig. (2-tailed)	.502	.264	.502
		N	7	7	7
	Validation Process	Correlation Coefficient	.466	.514	.466
		Sig. (2-tailed)	.292	.237	.292
		N	7	7	7
	Quality Assurance System	Correlation Coefficient	0.000	.132	0.000
		Sig. (2-tailed)	1.000	.778	1.000
		N	7	7	7
	Software	Correlation Coefficient	.308	.113	.308
		Sig. (2-tailed)	.502	.809	.502
		N	7	7	7
	Hardware	Correlation Coefficient	.272	.076	.272
		Sig. (2-tailed)	.555	.871	.555
		N	7	7	7
	Physical Space	Correlation Coefficient	.117	.095	.117
		Sig. (2-tailed)	.804	.839	.804
		N	7	7	7
	Network	Correlation Coefficient	.450	.241	.450
		Sig. (2-tailed)	.311	.603	.311
		N	7	7	7
**. Correlation is significant at the 0.01 level (2-tailed).					
*. Correlation is significant at the 0.05 level (2-tailed).					

Table 7.86 provides the correlation results by showing the benefits with their related competencies. The correlated BIM maturity competencies have been listed regarding the degree of correlation from high to low. It can be seen that benefits 1 and 3 have a correlation with only BIM skills.

Table 7.86: Spearman correlation summary of Disaster Management

NO	Benefit description	Related maturity competencies (from high correlation to low correlation)
1	Provide real-time accurate information about any emergency event	2. BIM skills
2	Improve the effectiveness of emergency response	2. None
3	Minimize risks to responders	4. BIM skills

b) Overall relationship

In order to recognise the BIM maturity competencies that affect BIM use in Disaster Management, a comparative table has been developed to show the requirements, benefits, and correlated BIM maturity competencies (Table 7.87). It can be concluded that, if client organisations aim to achieve the desired benefits from using BIM in Disaster Management, they have to develop their BIM skills. Therefore, currently clients can use the proposed related competencies as guidance without any guarantee that improving these competencies will improve BIM benefits achievements.

Table 7.87: Related maturity competencies of the Disaster Management

Requirements	Benefits	Proposed related maturity competencies	Correlated competencies
1. Suitable software and hardware like Building Automation System (BAS) and Computerized Maintenance Management System (CMMS), this software need to be connected to the record model. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff are able to make appropriate decisions during an emergency. 4. Quality Assurance system.	1. Provide real-time accurate information about any emergency event for a different type of responders like police, fire, and public safety officials. 2. Improve the effectiveness of emergency response. 3. Minimise risks to responders.	1. BIM skills 2. Training 3. Software 4. Hardware 5. Quality assurance system 6. BIM committee	1. BIM skills

7.5.21.3 Summary

Grounded by above correlations' analysis, the most significant correlation has been found between benefits 1 and 3 and BIM skills only, as shown in Table 7.87. However, benefit 2 did not show any correlation with BIM maturity competencies, and this may be due to several reasons:

a) Currently, client organisations are not using BIM in Disaster Management to access this benefit.

b) Client organisations are not presently able to predict this benefit due to the limitations in their BIM competencies.

c) There are other competencies aside from those proposed that may affect the client's ability to predict this benefit.

In summary, from Table 7.88 it can be seen that the main competency that influences BIM implementation in Disaster Management, and that supports client to achieve the desired benefits, is BIM skills

7.6 Summary of the findings

The quantitative data analysis reveals several significant findings that can be used to develop some conclusions. Starting with, all client organisations that participated in this study show a limited development in BIM maturity competencies, which mainly reached maturity level 2. UK construction clients are still at the beginning of their BIM implementation journey. Therefore, they are in good position to benefit significantly from the proposed BIM maturity model, which can support them in managing this change.

Design Review, Clash Detection, and Record Model have been used by most of the participating client organisations, this shows that they are currently using BIM to validate the information coming from their supply chain. Despite the importance of these BIM uses, there is significant value to be achieved if BIM has also been used in other areas, such Asset Management, Asset Maintenance, and Asset System Analysis. However, the current ability of the participating client organisations prevents them from extending their BIM uses. Nevertheless, the relationship between BIM maturity competencies and BIM uses benefits will support client organisations to expand their uses by investing in the right competencies to achieve their desired benefits.

In the same context, twenty-one BIM uses and benefits were presented alongside their correlations with the BIM maturity competencies. It has been found that each BIM use requires client organisations to improve certain competencies in order to improve their chance of achieving the desired benefits. Some of these BIM uses have a different level of positive correlation with particular competencies that can greatly affect clients' abilities to use BIM in certain areas. Moreover, if client organisations have a limited time and budget for development they can use a correlation ranking to decide which competency they need to develop first.

Table 7.88 and Figure 7.29 show only those frequencies of BIM maturity competencies that have a significant correlation with BIM uses. It can be seen that BIM vision, management support, data sharing, training, BIM skills and technical competencies are the most frequent competencies that show a significant correlation with the BIM uses. This means that these competencies in particular, can be considered a baseline for any BIM maturity development plan, which means that client organisations should develop these competencies as the first step in their BIM implementation process. Meanwhile, the degree of development (the maturity level) will be determined through the desired benefits. For instance, if a certain benefit shows a significant correlation with particular competencies, this means that these competencies need to be developed to high level of maturity in order to optimise the corresponding benefit. In addition, the BIM uses also show a correlation with other competencies, which require client organisations to improve these competencies and include them in their development plan in order to achieve some BIM uses benefits. Showing that BIM uses only have a positive correlation with some competencies, does not necessarily mean the other competencies are not important. Although all competencies are important in terms of BIM implementations, client organisations can use the correlation results to set up their development priorities

Some of BIM uses show no correlation with any of BIM maturity competencies, or with just a few, such as the Energy and Lighting Analysis, Code Validation, Record Model, Asset System Analysis, Space Tracking, and Disaster Management. This result may be due to a number of reasons, which are as follows:

a) There are other competencies that are not included in the proposed BIM maturity model that can affect a client organisation's ability to use BIM in certain areas.
b) Client organisations' current situations are not sufficiently mature to use BIM in these certain areas. This can be seen through the small number of client

organisations who are currently using BIM in Disaster Management, Space Tracking, Code Validation, and Energy Analysis.

c) The absence of real cases where BIM is used in these areas prevents the participants from evaluating their current BIM benefits assurance level.

From this part of validation process (quantitative part), it can be concluded that all BIM maturity competencies show different levels of correlation with BIM uses benefits; this illustrates that the proposed BIM maturity model has a good level of applicability to assess the UK construction clients against BIM implementation development.

Table 7.88: The frequencies of significant correlated BIM maturity competencies with BIM uses

Uses/competencies	MS1	MS2	MS3	MS4	MS5	MS6	MS7	MS8	MP1	MP2	MP3	MP4	MP5	MPr1	MPr2	MPr3	MT1	MT2	MT3	MT4
Existing Condition Modelling					√	√									√					√
Cost Estimating		√		√	√		√							√	√				√	
Phase Planning					√							√					√	√	√	√
Design Authority													√							√
Design Review		√		√								√					√	√		
Engineering Analysis									√								√			
Energy Analysis				√																
Lighting Analysis																				
Sustainability Evaluation																				
Code Validation																				
3D Coordination		√		√	√	√			√		√		√	√			√	√	√	√
Construction System Design		√							√	√										
Site utilisation Planning									√				√							
Digital Fabrication												√					√	√	√	

3D control and Planning									√				√							
Record Model																				
Building Maintenance Scheduling							√													
Building Systems Analysis							√													
Asset Management	√	√																		
Space Management and Tracking													√							
Disaster Management													√							
Frequency	**1**	**5**	**0**	**4**	**4**	**2**	**3**	**0**	**5**	**1**	**1**	**3**	**6**	**2**	**2**	**0**	**5**	**4**	**4**	**4**

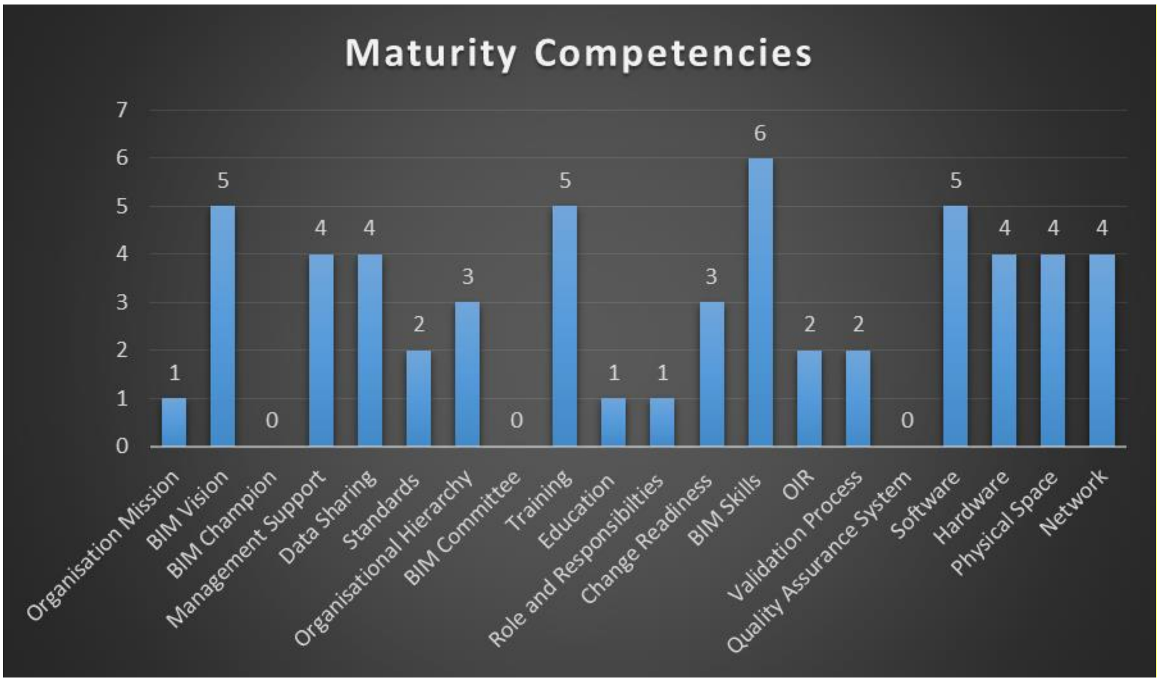

Figure 7.29: BIM maturity competencies frequencies with significant correlation

7.7 Final conceptual assessment framework

This section aims to present the final version of the BIM maturity-benefits relationship conceptual assessment framework for UK construction clients by exploring the effects of the validation process results on the initial version of the proposed framework.

7.7.1 Validation step 1 (qualitative data analysis and results)

As critically discussed in Chapter six, the qualitative validation step aimed to validate the proposed list of critical success of BIM maturity competencies which are proposed based on literature and examine the importance of the BIM maturity- benefits relationship for client organisations. This was considered the first step that was required before validating the relationship between BIM maturity competencies and BIM uses benefits.

The achievement of all qualitative validation objectives reveals two main conclusions which have been considered as crucial for the conceptual assessment framework validation. Firstly, the proposed list of BIM maturity competencies has been considered valid and can be used to assess the UK construction clients against BIM implementation process. This has been achieved via exploring the BIM maturity competencies that support UK construction clients to perform their roles such as developing their EIR, information validation, and lead BIM implementation process. 19 competencies have been validated as critical success factors for UK construction clients which improving these competencies will increase client organisations chance to achieve their desired benefit of BIM.

The BIM maturity, BIM uses benefits, and the relationship between them has been validated as vital terms that will affect BIM implementation inside client organisations significantly. BIM benefits have found as the common motivation factor that attracted UK construction clients to implement BIM. Therefore, adding more clarification regarding benefits achievement will increase BIM implementation ratio among client organisations. In addition, BIM maturity importance awareness have been reached considerable level among participated client organisations and they believed that improving their BIM maturity will support them to achieve their desired benefits of BIM. Finally, the participated clients show clearly the importance of the relationship between maturity and benefits. However, the absence of a formulated relationship prevents them to gather the benefits of it.

Based on the qualitative validation step, the proposed BIM maturity assessment model and BIM uses benefits were used in the quantitative validation step by assessing responder against BIM maturity and benefits assurance via online questionnaire to validate the relationship between BIM maturity competencies and BIM uses benefits.

