

**A web-based Decision Support System (DSS) to assist
SMEs to broker risks and rewards for BIM adoption**

By

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**A thesis submitted in partial fulfilment of the requirement of the University of the West of
England for the degree of Doctor of Philosophy (PhD)**

October 2017

DECLARATION

DECLARATION

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is being submitted concurrently in candidature for any other degree or other award. I confirm that the intellectual content of the work is the result of my own efforts and no other person.

Thep Thanh Lam

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ABSTRACT

Building Information Modelling (BIM) usage in the UK's construction industry has recorded a significant increase over the last few years. However, available evidence suggests that BIM adoption amongst larger construction firms and innovators seems to be dominant, while the uptake of BIM by Small and Medium Sized enterprises (SMEs) remains relatively poor. Consequently, SMEs are currently lagging behind and are losing out in winning publicly funded projects. SMEs have not fully recognised the benefits of using BIM in project delivery. Guidance and frameworks to assist SMEs to make an informed decision about BIM adoption are currently lacking. It appears that SMEs are yet to be convinced that BIM is beneficial to them, and remain concerned about the potential risks to their business. Guidance and frameworks to assist SMEs in making an informed decision about BIM adoption are currently lacking.

This study seeks to bridge this gap and provide a decision-support system (DSS) to assist in the analysis of the risks and rewards of adopting BIM by SMEs, in project delivery. As a result, a conceptual framework was developed to give a theoretical foundation to the study of brokering risks and rewards in the adoption of BIM for project delivery. This framework is comprehensive and includes trading off risks and rewards associated with several criteria, such as stage of involvement, project value, funding, and the procurement route chosen. The approach was validated by a representative sample of BIM users. The results of the validation of the framework provided an informed basis for the development of the DSS. The latter was validated by a sample of SMEs, according to several criteria such as ease of use of the Graphical user interface (GUI), quality of information, level of information presented, trading off risks and rewards of adoption of BIM in project delivery.

The findings of the framework validation revealed that early design stage, project size between £5m and £50m, private funding, and integrated project delivery procurement are the best opportunities that enable SMEs to maximise the benefits and minimise the risks, when adopting BIM. Regarding the DSS validation, most participants reported that they had found the DSS easy to use, especially the GUI. They were also positive about the level and quality of information and knowledge provided by the DSS. In particular, they found the DSS informative to broker risks and rewards for BIM adoption.

LIST OF PUBLICATIONS

Conference paper

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LIST OF ABBREVIATIONS

The following abbreviations have been used in this thesis:

AEC Architecture, Engineering and Construction

AECO	Architecture, Engineering, Construction, and Operation
AHP	Analytic Hierarchy Process
AIA	American Institute of Architects
BCO	the British Council for Offices
BIM	Building Information Modelling
BSI	British Standards Institute
CAD	Computer Added Design
CIB	Council for Research and Innovation in Building and Construction
CIC	Construction Institution Council
COBie	Construction Operations Building Information Exchange
CSS	Cascading Style Sheet
DEA	Data Envelopment Analysis
DSS	Decision Support System
GDP	Gross Domestic Product
GUI	Graphical User Interface
GVA	Gross Value Added

LIST OF ABBREVIATIONS AND SYMBOLS

HTML	Hypertext Mark-up Language
HTML5	Hypertext Mark-up Language 5
ICT	Information and Communication Technology
IFC	The Industry Foundation Classes
IPD	Integrated Project Delivery
MADM	Multi Attribute Decision Making
MAUT	Multi-Attribute Utility Theory
MCA	Multi-Criteria Analysis
MCDM	Multi-Criteria Decision-Making
MEP	Mechanical, Electrical and Plumbing
NBS	National Building Specifications
NIBS	National Institute for Building Science
PAS	Publicly Available Specification
PHP	Hypertext Pre-Processor
ROI	Return on Investment
SMEs	Small and Medium-sized Enterprises
SPSS	Statistical Package for the Social Sciences
UK	The United Kingdom
VAHP	Voting Analytic Hierarchy Process

LIST OF ABBREVIATIONS AND SYMBOLS

XML	eXtensible Markup Language
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CHAPTER 1: INTRODUCTION TO THE RESEARCH

1.1. INTRODUCTION

Building Information Modelling (BIM) has recently gained widespread attention and is considered one of the most fertile areas for new ideas in terms of the development of Architecture, Engineering and Construction (AEC). BIM was described by the SEC Group (2013) as “a way of working” whereby stakeholders can use BIM digital modelling to share information and knowledge, collaboratively harnessing the talents and insights of all participants to reduce waste and optimise efficiency through all phases of design, fabrication and construction.

Governments around the world are promoting BIM’s capacity to eliminate waste on public projects, and even mandating its use as part of their cost saving strategy and reform of the public construction sector. In the United Kingdom, the government declared that by 2016 no public projects can be accepted unless they use BIM (British Standards Institute, 2013).

According to SmartMarketReport (2012), there has been a spectacular increase in the rate of BIM adoption, which has expanded from adoption by 17% of the construction industry in 2007 to adoption by 71% in 2012. This trend tangibly demonstrates the powerful value proposition of BIM to a broad range of companies across the construction industry.

A survey published by the National Building Specifications (NBS) in 2013 shows that the percentage of the industry using BIM rose from 13% in 2010 to 39% in 2012. Ninety-one percent of the industry did not use BIM but were aware of it (85%), while 77% said that they would be using it in the next year (NBS, 2013). However, the finding of the latest report of NBS-2016 indicates that only 54% of respondents said they are using BIM in their projects (NBS, 2016). Additionally, SmartMarket Report (2014) reports that the percentage of contractors that have been using BIM for 1–2 years and for 3–5 years were 47% and 41% respectively (SmartMarket Report, 2014).

It is hoped that the arrival of BIM will provide a powerful boost to development and innovation in the industry in the areas of AEC, such that AEC industry players will be integrated together to perform as a team, working collaboratively for the same objective,

with client gratification at the core of their interest. BIM technology has the potential to deliver an array of benefits associated with project delivery. Depending on various key factors affecting organisations if and when they adopt BIM to implement construction projects, project participants can potentially reap a great number of benefits.

They may also, however, face various kinds of risk. The evidence indicates that the key factors impacting on organisations in adopting BIM to deliver construction projects are closely associated with four factors:

- Stages of project involvement (Al-Hammad *et al.*, 1997; Bryde *et al.*, 2013; Negendahl, 2015; Succar, 2012; Arditi *et al.*, 1999; Oti *et al.*, 2015).
- Project values (Bryde *et al.*, 2013; Negendahl, 2015; Eastman *et al.*, 2011; Liu *et al.*, 2010; Azhar *et al.*, 2011; Migilinskas *et al.*, 2013; Won *et al.*, 2013).
- Source of funding (Bryde *et al.*, 2013; Negendahl, 2015; Volk *et al.*, 2014).
- Procurement routes (Eastman *et al.*, 2011; Negendahl, 2015; Eastman *et al.*, 2011; Eadie *et al.*, 2015; Luu *et al.*, 2013; Byrne *et al.*, 2011; Cox *et al.*, 2011; Hogg *et al.*, 2007; Hughes *et al.*, 2006).

It is important to identify the extent to which one key factor has the greatest impact on an organisation, and identify its relevant risks and rewards, since this can help organisations to foresee, before investing in BIM for their organisations, the risks they may face and the rewards they may reap.

1.2. PROBLEM STATEMENT

Emerging information and communication technology (ICT) generates enormous opportunities for enhancing effectiveness of project delivery as well as creates new business opportunities. Thus