7.7.2 Validation step 2 (quantitative data analysis and results)

As has been considered in the previous sections of this chapter, the quantitative validation step aimed to validate the proposed relationship between BIM maturity competencies and

BIM uses benefits which will help client organisation to invest on only valuable competencies. This aim has been met through the application of correlation analyses on both the maturity and benefits assessment results that were collected through an online questionnaire. Several conclusions have been drawn from the quantitative validation, which have significant importance on the formulation of the final version of the proposed conceptual assessment framework. Firstly, Most of BIM uses show a different level of correlation with different BIM maturity competencies, ranging from significant to good. This means that each BIM competency has a different level of importance, reflecting its relationship with client organisations' desired benefits from BIM.

Secondly, there are certain competencies that show a significant relationship with most BIM uses, and these are; BIM vision, management support, data sharing, training, BIM skills and technical competencies. These competencies should be treated as a priority in any client organisation's BIM development plan due to their impact of corresponding benefits achievement.

However, only seven BIM uses, which are energy analysis, lighting analysis, code validation, record model, asset management, space tracking, and disaster management, show a limited correlation with a few competencies. This weak relationship did not actually reflect the amount of the requirements that clients need to provide to use BIM effectively in these areas, which were identified within the literature. Therefore, the framework will only be able to demonstrate the relationship between BIM maturity competencies and BIM benefits for the remaining 14 BIM uses only, leaving these excluded seven uses for future research.

7.7.3 Final version of the conceptual assessment framework

Figure 7.30 shows the final version of the conceptual assessment framework that explains the relationship between BIM maturity competencies and BIM uses benefits. It can be seen that this framework has been validated to work on 14 instead of 21 BIM uses and this was due to the difficulties in identifying any convincing relationship between the excluded BIM uses and the BIM maturity competencies. In addition, it can be seen that the relationship has been classified into categories. The first is called 'significant relationship' and is represented by red arrows; this results from the significant correlation analysis results. The second category is the good relationships that are represented by blue arrows; this is also based on the results of the correlation analysis. Only the Existing Condition Modelling and Clash Detection BIM uses have been shown in the Figure as example of relationship visualisation. The other BIM uses' relationships with the maturity competencies will be presented in Appendix E. To enhance the UK client organisations' use of this framework and increase their chance of achieving the desired benefits of BIM and expand the research framework from theoretical to practical application, it is essential to provide a practical usage guide, which will simplify the framework implications for client organisations and make sure that client will follow the right steps to use this framework efficiently.

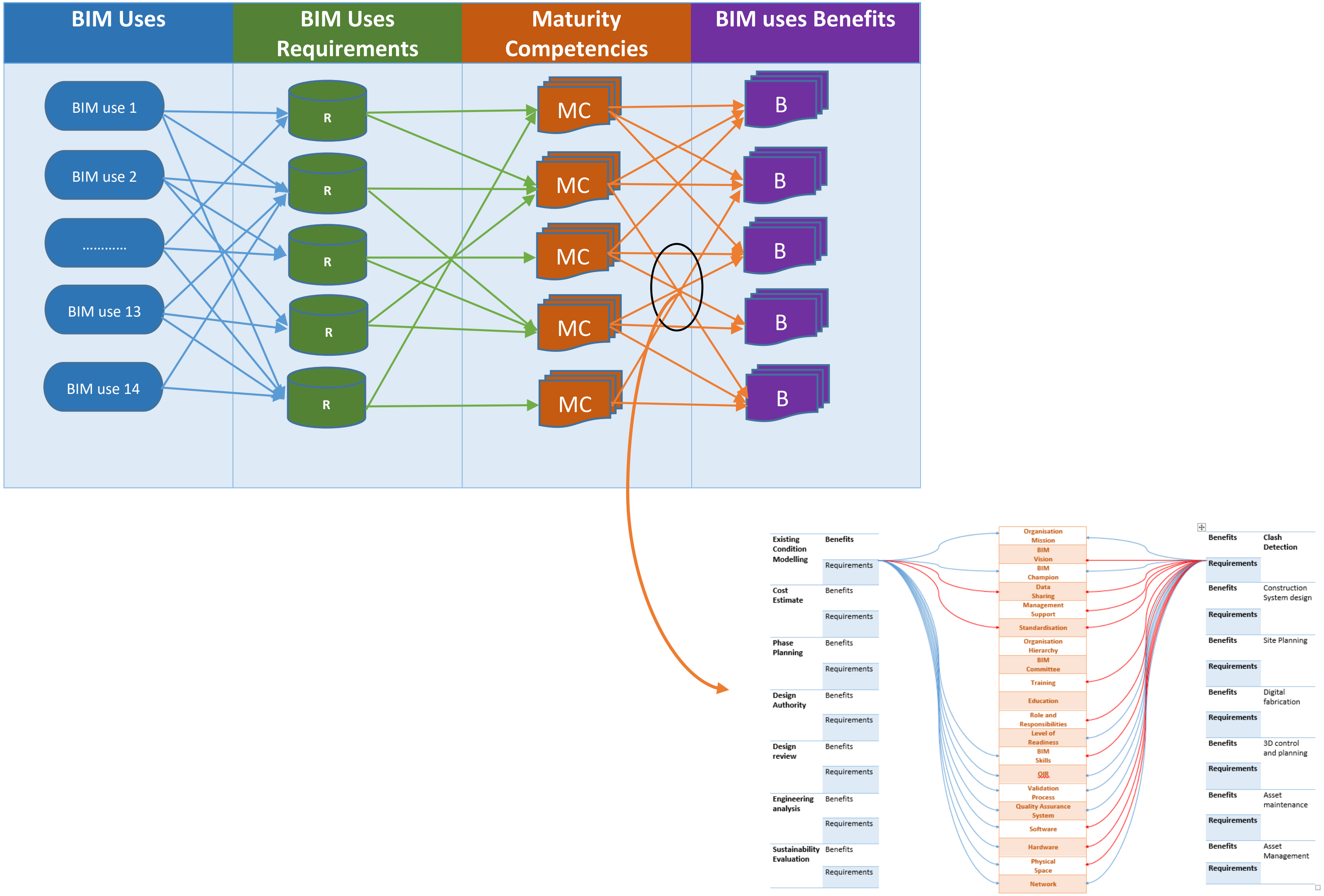

Figure 7.30: The final conceptual assessment framework

7.7.4 Testing final framework applicability

The aforementioned relationship between BIM maturity competencies and BIM uses benefits will be used to evaluate BIM implementation process for the six case studies that have been discussed in chapter six. For each case study, one BIM uses will be investigated to assess the relationship between BIM use benefits and maturity competencies.

1- Case study one

For this case study design review as a BIM use will be discussed in details. It can be seen from the table (7.89) that five competencies show significant correlation with this BIM use such as BIM vision, management support, role and responsibilities, software, and hardware. These competencies maturity levels range from three to five, which can be considered as recognisable improvement in these competencies. The desired benefits from using BIM in design review process also have been reached high level of assurance range from three to five except for benefit 6. This means that the correlated competencies have real impact on the benefits and it can be recommended that case study one is moving in the right direction in term of competencies improvement. Regarding benefits six, the situation can be explained because this benefit can also affected by another BIM uses such as clash detection.

Table 7.89: The relationship between BIM maturity competencies and BIM uses benefits for case study one.

No	Case study	BIM Uses	Correlated competencies from framework	Current maturity level from assessment.	Benefits	Current assurance level
1	National Public 1	Design review	BIM vision	4	Reduce the cost and time of design preview process.	3
			Management support	4	Improve real time during the checking process.	5
			Role and responsibilities	3	Increase the design review process efficiency.	3

			Software	3	Enhance the project safety plan.	4
			Hardware	5	Increase the communication and collaboration between the project stakeholders.	5
					Validate the component constructability.	2

2- Case study two

For this case study design review as a BIM use also will be discussed in details. It can be seen from the table (7.90) that five competencies show significant correlation with this BIM use such as BIM vision, management support, role and responsibilities, software, and hardware. These competencies maturity levels range from one to three, which can be considered as low improvement in these competencies. The desired benefits from using BIM in design review process also have been prevented to reach a high level of assurance, which currently range from two to three except for benefit. This means that the correlated competencies have real impact on the benefits and it can be recommended that case study two need to improve these particular competencies in order to improve their chance to achieve the desired benefits of BIM. Regarding benefits six, the situation can be explained because this benefit can also affected by another BIM uses such as clash detection.

Table 7.90: The relationship between BIM maturity competencies and BIM uses benefits for case study two.

No	Case study	BIM Uses	Correlated competencies from framework	Current maturity level from assessment.	Benefits	Current assurance level
1	National Public 2	Design review	BIM vision	3	Reduce the cost and time of design preview process.	3

			Management support	2	Improve real time during the checking process.	3
			Role and responsibilities	2	Increase the design review process efficiency.	3
			Software	1	Enhance the project safety plan.	3
			Hardware	1	Increase the communication and collaboration between the project stakeholders.	3
					Validate the component constructability.	2

3- Case study three

For this case study phase planning as a BIM use will be discussed in details. It can be seen from the table (7.91) that five competencies show significant correlation with this BIM use such as data sharing, level of readiness, physical space, software, network, and hardware. These competencies have been reached level four in maturity, which can be considered as a recognisable improvement in these competencies. The desired benefits from using BIM in phase planning process also have been reached high level of assurance range from three to five except for benefit 5. This means that the correlated competencies have real impact on the benefits and it can be recommended that case study three is moving in the right direction in term of competencies improvement. Regarding benefits five, the situation can be explained because this benefit can also affected by another BIM uses in construction and operation stages.

Table 7.91: The relationship between BIM maturity competencies and BIM uses benefits for case study three.

No	Case study	BIM Uses	Correlated competencies from framework	Current maturity level from assessment.	Benefits	Current assurance level
1	Local Public 1	Phase Planning	Data sharing	4	To produce a full understanding of the phasing schedule to all project stakeholders	5
			Level of readiness	4	To produce a dynamic project plan	3
			Software	4	The identification of a schedule, sequencing or phasing issues	3
			Hardware	4	A more readily constructible, operable and maintainable project	3
			Physical space	4	To monitor the procurement status of project materials	2
			Network	4	An increase in productivity and decrease in waste on job sites	3

					Exploring different design options and concepts	3

4- **Case study four**

For this case study phase planning as a BIM use will be discussed in details. It can be seen from the table (7.92) that five competencies show significant correlation with this BIM use such as data sharing, level of readiness, physical space, software, network, and hardware. These competencies maturity levels ranged from three to five, which can be considered as a recognisable improvement in these competencies. The desired benefits from using BIM in phase planning process also have been reached high level of assurance range from three to five also. This means that the correlated competencies have real impact on the benefits and it can be recommended that case study one is moving in the right direction in term of competencies improvement.

Table 7.92: The relationship between BIM maturity competencies and BIM uses benefits for case study four.

No	Case study	BIM Uses	Correlated competencies from framework	Current maturity level from assessment.	Benefits	Current assurance level
1	Private 1	Phase Planning	Data sharing	4	To produce a full understanding of the phasing schedule to all project stakeholders	5
			Level of readiness	3	To produce a dynamic project plan	3
			Software	5	The identification of a schedule,	5

					sequencing or phasing issues	
			Hardware	5	A more readily constructible, operable and maintainable project	5
			Physical space	5	To monitor the procurement status of project materials	3
			Network	3	An increase in productivity and decrease in waste on job sites	5
					Exploring different design options and concepts	3

5- **Case study five**

For this case study design review as a BIM use will be discussed in details. It can be seen from the table (7.93) that five competencies show significant correlation with this BIM use such as BIM vision, management support, role and responsibilities, software, and hardware. These competencies maturity levels range from one to four, which can be considered as not quite steady improvement in these competencies. The desired benefits from using BIM in design review process also have the variation in the level of assurance, which range from one to three. This means that the correlated competencies have real impact on the benefits and specially the technical competencies and it can be recommended that case study five need to improve theses competencies urgently.

Table 7.93: The relationship between BIM maturity competencies and BIM uses benefits for case study five.

No	Case study	BIM Uses	Correlated competencies from framework	Current maturity level from assessment.	Benefits	Current assurance level
1	Private 2	Design review	BIM vision	3	Reduce the cost and time of design preview process.	2
			Management support	4	Improve real time during the checking process.	2
			Role and responsibilities	3	Increase the design review process efficiency.	1
			Software	1	Enhance the project safety plan.	1
			Hardware	1	Increase the communication and collaboration between the project stakeholders.	3
					Validate the component constructability.	3

6- Case study six

For this case study design review as a BIM use will be discussed in details. It can be seen from the table (7.94) that five competencies show significant correlation with this BIM use such as BIM vision, management support, role and responsibilities, software, and hardware. These competencies maturity levels range from two to three, which can be considered as not quite considerable improvement in these competencies. The desired benefits from using BIM in design review process show different behavior in their level of assurance, which range from two to five. This means that the correlated competencies maturity limited improvement helped this client organisation to reach good level of benefits assurance.

Table 7.94: The relationship between BIM maturity competencies and BIM uses benefits for case study six.

No	Case study	BIM Uses	Correlated competencies from framework	Current maturity level from assessment.	Benefits	Current assurance level
1	Private 2	Design review	BIM vision	2	Reduce the cost and time of design preview process.	4
			Management support	2	Improve real time during the checking process.	5
			Role and responsibilities	2	Increase the design review process efficiency.	4
			Software	3	Enhance the project safety plan.	2
			Hardware	3	Increase the communication and collaboration between the project stakeholders.	3
					Validate the component constructability.	2

This step shows that the relationship between BIM maturity competencies and BIM uses benefits has practical implication throughout the aforementioned six case studies. In addition, it can be concluded that this relationship can be used by client organisation currently to identified the weakness and strengthen regarding BIM maturity development.

7.7.5 Framework practical implementation

Considering that using the research framework is not a straightforward step due to several information needed such as current BIM maturity status regarding different types of competencies and identifying the desired benefits of BIM. In addition, UK construction clients currently are suffering from lack of BIM understanding. Therefore, providing a framework without practical and simple guide will result in this framework will not receive the required attention commensurate with its importance. For all above reasons, providing a practical usage guide of the conceptual assessment framework is essential. This guide consists of four main stages which are matching the required information as follows (Figure 7.31):

1. **Assessment**

   As explained previously, a current BIM maturity statue is required. Therefore, client organisations will assess themselves against the BIM maturity assessment model in order to identify their current level of BIM maturity regarding different competencies. In addition, they need to assess themselves against the BIM uses and their corresponding benefits to identify which BIM uses are currently required to improve their business needs.

2. **Analysis**

   All assessment results will be used through the conceptual framework, using the relationship between BIM maturity competencies and BIM uses benefits. This step is important to identify the current weakness and strengths and help to optimise clients' efforts by focusing on only improving competencies that will increase client chance to achieve the desired benefits of BIM.

3. **Gap identification**

   At this stage, the gaps, in terms of the development of maturity competencies, will be identified. Several recommendations will be explained in order to improve the client organisation's BIM benefits achievement. These recommendations based on the relationship that has been establish in this research. In addition, these recommendations must consider the availability of clients' time and efforts in determining development priority.

4. **Improvement**

   The client organisation should proceed with the improvements based on the recommendations from stage 3. After the improvements have taken place, the cycle will start again when the client organisation needs to further assess themselves to evaluate their improvements.

Figure 7.31: The practical usage of the assessment conceptual framework

7.8 Summary

This chapter has accomplished one of the main objectives of the study, by holistically investigating the relationship between BIM maturity competencies and BIM uses benefits. In this chapter, the process of determining the relationship was discussed, and details about the data collection and analysis procedures for the internet survey instrument used in the validation process were described. The quantitative methods employed as part of this mixed method research were presented, and 65 validated responses from 26 client organisations were collected, analysed and discussed. The BIM uses showed different types of correlation with different BIM maturity competencies, which required client organisations to improve these competencies to access the BIM uses benefits. The final version of the framework and its practical uses were discussed in detail. In the next chapter the conclusions that can be drawn from the conduct of this research are presented.

Chapter 8: Conclusions, Research Contributions & Future Research

8.1 Introduction

Chapter Seven provided a discussion based on the results and data analysis which covering the validation process of the research framework. This chapter will conclude this study by presenting the synthesised outcomes in relation to the research aim and objectives. Accordingly, the findings for each objective of the study are provided and discussed. The novelty of this research and the contributions of this research concerning BIM maturity and benefits for UK construction clients are discussed. There is consensus within the scientific community that there are limitations with conducting any research (Saunders et al., 2009). The limitations associated with this research are presented in this chapter. Finally, future research that may be continued based on the findings of this research is discussed.

8.2 Synthesis on the objectives of the study

As specified in Chapter 1, this study explored the relationship between BIM maturity competencies and BIM uses benefits for the UK construction client; the rationale for this exploration was based on the importance of the study area and the gap identified from the literature review in Chapters 2 and 3. The aim of the study was examined through five research objectives. The first objective was to identify the importance of BIM for UK construction client organisations and for client roles in the BIM implementation process; this was achieved by way of a comprehensive literature review. The second objective was to identify the possible areas where BIM can be used and to investigate the corresponding benefits and requirements for each BIM use from the client perspective; this was also addressed through the literature review. The third objective was to establish a BIM organisation maturity assessment model which can be used to evaluate UK construction clients; this was achieved by way of a comprehensive literature review and supported by expert interviews. The fourth objective was to validate the proposed BIM maturity model and identify the relationship between client roles and the proposed BIM maturity competencies; these were addressed via the case study findings and supported by the literature review and expert opinions. The fifth objective was to establish, validate, and produce a final assessment conceptual framework to explain the relationship between BIM maturity competencies and BIM uses benefits from the perspective of UK construction clients; this was objectively validated using an online questionnaire, supported by expert opinion and the literature review. The following sections will summarise and present the key findings related to each objective.

- **Objective 1: Identify the importance of BIM for the UK construction clients and client roles in BIM implementation process.**

  The first objective of the study needed to develop a coherent, comprehensive understanding regarding BIM implementation within client organisations. This objective was met through the literature review, which provided direction in setting the major determinants for investigation through the study; for example, the UK construction industry current challenges and trends, BIM definition, BIM for client organisations, BIM implementation in the UK construction industry, and clients' roles in the BIM implementation process. This review helped to identify the knowledge gap, and this led to the selection of the study sample which is UK construction clients, and the identification of the synthesised research area. This, in turn, helped to develop a guiding framework for the conduct of the study.

  The knowledge gap was identified as despite clients, in particular, can significantly benefit by adopting BIM as a process and tool to guide their delivery process to higher quality and performance for a whole asset life cycle, there is a lack of clarification regarding BIM benefits from a client's perspective, and the required development in which UK construction clients need to invest to increase their opportunity of achieving the desired benefits of BIM. In addition, there is no clear definition regarding clients' roles in the BIM implementation process and what clients have to do to fulfil their roles. Therefore, the sample population for this study was client organisations, including all types of client, namely public, private, and mixed.

  Following the same client role classifications, which have been derived from literature, clients' roles in the BIM implementation process can also be classified into two main categories; developing EIR and information validation. The capabilities of clients to fulfil these two roles highlights the extent of their readiness to lead a BIM implementation process within the construction industry; this readiness is considered essential in optimising the desired benefits of BIM. Despite several studies which focus on the importance of client leadership, there is a lack of research into BIM leadership characteristics in terms of the particular competencies and proficiencies that clients need in order to lead a BIM implementation process throughout a supply chain.

- **Objective 2: Identify the possible area where BIM can be used and investigate the corresponding benefits and requirements for each BIM uses from the clients' perspective.**

  This Second objective was satisfied by an extensive literature review of the areas in which BIM could be used throughout project lifecycle (Chapter 2) to explore the potential requirements and benefits from the client's perspective. The literature covered issues related to BIM uses benefits for client organisations and the requirements that clients need to provide to use BIM in their projects effectively. The literature revealed that benefits are considered the direct outcomes from using BIM in the different areas across the project lifecycle. Selecting areas where BIM should be used in order to achieve the desired benefits represents a challenging task to the client organisation. This task requires knowledge regarding each BIM use and knowledge of the requirements that a client needs to provide in order to use BIM in particular areas. In total, 21 areas were identified through the literature which could be used and that produce different types of benefits for the client organisation. Some of these areas are fit for particular stages of the project lifecycle such as design analysis while others extend to cover several stages such as cost estimate. In addition, the literature reveals that using BIM in different areas across the project lifecycle needs a set of requirements to ensure that it runs effectively and thus ensure the desired benefits are achieved. The failure to fully provide these requirements will reflect directly on the benefits of the use. The BIM uses requirements are not constant but rely entirely on the user. Therefore, different types of requirements that the client needs to provide to be able to use BIM in different areas across the project lifecycle have been identified. Identifying these requirements will help clients to understand what they have to provide to use BIM effectively in different areas. However, the requirements are generic and the link between providing these requirements and the client's roles in the BIM implementation process is absent. For instance, one of the common requirements is that, 'client staff are able to manipulate navigate, and review a 3D model. 'However, it is unclear as to how meeting this requirement can help clients to fulfil their role in building their EIR, or their validation process which may help to lead their BIM implementation process. In addition, in terms of excellence, it is unclear as to what level clients must have to provide this requirement to achieve the desired benefits. Furthermore, providing these requirements and their implications for BIM benefits are still generic and without any valuable relationship.

- **Objective 3: Establish a BIM organisation maturity assessment model which can be used to evaluate UK construction clients.**

  This objective was addressed by undertaking an extensive review regarding the areas of BIM maturity, BIM competency, and client organisations in order to establish a BIM maturity model which can be used to evaluate UK construction clients regarding BIM implementation process. The literature reveals that the terms competency and maturity have been used previously to manage and assess different types of innovation in the construction industry, and these terms can be used to assess BIM implementation across the UK construction industry. Therefore, to implement BIM in a construction project successfully, all project participants, as BIM users, must have minimum BIM capabilities to show their (cap)ability to use BIM efficiently. BIM maturity assessment models have been development and used for self-assessment and to assess project stakeholders against the BIM capabilities levels in terms of excellence. In addition, several maturity assessment models have been identified to assess different types of BIM user against BIM implementations; however, only a few can be used to assess client organisations in particular.

  Moreover, it has been found that the Succar (2009) and CIC (2012) models have the potential to assess client organisation in the UK due to the clarity in their evaluation methodologies which are explained in detail for each model in order to provide a full understanding of the BIM competencies and maturity levels. In addition, these two models can be used to assess a client organisation against a BIM implementation as they consider the client organisation in their assessment methodology. Nineteen competencies were selected to represent client proficiency in BIM implementation due to their suitability to support client organisations in BIM implementation process. A BIM maturity model has been established based on these selected competencies. The proposed BIM maturity assessment model has been evaluated by experts through a pilot study, and as an initial validation step. Throughout this validation step few amendments have been done on the proposed maturity model. These amendments based on changing the proposed maturity levels descriptions and exclude BEP from selected competencies because this competency is not related to client organisation and have been replaced by new competency called validation process.

- **Objective 4: Validating the proposed BIM maturity model and identify the relationship between client roles and the proposed BIM maturity competencies.**

  A set of critical success competencies has been identified through the qualitative data collection and analysis to support client organisations to fulfil their roles from developing their EIR, validating information to finally leading a BIM implementation process. Six case studies and 15 interviews involving different types of clients, such as public (national and local), private (retailers and estates), and mixed (universities) have been consulted to establish the relationship between client organisation roles and BIM maturity competencies.

  From the qualitative data analysis and discussion, it has been found that the proposed BIM maturity model is suitable for assessing UK construction client organisations against BIM implementation processes. All the proposed competencies except organisation hierarchy have been identified by participated client organisations as essential competencies which are supporting them to fulfil their roles as client. In addition, it can be concluded that, reaching client BIM objectives does not necessarily mean that clients must improve all BIM competencies as the previous maturity model suggested. Instead, it mainly depends on client business needs, which identify the required competencies and the level of improvement that may help the client to achieve their desired benefits. In addition, it was found that some clients choose the same competencies for different roles, which means that the client is aware that improving the maturity of these competencies will help them to improve their BIM ability and move beyond just developing EIR to validating the information; alternatively, it may will help them to lead a BIM implementation process. In addition, the differences in selecting the required competencies to perform a validation role reflect that each client has different needs that can be met by improving different types of competency. However, it can summaries the relationship between client roles and BIM maturity competencies in three main areas. Firstly, Client organisations need to invest in certain competencies to improve the ability to establish their EIR such as BIM vision, BIM skills, standards, and data sharing. Secondly, Client organisations have to improve some certain competencies to increase their ability to validate BIM model such as BIM champion, data protection, and BIM technology. Finally, improving Organisation Information Requirement (OIR) competency inside client organisations will support improve their efficiency to lead BIM implementation process. Therefore, to avoid investing in the development of unnecessary competencies, it is important to establish a relationship between maturity competencies and BIM uses benefits. This will enable clients to improve only those competencies that can produce value for their business.

- **Objective 5: Establish, validate and produce a final assessment framework to explain the relationship between BIM maturity competencies and BIM uses benefits from the UK construction clients' perspective.**

  Finally, the initial relationship between BIM uses benefits and BIM maturity competencies was established by linking the identified BIM uses requirements with the BIM maturity competencies to find out is it possible to the related competencies from requirements understanding only. The quantitative data collection, which was conducted via an online questionnaire, and the subsequent descriptive and inferential analyses, have been used to validate the relationship between BIM maturity competencies and BIM uses benefits. The descriptive analysis has been used to measures of central tendency and measures of variability, or spread. The inferential analysis has been used to explore the relationship between BIM maturity competencies and BIM uses benefits via Spearman's correlation analysis.

  Twenty-one BIM uses and benefits were presented alongside their correlation with BIM maturity competencies. It has been found that each BIM use requires the client to improve certain competencies in order to accurately predict the desired benefits. Some of these BIM uses have a significant correlation with certain competencies, which can greatly affect the client's ability to use BIM in particular areas and achieve the desired benefits. Moreover, if client organisations have a limited time and budget for development they can use a correlation ranking to decide which competency they need to develop first. Furthermore, it can be seen that BIM vision, management support, data sharing, training, BIM skills and technical competencies are the most frequent competencies that show a significant correlation with the BIM uses. This means that these competencies in particular, can be considered a baseline for any BIM maturity development plan, which means that client organisations should develop these competencies as the first step in their BIM implementation process.

  The schematic representation of the BIM maturity competencies-BIM uses benefits assessment relationship framework for UK construction clients has been presented and discussed in detail. Only fourteen BIM uses have been found they have a relationship with BIM maturity competencies. The other seven BIM only show low or no relationship with BIM maturity competencies. However, BIM vision, management support, data sharing, training, BIM skills and technical competencies are the most frequent competencies that show a significant correlation with the BIM uses. The aforementioned competencies can be considered as core competencies for client organisations and improving them will increase their chances to achieve the dersired benefits of BIM. A usage guide has been established to simplify the usage of the research framework and prevent any misunderstanding. Providing such a framework will support client organisations to identify the critical success competencies that they need to improve in order to increase their chance of achieving the desired benefits of BIM implementation.

8.3 Contribution to knowledge

The main contributions of this study, as they relate to academic research and practice in the UK construction industry, are presented in this section.

8.3.1 Academic contribution

The value of this research is associated with the extent to which it contributes to academia and will be demonstrated in the following sub-sections:

1. **Identification of the critical success BIM maturity competencies for the UK construction clients.**

   This research contributes to academia by providing a validated set of critical success BIM maturity competencies for UK construction clients. This is the first list of its kind, which has also summarised the competencies that UK client organisations need to invest in for their development; these will allow them to gather a suitable level of knowledge and understanding to use BIM effectively.

2. **Identification of the relationship between client organisations' roles and the critical success BIM maturity competencies.**

   Clients can play a vital role in the BIM implementation process within the construction industry. It is crucial that clients understand their roles in the BIM implementation process so they are able to request and issue the right information, at the right time and to the right level of quality. This research contributes to academic knowledge by identifying client roles in the BIM implementation process and by connecting them with the BIM maturity competencies. This will enhance the importance of the BIM maturity competencies within BIM implementation from a clients' perspective. In addition, it will help client organisations evaluate their ability to fulfill their roles by assessing the related competencies.

3. **Identification of the relationship between BIM uses benefits and the critical success BIM maturity competencies.**

   This research contributes to academic knowledge by producing a validated framework that explains the relationship between BIM maturity competencies and BIM uses benefits. This relationship is crucial to client organisations in helping them guide their development to increase their chance of achieving the desired benefits of BIM instead of wasting time and effort by investing in unnecessary improvements.

8.3.2 Practice contribution

This research contributes to practice in providing a conceptual assessment framework that explains the relationship between BIM maturity competencies and BIM uses benefits. This framework has a vital role in helping UK construction clients to improve their BIM knowledge and understanding by clarifying all the required improvement that client organisation need to develop in order to increase their opportunity to achieve the desired benefits of BIM. In addition, this research provides a usage guide of the conceptual framework to simplify the practical use of the framework. This practical usage guide consists of four main stages, which are assessment, analysis, gap identification, and improvement. These stages are formulated in a continuous circle that allows for ongoing monitoring and development by the client organisation.

8.4 Limitations of the study

Throughout the study, attention was paid to increase the acceptability of the research findings; hence a number of measures were taken to increase reliability, validity and credibility of the study. The study followed a rigorous research process while increasing the depth of the study through various measures, such as the use of multiple data collection methods, considering different perspectives regarding the same research issue, and collecting the data at different time periods. Thus, this study implemented a cross-section case study approach with six different types of organisations that were selected to reflect an appropriate range of UK construction clients. However, due to the PhD's timescale limitations, the researcher was unable to include other types of client, such as state clients, or include client organisations' sizes as one of the factors that affects BIM implementation.

Due to lack of UK clients who implement BIM in their organisations and extend their implementation after design and construction, this study was limited by the number of online survey responders which only generated 65 responses from 26 organisations. In addition, the researcher was not able to establish a relationship between some BIM uses in the operation and maintenance stages due to the lack of information from responders involved in these stages.

The framework was validated using an online questionnaire of UK construction clients' participants. The online survey approach also has its drawbacks since it is difficult to get a high response rate and also have a representative sample (Wright, 2005). Online questionnaire also propose that respondents are paying careful attention to the words when answering the survey questions and as such it cannot be assured that it is in fact true. Questionnaire respondents may also be under the impression of doing a favour to researcher and may provide what they perceive to be the answers the researcher is expecting (Wyse, 2012). The data collected in the qualitative and quantitative stages of the research represents a snapshot view of the participants' opinions regarding the issues identified in this thesis. It is impossible to predict how these opinions might vary in longitudinal study of using the framework on a certain client. It is unknown how the results might vary if a higher number of construction professionals had participated in this study.

8.5 Future research

In view of the contribution to knowledge and the limitations of this study, future research could aim to address the limitations mentioned and build on the findings to understand what it means to attain a higher level of maturity in implementing BIM. A number of research directions can be highlighted, as follows:

1. Future studies could be carried out by including other types of client organisations with two participate organisations for each type at least to be able to establish a sufficient comparative study to examine client types' effects on the BIM implementation process. This comparative study will help to identify the business needs effects on the BIM implementation process in terms of benefits and critical success BIM competencies.
2. Establish Key Performance Indicators (KPIs) in terms of BIM maturity improvements. This can be done by transfer the benefits in to measurable business improvements.

These KPIs would help client organisations to monitor and benchmark their maturity improvement with regards to business benefits.

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Appendix A

NO	BIM uses	Benefits	Sources
1	Existing condition modelling	1. Increase the efficiency and accuracy of existing conditions documentation and representation. 2. Help in future modelling and 3D design coordination. 3. Provides an accurate representation and visualisation of work that has been put into place. 4. Real-time quantity verification for accounting cost estimation purposes. 5. Disaster Planning. 6. Time Saving Utility Design.	1. (John M. Russo, 2012) 2. (Wang, 2011) 3. (Yusuf Arayici and Hamilton, 2005) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
2	Cost Estimate	1. Accurate estimate material quantities and generate real-time revisions if needed. 2. Stay within budget constraints while the design progresses 3. Better visualisation for project element that must be estimated. 4. Provide accurate cost information to project stakeholders will help to enhance the decision-making process. 5. Focus on more value adding activities in estimating (identifying construction assemblies, generating pricing and factoring risks) which are essential for high-quality estimates 6. Exploring different design options and concepts within the owner's budget 7. Saving estimate process time and allowing the project team to focus on more important issues which may increase project quality.	1. (BuildLACCD, 2009) 2. (UK BIM Standarded, 2012) 3. (Pennanen et al., 2011) 4. (Sabol, 2008c) 5. (Sabol, 2008b) 6. (Construction, 2012) 7. (Penn State, 2012) 8. (Becerik-Gerber et al., 2012) 9. (UK BIM Standarded, 2012) 10. (Smart market Report 2012) 11. (Reddy, 2012) 12. (Eastman, 2011)
3	Phase Planning	1. Produce full understanding of the phasing schedule to all project stakeholders. 2. Produce dynamic project plan which will be affected by any change	1. (Sulankivi et al., 2010) 2. (J. Zhang and Hu, 2011) 3. (**V. K. Saini, Mhaske, Sumedh**, 2013) 4. (Godawa, 2012) 5. (Construction, 2012) 6. (Penn State, 2012)

NO	BIM uses	Benefits	Sources
		happened in the project during any phase through project life cycle. 3. Identification of schedule, sequencing or phasing issues 4. More readily constructible, operable and maintainable project 5. Monitor procurement status of project materials 6. Increased productivity and decreased waste on job sites by creating optimum project construction plan. 7. Exploring different design options and concepts within the owner's expected handover time.	7. (Becerik-Gerber et al., 2012) 8. (UK BIM Standarded, 2012) 9. (Smart market Report 2012) 10. (Reddy, 2012) 11. (Eastman, 2011)
4	Design Authority	1. Provide real and accurate information for all project stakeholders. 2. The powerful visualisation tool in this application will help to speed up the decision-making process. 3. Efficient collaboration between project stakeholders. 4. Improved quality control and assurance systems.	1. (Atherton, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012) 7. (Eastman, 2011)
5	Design review	1. Reduce the cost and time were spent on checking process. 2. The stakeholder feedbacks, a client in particular could be considered in real time during the checking process. 3. Increase the design review process efficiency. 4. Enhance the project safety plan. 5. Increase the communication and collaboration between the project stakeholders. 6. Validate the component constructability.	1. (Sullivan, 2007) 2. (Campbell, 2012) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012) 8. (Reddy, 2012) 9. (Eastman, 2011)

NO	BIM uses	Benefits	Sources
6	Engineering analysis	1. Saving time and cost due to the automation of the analysis process. 2. This application will help to increase the accuracy and efficiency of the outcomes. 3. The ability to produce different design solution. 4. Reduce the design stage period with high-quality outcomes.	1. (Kulkarni, 2007) 2. (Wyatt, 2007) 3. (J. Harty and Laing, 2010) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
7	Energy analysis	1. Save time and costs due to the automation in obtaining building and system information from BIM model. 2. Improve the accuracy of energy analysis outcomes. 3. Auto checking through codes. 4. Display different energy scenario in order to produce the optimum energy saving and reduce the cost in general.	1. (Jenicek et al., 2011) 2. (Council, 2003) 3. (Krygiel and Nies, 2008) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
8	Lighting analysis	1. Save time and cost in order to provide additional models. 2. Improve the accuracy of energy analysis outcomes. 3. Display different energy scenario in order to produce the optimum light energy saving and reduce the cost in general. 4. Improve the quality of the design outcomes. 5. Reduce the cycle time of the design stage.	1. (Jamnický, 2014) 2. (Azhar et al., 2009) 3. (Aksamija, 2012) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
9	Sustainability Evaluation	1. Provide good evaluation in early design stage will increase the efficiency of the project and reduce cost and time.	• (Krygiel and Nies, 2008) 1. (Azhar et al., 2011) 2. (Dowsett and Harty, 2012)

NO	BIM uses	Benefits	Sources
		2. The speed and access of information help to review many of the alternatives at a specific time. 3. Improve the project quality. 4. Reduces documentation load after design and accelerates certification because concurrently prepared calculations can be used for verification. 5. It optimised building performance via improved energy management. 6. Add more attention on the environmentally friendly and sustainable design. 7. Provide valuable information for future use.	3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012) 8. (Reddy, 2012) 9. (Eastman, 2011)
10	Code Validation	1. Checking the building design against specific codes. 2. Reduce the errors and omissions due to early code checking. 3. The automation process in code checking will give the team to focus on more important issues. 4. Saves time on multiple checking for code compliance and allows for a more efficient design process since mistakes cost time and money.	1. (Wix et al., 2008) (Wix, Nisbet, & Liebich, 2008) (Wix et al., 2008) 2. (S. Zhang, Teizer, Lee, Eastman, & Venugopal, 2013) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (A. A. Becerik-Gerber, Burcin et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012) 8. (Reddy, 2012)
11	3D Coordination	1. Coordinate building project through a model 2. Reduce the requests for information (RFI) in the construction stage. 3. Increase productivity for the project in general. 4. Reduce budget cost. 5. Improve and step up the construction process. 6. Increase the as-built model accuracy.	1. (Grilo and Jardim-Goncalves, 2010)Singh (2011) 2. (Singh et al., 2011) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012)

NO	BIM uses	Benefits	Sources
			7. (Smart market Report 2012) 8. (Reddy, 2012) 9. (Eastman, 2011)
12	Construction System Design (Virtual Mockup)	1. Increase constructability and safety of a complex building system. 2. Increase productivity at the construction stage. 3. Increase safety awareness of a complex building system 4. Improve the collaboration between project stakeholders. 5. Reduce the change order in the construction stage. 6. Improve cost estimation and time scheduling.	1. (Maing, 2012a) 2. (Filkins, 2012) 3. (Maing, 2012b) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
13	Site analysis	1. Enhance the decision-making process through providing all the require information that may need it to choose the suitable site for the project. 2. Decrease costs of all additional work may need it to prepare the site before stat the project. 3. Increase energy efficiency. 4. Increase safety.	1. (X. Zhang et al., 2009) 2. (Middlebrooks, 2008) 3. (Wang, 2011) 4. (Azhar et al., 2011) 5. (Construction, 2012) 6. (Penn State, 2012) 7. (Becerik-Gerber et al., 2012)
14	Digital Fabrication	1. Increase the information quality. 2. Improve the design outcomes. 3. Increase fabrication productivity and safety.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012) 7. (Eastman, 2011) 8. (Hergunsel, 2011)

NO	BIM uses	Benefits	Sources
15	3D Control and Planning (Digital Layout)	1. Improve the information accuracy. 2. Increase efficiency and productivity at construction stage. 3. Reduce rework. 4. Improve the collaboration between project stakeholders.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012)
16	Record Modelling	1. Help in future operation and maintenance. 2. Improve the accuracy and availability of information for future use. 3. Minimize dispute between project stakeholders. 4. Provide owner with an accurate model of building, equipment, and spaces within a building to create possible synergies with other BIM Uses. 5. Minimise building turnover information and required storage space for this information. 6. Easily assess client requirement data such as room areas or environmental performance to as-designed, as-built or as performing data.	1. (Gelder, 2013) 2. (Sabol, 2008a) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012) 8. (Reddy, 2012) 9. (Eastman, 2011) 10. (Hergunsel, 2011)
17	Asset (Preventative) Maintenance Scheduling	1. Help to adapt a proactively maintenance plan. 2. Optimum maintenance staff distribution. 3. Record and track maintenance history. 4. Reduce the unexpected maintenance. 5. Selection the cost effective maintenance approach.	1. (Akcamete et al., 2010) 2. (X. Zhang et al., 2009) 3. (Hedges, 2007) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011) 11. (Hergunsel, 2011)

NO	BIM uses	Benefits	Sources
18	Asset Systems Analysis	1. Make sure that the building is operating according to the specified standards. 2. Help to identify opportunities to modify system operations to improve the overall building performance. 3. Develop different scenarios to improve building performance.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012) 7. (Eastman, 2011) 8. (Hergunsel, 2011)
19	Asset Management	1. Provide quick access to the operations, maintenance owner user manuals, and equipment specifications. 2. Provide real-time information about the facility performance and equipment condition. 3. Produce accurate quantity take-offs for different future use. 4. Update the existing record model.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012) 7. (Eastman, 2011)
20	Space Management and Tracking	1. Time and cost saving process in identify and allocate space for appropriate building use. 2. Increase the efficiency of transition planning and management 3. Provide accurate information about tracking the use of current space and resources. 4. Help in the planning process for future space needs in the facility.	1. (FM System, 2013) 2. (L. BIM, 2012) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012)
21	Disaster Management	1. Provide real-time accurate information about any emergency event for a different type of responders like police, fire, and public safety officials. 2. Improve the effectiveness of emergency response. 3. Minimize risks to responders.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (Smart market Report 2012) 5. (Hergunsel, 2011)

Appendix B

NO	BIM uses	Descriptions	Requirements	Sources
1	Existing condition modelling	This application helps the project team to create the 3D model contain the entire external environment which surrounded the proposed project.	1. The staff are able to manipulate navigate, and review a 3D model. 2. Familiarity with Building Information Model authoring tools. 3. The familiarity with 3D laser scanning tools. 4. The familiarity with conventional surveying tools and equipment. 5. Ability to determine what is the optimum level of detail which may able to add "value" to the project. 6. Ability to select the appropriate software to create the site linked BIM model.	1. (John M. Russo, 2012) 2. (Wang, 2011) 3. (Yusuf Arayici and Hamilton, 2005) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
2	Cost Estimate	This application will help to produce accurate quantity take-off and cost estimate through all project life cycle stages. The cost effect due to any changes can be seen directly from this application.	1. Quality assurance system to check design deliverables. 2. Roles and responsibilities. 3. Level of development (LOD) 4. Collaboration 5. Ability to define specific design modelling deliverables.	1. (BuildLACCD, 2009) 2. (UK BIM Standarded, 2012) 3. (Pennanen et al., 2011) 4. (Sabol, 2008c) 5. (Sabol, 2008b) 6. (Construction, 2012) 7. (Penn State, 2012) 8. (Becerik-Gerber et al., 2012) 9. (UK BIM Standarded, 2012) 10. (Smart market Report 2012) 11. (Reddy, 2012)

NO	BIM uses	Descriptions	Requirements	Sources
				12. (Eastman, 2011)
3	Phase Planning	This application will add the 4D (Time) to 3D model. Effective and accurate project process planning by using this application help the project stakeholders to fully understanding the project consequences.	1. Project planning team must be familiar with construction project scheduling and general construction process. 2. Project planning team are able to manipulate navigate, and review a 3D model and all 4D software. 3. Hardware and all 4D software.	1. (Sulankivi et al., 2010) 2. (J. Zhang and Hu, 2011) 3. (V. K. Saini, Mhaske, Sumedh, 2013) 4. (Godawa, 2012) 5. (Construction, 2012) 6. (Penn State, 2012) 7. (Becerik-Gerber et al., 2012) 8. (UK BIM Standarded, 2012) 9. (Smart market Report 2012) 10. (Reddy, 2012) 11. (Eastman, 2011)
4	Design Authority	By this application, the modeller can create the 3D model of the project according to the client criteria and requirements.	1. The staff are able to manipulate navigate, and review a 3D model. 2. The staff have good experience in design and construction means and methods. 3. Quality assurance program to check the design deliverables. 4. Collaboration between the project stakeholders. 5. Hardware and software have the ability to	1. (Atherton, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012) 7. (Eastman, 2011)

NO	BIM uses	Descriptions	Requirements	Sources
			support all above requirements.	
5	Design review	By using this application, the project stakeholders can provide their comments and feedback on the 3D model for the project.	1. The staff are able to manipulate navigate, and review a 3D model. 2. Team roles and responsibilities. 3. The reviewer must have a good understanding of the integration between building systems. 4. Hardware and software have the ability to support all above requirements.	1. (Sullivan, 2007) 2. (Campbell, 2012) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012) 8. (Reddy, 2012) 9. (Eastman, 2011)
6	Engineering analysis	A process in which intelligent modelling software uses the BIM model to determine the most effective engineering method based on design specifications.	1. The staff are able to manipulate navigate, and review a 3D model. 2. The staff are able to assess a model through engineering analysis tools. 3. Knowledge of construction means and methods. 4. Design and construction experience. 5. Code checking.	1. (Kulkarni, 2007) 2. (Wyatt, 2007) 3. (J. Harty and Laing, 2010) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) (Eastman, 2011)
7	Energy analysis	This application represents a	1. The staff must have at least basic knowledge about building energy	1. (Jenicek et al., 2011)

NO	BIM uses	Descriptions	Requirements	Sources
		process of exploring different energy saving alternatives in early design using 3Dmodel/BIM technology.	systems and its standards. 2. The staff have a knowledge and experience about building system design in general. 3. The staff are able to manipulate navigate, and review a 3D model. 4. The staff are able to check a model through engineering analysis tools. 5. Software and hardware (for read and store data or may be some time to check the design result). 6. Collaboration between the project stakeholders. 7. Team roles and responsibilities. 8. Level of details. 9. Quality assurance system to check the design deliverables. 10. Model breakdown element for project use. 11. Codes and standards.	2. (Council, 2003) 3. (Krygiel and Nies, 2008) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) (Eastman, 2011)
8	Lighting analysis	Lighting analysis Application and rendering tools can help to simulate lighting and daylighting in the building. Both quantitative and qualitative analyses are important.	1. The staff are able to manipulate navigate, and review a 3D Lighting Model 2. The staff are able to assess a model through engineering analysis tools 3. The staff must have at least basic lighting expertise. 4. The level of details.	1. (Jamnický, 2014) 2. (Azhar et al., 2009) 3. (Aksamija, 2012) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012)

NO	BIM uses	Descriptions	Requirements	Sources
				8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
9	Sustainability Evaluation	This application can evaluate the complex building performance analyses to ensure an optimised sustainable building design.	1. The staff is able to manipulate navigate, and review a 3D model. 2. The staff must have knowledge about the most updating sustainability checking systems. 3. The staff is able to organise and manage the database. 4. The required software and hardware.	1. (Krygiel and Nies, 2008) 2. (Azhar et al., 2011) 3. (Dowsett and Harty, 2012) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
10	Code Validation	This application will assists with validating code compliance by automatically checking building codes.	1. Collaboration between the project stakeholders. 2. Quality Assurance to check design deliverables. 3. Standards. 4. Suitable software and hardware. 5. Teams roles and responsibilities. 6. The team are able to use code validation software and previous knowledge and experience with checking codes is needed.	1. (Wix et al., 2008) (Wix et al., 2008) 2. (S. Zhang et al., 2013) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012)

NO	BIM uses	Descriptions	Requirements	Sources
				7. (Smart market Report 2012) 8. (Reddy, 2012)
11	3D Coordination	A process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems.	1. Suitable software and hardware. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff have at least basic knowledge about BIM model applications for facility updates. 4. The staff have at least a basic knowledge of building systems. 5. Collaboration between the project stakeholders. 6. The level of Details.	1. (Grilo and Jardim-Goncalves, 2010)Singh (2011) 2. (Singh et al., 2011) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012) 8. (Reddy, 2012) 9. (Eastman, 2011)
12	Construction System Design (Virtual Mockup)	This application can represent the proposed design and is usually built before the design is	1. Suitable software and hardware. 2. The staff are able to manipulate navigate, and review a 3D model.	1. (Maing, 2012a) 2. (Filkins, 2012) 3. (Maing, 2012b) 4. (Construction, 2012)

NO	BIM uses	Descriptions	Requirements	Sources
		completed in order to study proposed construction details, test for performance, and clarify the appearance of the final structure.	3. The staff are able to make appropriate construction decisions supported by a 3D System Design Software. 4. The staff have at least a basic knowledge of construction practices for each component.	5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011)
13	Site analysis	This application can be used to simulate all the existing facilities during different project phase in order to optimise the project construction process.	1. The staff are able to manipulate navigate, and review a 3D model. 2. The familiarity of local authority's system (GIS, database information). 3. Suitable software and hardware.	1. (X. Zhang et al., 2009) 2. (Middlebrooks, 2008) 3. (Wang, 2011) 4. (Azhar et al., 2011) 5. (Construction, 2012) 6. (Penn State, 2012) 7. (Becerik-Gerber et al., 2012)
14	Digital Fabrication	This application is enabling digital design-to-fabrication workflows for all of the building disciplines, including the use of structural building information models for the digital fabrication of structural steel.	1. Suitable software and hardware. 2. The staff are able to understand the fabrication models methods. 3. The staff are able to manipulate navigate, and review a 3D model. 4. Ability to extract digital information for fabrication from 3D models. 5. The level of details.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012) 7. (Eastman, 2011)

NO	BIM uses	Descriptions	Requirements	Sources
				8. (The U.S. Department of Veterans Affairs (VA) Office of Construction & Facilities Management (CFM), 2010) 9. (Hergunsel, 2011)
15	3D Control and Planning (Digital Layout)	An application that utilises information model to layout facility assemblies or automates control of equipment's movement and location.	1. Suitable software, hardware and equipment. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff are able to interpret if model data is appropriate for layout and equipment control.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012)
16	Record Modelling	The model includes the integration of the as-built from the Sub-contractors. Furthermore, each object property in the model can also include links to submittals, operations and maintenance, and warranty information.	1. The staff are able to manipulate navigate, and review a 3D model. 2. The staff are able to use BIM modelling application to update building information. 3. The staff have at least basic knowledge about building operation and ambience in order to check the input information. 4. Effective collaboration between the project stakeholders.	1. (Gelder, 2013) 2. (Sabol, 2008a) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012) 8. (Reddy, 2012) 9. (Eastman, 2011) 10. (Hergunsel, 2011)

NO	BIM uses	Descriptions	Requirements	Sources
			5. Suitable software, hardware and equipment. 6. The level of Details. 7. Quality Assurance system.	
17	Asset (Preventative) Maintenance Scheduling	This application used to check the functionality of the building components. And produce a real-time information about the maintenance dates.	1. Suitable software and hardware like Building Automation System (BAS) and Computerized Maintenance Management System (CMMS) , this software need to be connected to the record model 2. The staff are able to understand all the required software, hardware and typical equipment. 3. The staff are able to manipulate navigate, and review a 3D model. 4. Quality Assurance system.	1. (Akcamete et al., 2010) 2. (X. Zhang et al., 2009) 3. (Hedges, 2007) 4. (Construction, 2012) 5. (Penn State, 2012) 6. (Becerik-Gerber et al., 2012) 7. (UK BIM Standarded, 2012) 8. (Smart market Report 2012) 9. (Reddy, 2012) 10. (Eastman, 2011) 11. (Hergunsel, 2011)
18	Asset Systems Analysis	This Application will measure the existing building's performance and compare it with specified design.	1. Suitable software and hardware. 2. The staff have at least basic knowledge about CMMS and building control systems with Record Model 3. The staff are able to understand typical equipment operation and maintenance practices 4. The staff are able to manipulate navigate, and review a 3D model.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012)

NO	BIM uses	Descriptions	Requirements	Sources
			5. Quality Assurance system.	7. (Eastman, 2011) 8. (Hergunsel, 2011)
19	Asset Management	An application in which BIM is utilised to effectively distribute, manages, and track appropriate spaces and related resources within a facility.	1. Suitable software and hardware. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff are able to manipulate an asset management system 4. The staff have at least basic information about building operation system. 5. Quality Assurance system.	1. (Construction, 2012) 2. (Penn State, 2012) 3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012) 7. (Eastman, 2011)
20	Space Management and Tracking	This application is managing the real-time information about the spaces in the building.	1. Suitable software and hardware. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff are able to check current space and manage appropriately for future needs. 4. The staff have at least basic knowledge about facility management. 5. The staff are able to integrate the record model with facility management applications in order to update the final record model. 6. Quality Assurance system.	1. (FM System, 2013) 2. (L. BIM, 2012) 3. (Construction, 2012) 4. (Penn State, 2012) 5. (Becerik-Gerber et al., 2012) 6. (UK BIM Standarded, 2012) 7. (Smart market Report 2012)
21	Disaster mangement	This application will help the emergency	1. Suitable software and hardware like Building Automation System (BAS) and Computerized	1. (Construction, 2012) 2. (Penn State, 2012)

NO	BIM uses	Descriptions	Requirements	Sources
		responders would have access to critical building information in the form of a model and information system to minimise the expected threats.	Maintenance Management System (CMMS), this software need to be connected to the record model Building Automation System (BAS) linked to Record Model. 2. The staff are able to manipulate navigate, and review a 3D model. 3. The staff are able to make appropriate decisions during an emergency. 4. Quality Assurance system.	3. (Becerik-Gerber et al., 2012) 4. (UK BIM Standarded, 2012) 5. (Smart market Report 2012) 6. (Reddy, 2012) 7. (Eastman, 2011) 8. (Hergunsel, 2011)

Appendix C

Maturity Item	Level 1 (Initial)	Level 2 (Identified)	Level 3 (Managed)	Level 4 (Integrated)	Level 5 (Optimised)
BME1- Organisation Mission	Basic Organisational Mission Established	Established Basic Organisational Goals	Organisation Mission address purpose, services, values at minimum	Goals are specific, measurable, attainable, relevant, and timely	Mission and Goals are regularly revisited, maintained and updated (as necessary)
BME2- BIM Vision	Basic BIM Vision is Establish	Established Basic BIM Objectives	BIM Vision address mission, strategy, and culture	BIM Objectives are specific, measurable, attainable, relevant, and timely	Vision and Objectives are regularly revisited, maintained and updated (as necessary)
BME3- BIM Champion	BIM Champion identified but with limited time committed to BIM initiative	BIM Champion with Adequate Time Commitment	Multiple BIM Champions with Each Working Group	Group Executive Level at BIM Champion with limit time commitment	Executive-level BIM Champion working closely with Working Group Champion
BME4- Management Support	Limited Support	Full support for BIM implementation with some resource commitment	Commitment for BIM implementation with appropriate resource allocation	Full commitment stopping short of continuous improvement effort	Full Support of continuous improvement efforts

BME5- Data Sharing Method and knowledge Management	Paper 2D CAD and some digital drawings shared due to contract terms.	Everything is document based, and documents are exchanged as per contract terms.	Digital information exchange (e.g. CAD file exchanged), A locked BIM model shared for information only.	BIM models exchanged in a proprietary format. Responsibility and ownership still hold in disciplines.	BIM model shared without restrictions. Ownership and responsibility are transferred.
BME6- Standardisation	no BIM guidelines, protocols or standards	Basic (BIM modelling, processes, data structure and classification) guidelines and standards are well defined according to market-accepted standards.	Modelling, presentation, quantification, specifications, data structure, processes and analytical properties of 3D models are managed through detailed BIM modelling standards.	(BIM, processes, data structure and classification) standards and guidelines are incorporated into the business process, quality management and performance improvement systems.	(BIM, processes, data structure and classification) guidelines and standards are continuously and proactively refined to reflect lessons learned and industry best practices.
BME7- Organisation Hierarchy	BIM Champion with limited authority.	Small BIM implementation team outside the typical organisation hierarchy	Interdisciplinary BIM Group created at organisation level	BIM Champion defined within each operating unit	BIM implementation team supports BIM use within operating units
BMP1- BIM committee	Small Ad-hoc Committee with only those interested in BIM	BIM Committee is formalised but not inclusive of all operating units	Multi-disciplinary BIM Planning committee established with members from all operative units	BIM committee includes members from all level including executives	BIM committee Decisions are integrated with organisational Strategic Planning essential

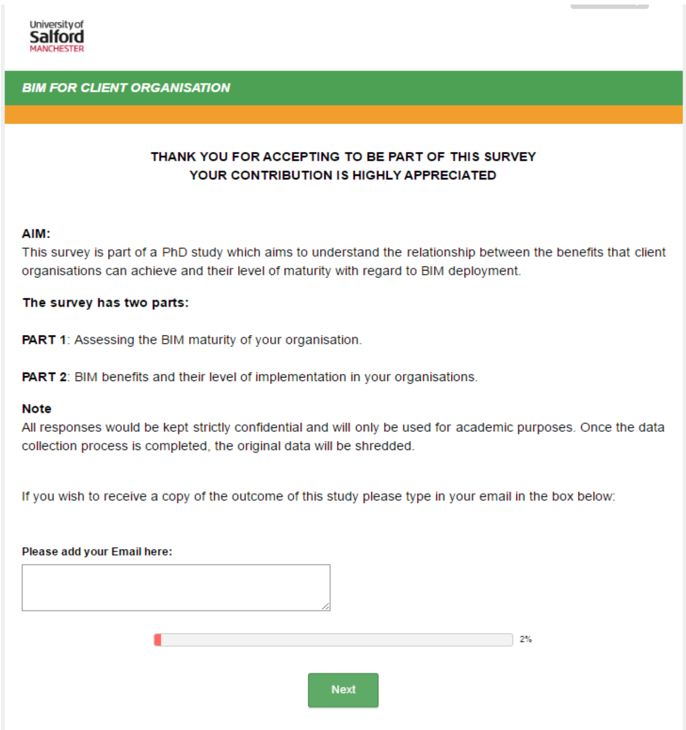
BMP2- Training Programs (may contain but not limited to BIM technology/authoring tools, Standards, methods and procedures and the commercial aspect)	Training program run by vendors - only for necessary personnel.	Internal Training program for all personnel that may interact with BIM. (provided only when needed).	Regularly conducted and routine training programs. Training requirements are managed to adhere to pre-set broad competency and performance objectives.	On-Demand training program established for the organisation, based on staff roles and respective competency objectives.	Training is seamlessly improved through lessons learned within the organisation.
BMP3- Education	Ad hoc education as needed	Formal Presentations on BIM and it's benefits	Regularly conducted employee education sessions	On-Demand education sessions established for the organisation	Education is seamlessly improved through lessons learned within the organisation
BMP4- Roles and Responsibilities	BIM is the responsibility of the BIM Champion. Roles are ambiguous.	BIM roles are informally defined and teams are formed accordingly. Each BIM project is planned independently.	BIM responsibility lies with each operating unit.	BIM responsibility lies with each person. BIM roles are embedded within the organisation.	BIM Responsibilities are regularly reviewed to ensure they are properly distributed.
BMP5- Level of Readiness	Established Need for BIM	Upper Management Buy-in	Operating Unit Buy in	All individuals buy in	"Willingness to change" is part of the culture.

BMP6- Skills	Performance is unpredictable and productivity depends on individual heroics. A mentality of "working around the system flourishes".	BIM competency is identified and targeted; BIM heroism fades but productivity is still unpredictable.	BIM competency is developed according to the project need.	BIM competency targets are embedded within the organisation. Productivity is now consistent and predictable.	BIM competency targets are continuously upgraded to match technological advances and align with organisational objectives. Process
BMRP1- organisation information requirements (OIR)	Ad hoc OIR inside the organisation	Basic OIR based on basic standards	Detailed OIR based on the asset management activities identified in the policy, strategy and plan (based on organisation own standards)	Detailed OIR based on industry standards	OIR is continuously and proactively refined to reflect lessons learned and industry best practices.
Validation Process	Ad hoc validation process	Basic validation process based on basic standards	Detailed validation process inside the organisation with limited communication with industry standards	Detailed validation process based on industry standards	Validation process is continuously and proactively refined to reflect lessons learned and industry best practices

BMRP2- Quality Assurance System	No quality control plans; neither for 3D models nor for documentation.	Quality targets and performance benchmarks are set but limited to the design stage only. Object information checking is basic.	Performance against benchmarks is set, monitored and controlled and extended to some deliverables in the construction stage. Object information checking is formal.	BIM performance benchmarks are incorporated into quality management and performance improvement systems throughout the project life cycle.	Quality improvement adherence to regulations is continuously aligned and refined. Benchmarks are repetitively revisited to ensure quality in processes and products throughout project life cycle. Technologies
BMT1-Software	Ad-hoc use of BIM software	BIM software is unified within the organisation	Interoperable and integrated BIM software for defined deliverables	Interoperable and integrated BIM software is deployed to meet strategic objectives.	Continuous updating of BIM software systems to enhance productivity and align with strategic objectives.
BMT2- Hardware	Ad-hoc hardware capable of running basic BIM software.	Equipment specifications are defined, budgeted for and standardised across the organisation.	A strategy is in place to manage and maintain BIM equipment.	A fully integrated BIM system with another organisational IT systems.	Continuous updating of BIM hardware systems in line with business strategy.
BMT3-Physical Space	Single workstation for viewing some BIM data.	The work environment and workplace tools are identified as factors affecting motivation and productivity.	BIM room for collaborating. The work environment used to enhance staff motivation, satisfaction and productivity.	Multiple collaborative workspaces. Workspace factors are integrated into	Continuous updating of BIM spaces. Workplace factors are reviewed constantly to ensure staff satisfaction and improve.

				performance strategies.	
BMT4- Network	Network solutions are ad-hoc. Stakeholders lack the network infrastructure necessary to harvest, store and share data.	Network solutions for sharing information and controlling access are identified within and between organisations.	Network solutions are well managed through common platforms (e.g. intranets or extranets).	Network solutions allow seamless real-time sharing of data through a well-defined process.	Network solutions are continuously assessed and modified. Networks facilitate data, storing and sharing between all stakeholders.

Appendix D



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BIM FOR CLIENT ORGANISATION

THANK YOU FOR ACCEPTING TO BE PART OF THIS SURVEY
YOUR CONTRIBUTION IS HIGHLY APPRECIATED

AIM:
This survey is part of a PhD study which aims to understand the relationship between the benefits that client organisations can achieve and their level of maturity with regard to BIM deployment.

The survey has two parts:

PART 1: Assessing the BIM maturity of your organisation.

PART 2: BIM benefits and their level of implementation in your organisations.

Note
All responses would be kept strictly confidential and will only be used for academic purposes. Once the data collection process is completed, the original data will be shredded.

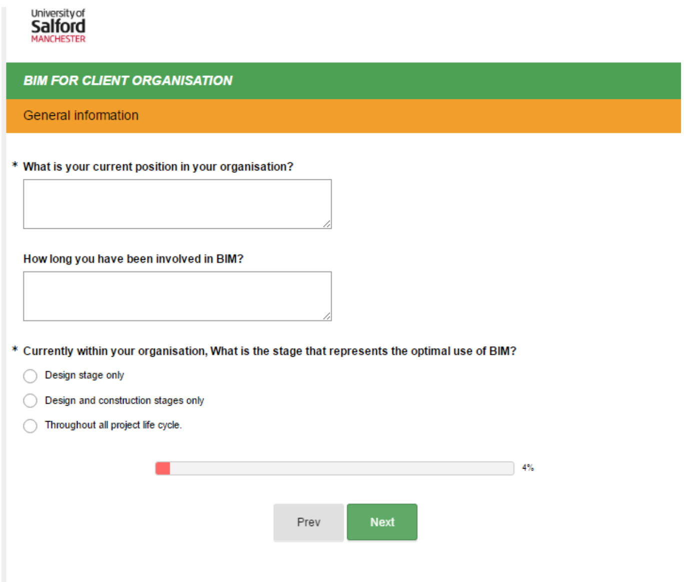
If you wish to receive a copy of the outcome of this study please type in your email in the box below:

Please add your Email here:

2%

Next

Questionnaire Front Page



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BIM FOR CLIENT ORGANISATION

General information

* **What is your current position in your organisation?**

How long you have been involved in BIM?

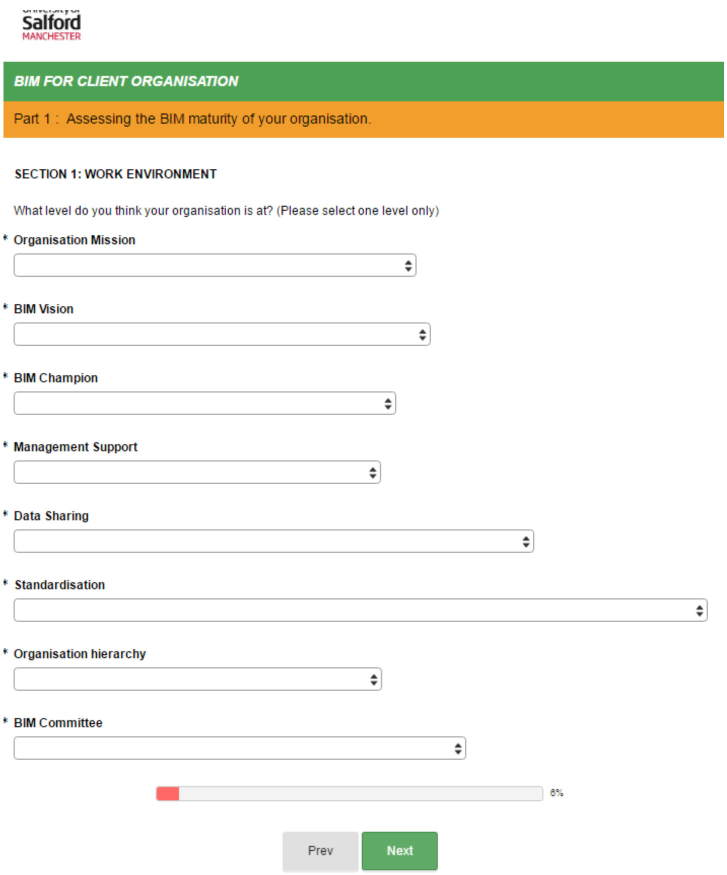
* **Currently within your organisation, What is the stage that represents the optimal use of BIM?**

- Design stage only
- Design and construction stages only
- Throughout all project life cycle.

4%

Prev Next

General information page



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BIM FOR CLIENT ORGANISATION

Part 1 : Assessing the BIM maturity of your organisation.

SECTION 1: WORK ENVIRONMENT

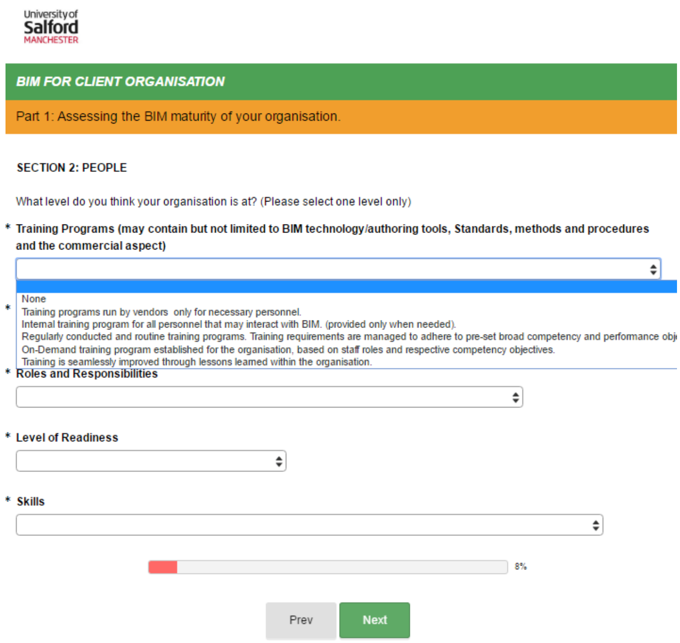
What level do you think your organisation is at? (Please select one level only)

* Organisation Mission
* BIM Vision
* BIM Champion
* Management Support
* Data Sharing
* Standardisation
* Organisation hierarchy
* BIM Committee

6%

Prev Next

Maturity assessment page 1



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BIM FOR CLIENT ORGANISATION

Part 1: Assessing the BIM maturity of your organisation.

SECTION 2: PEOPLE

What level do you think your organisation is at? (Please select one level only)

* Training Programs (may contain but not limited to BIM technology/authoring tools, Standards, methods and procedures and the commercial aspect)

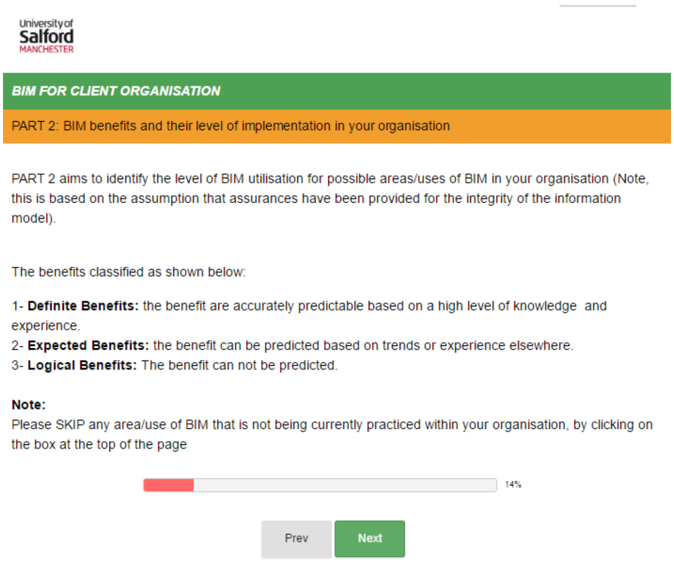
None
Training programs run by vendors only for necessary personnel.
Internal training program for all personnel that may interact with BIM. (provided only when needed).
Regularly conducted and routine training programs. Training requirements are managed to adhere to pre-set broad competency and performance obj
On-Demand training program established for the organisation, based on staff roles and respective competency objectives.
Training is seamlessly improved through lessons learned within the organisation.

* Roles and Responsibilities
* Level of Readiness
* Skills

8%

Prev Next

Maturity assessment page 2



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BIM FOR CLIENT ORGANISATION

PART 2: BIM benefits and their level of implementation in your organisation

PART 2 aims to identify the level of BIM utilisation for possible areas/uses of BIM in your organisation (Note, this is based on the assumption that assurances have been provided for the integrity of the information model).

The benefits classified as shown below:

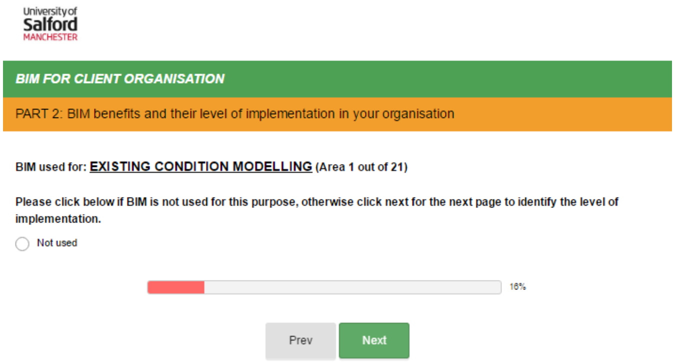
1- **Definite Benefits:** the benefit are accurately predictable based on a high level of knowledge and experience.
2- **Expected Benefits:** the benefit can be predicted based on trends or experience elsewhere.
3- **Logical Benefits:** The benefit can not be predicted.

Note:
Please SKIP any area/use of BIM that is not being currently practiced within your organisation, by clicking on the box at the top of the page

14%

Prev Next

Benefits assessment Introduction



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BIM FOR CLIENT ORGANISATION

PART 2: BIM benefits and their level of implementation in your organisation

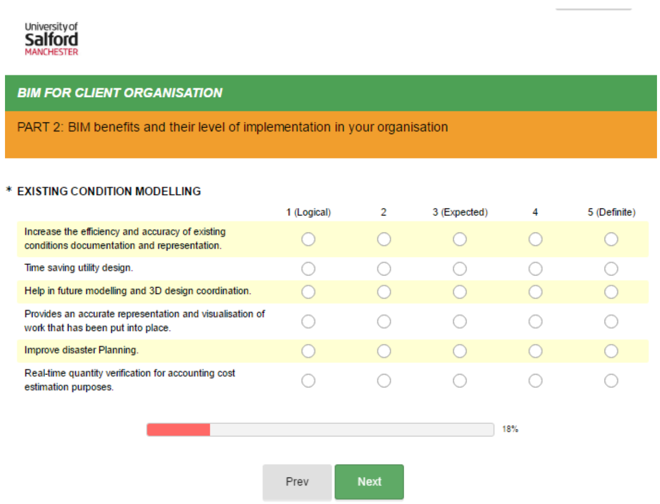
BIM used for: EXISTING CONDITION MODELLING (Area 1 out of 21)

Please click below if BIM is not used for this purpose, otherwise click next for the next page to identify the level of implementation.

Not used

18%

Prev Next



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BIM FOR CLIENT ORGANISATION

PART 2: BIM benefits and their level of implementation in your organisation

* EXISTING CONDITION MODELLING

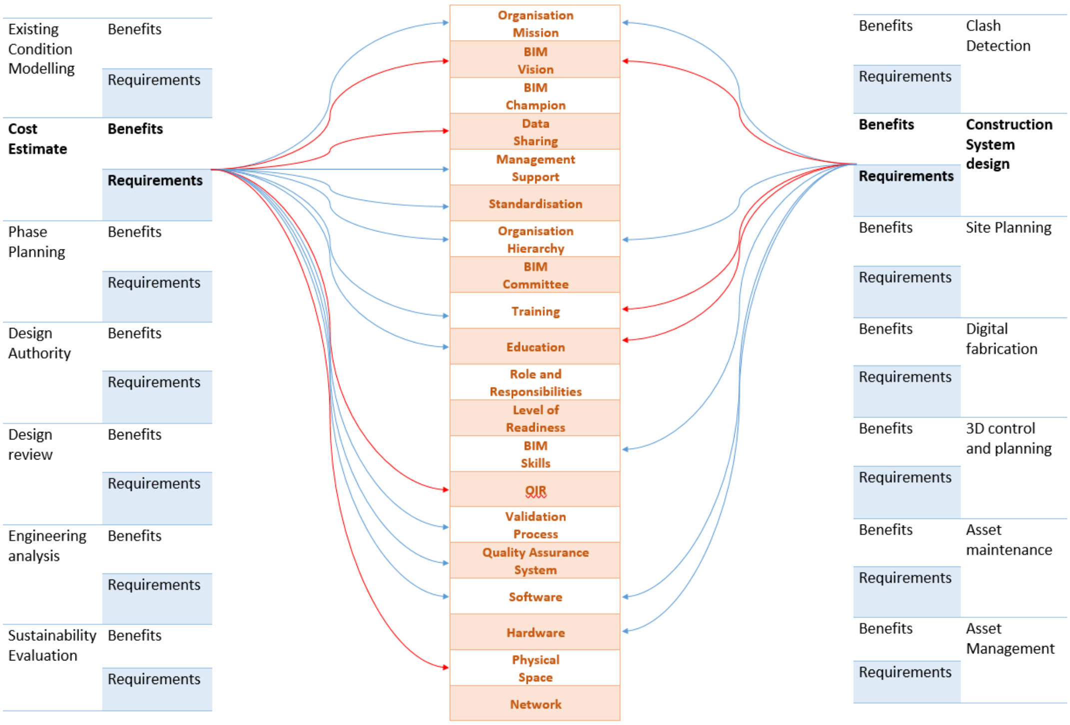
	1 (Logical)	2	3 (Expected)	4	5 (Definite)
Increase the efficiency and accuracy of existing conditions documentation and representation.	○	○	○	○	○
Time saving utility design.	○	○	○	○	○
Help in future modelling and 3D design coordination.	○	○	○	○	○
Provides an accurate representation and visualisation of work that has been put into place.	○	○	○	○	○
Improve disaster Planning.	○	○	○	○	○
Real-time quantity verification for accounting cost estimation purposes.	○	○	○	○	○

18%

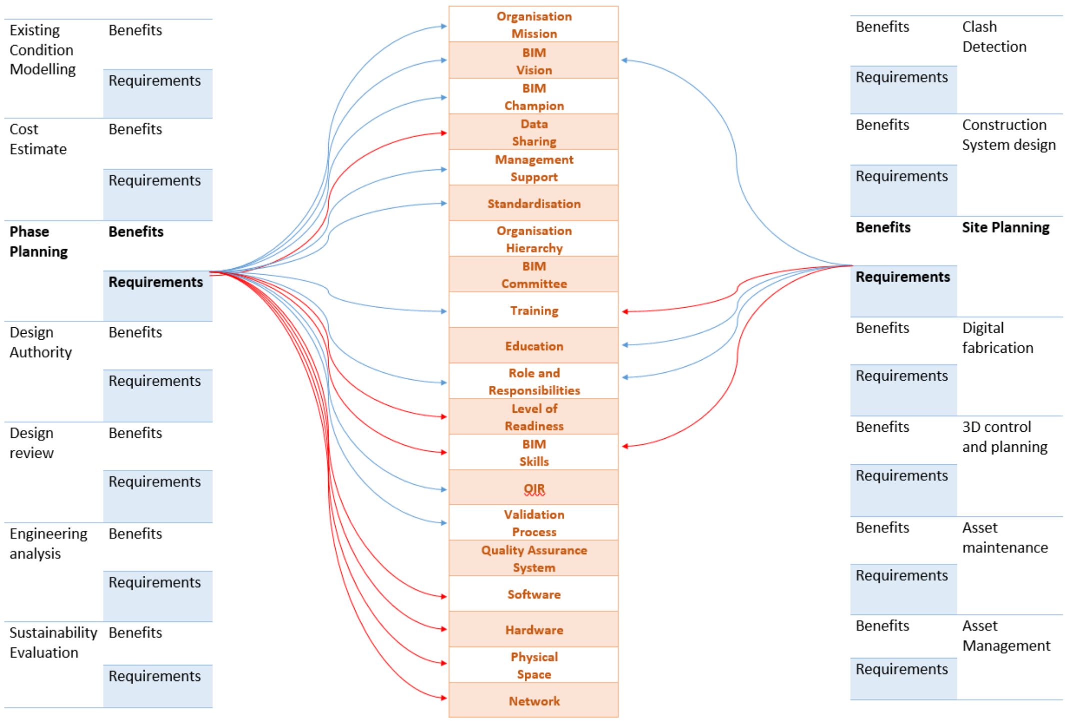
Prev Next

Existing condition Modelling (pages 1 and 2)

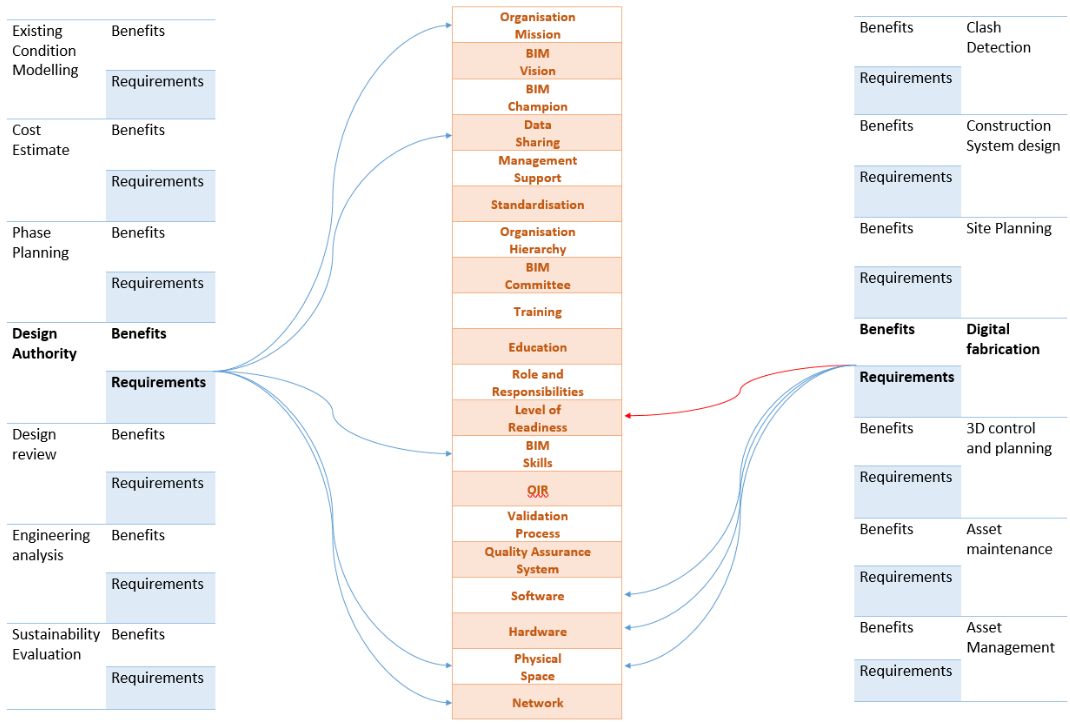
Appendix E



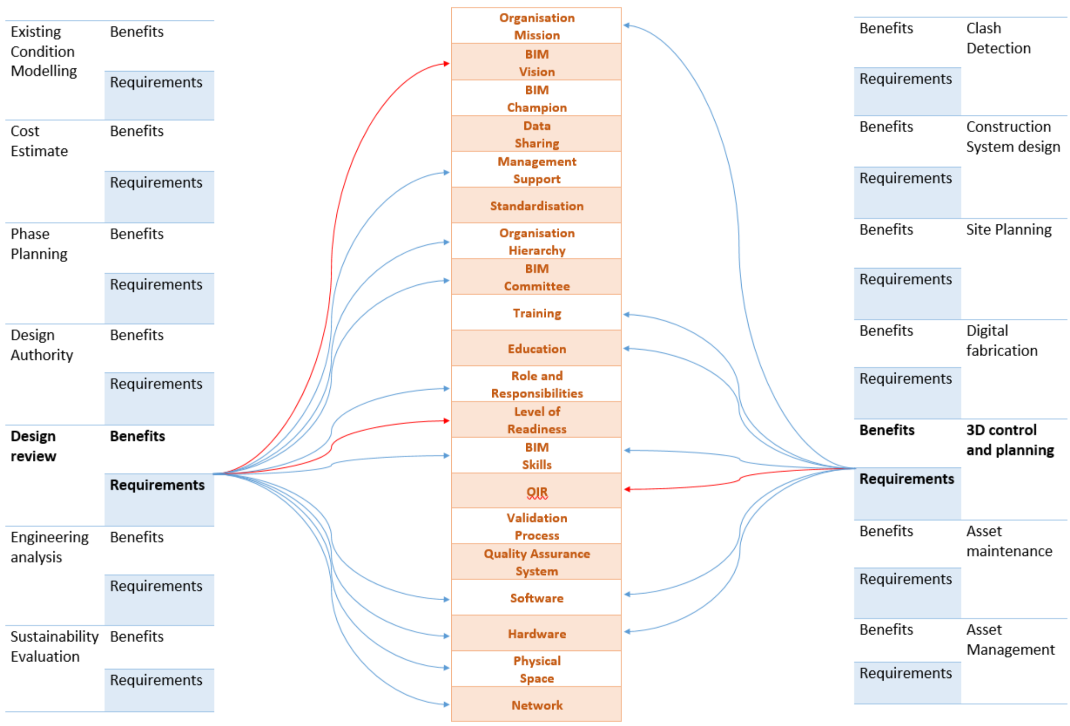
Cost Estimate and Construction System Design



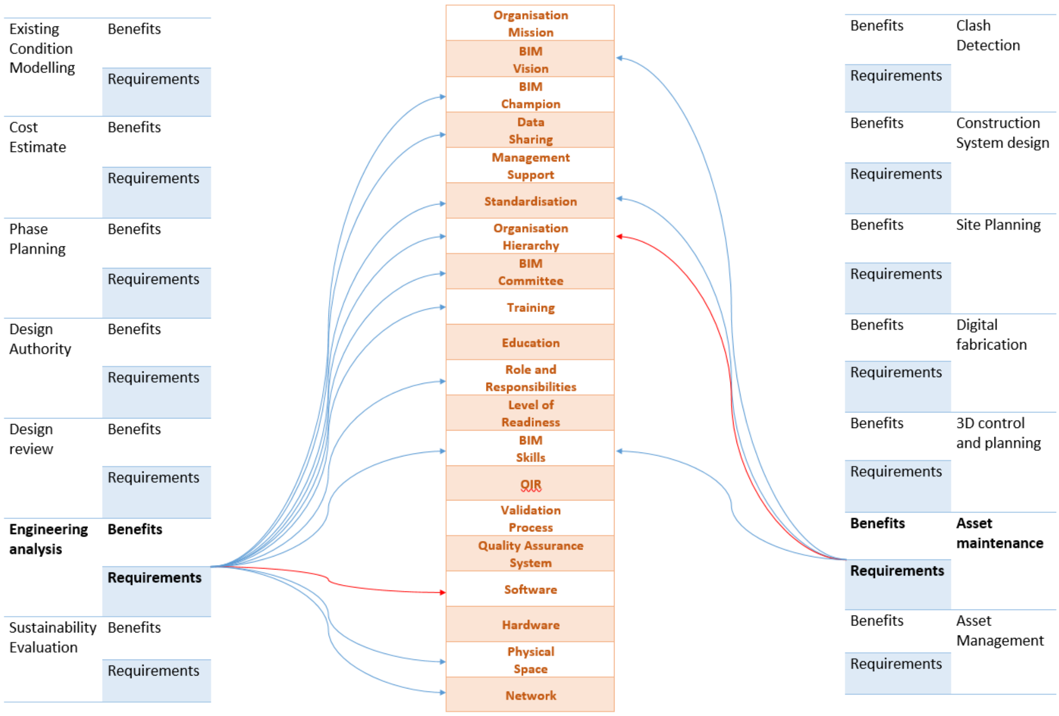
Phase Planning and Site Planning



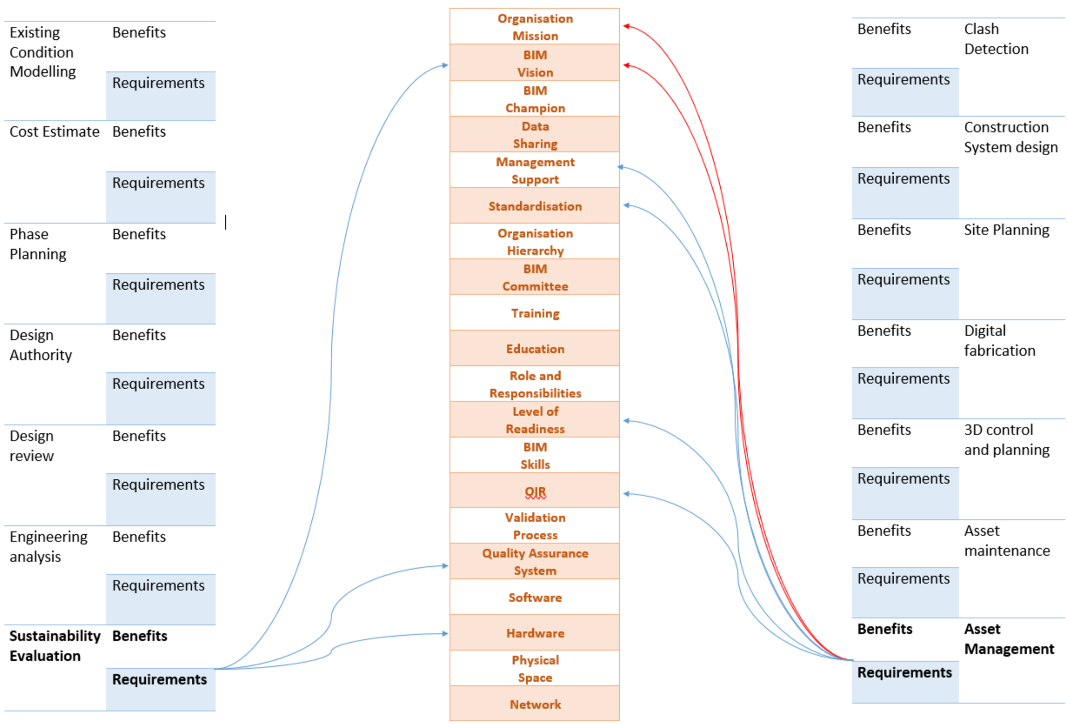
Design Authority and Digital Fabrication



Design Review and 3D Control and Planning



Engineering Analysis and Asset Maintenance



Sustainability Evaluation and Asset Management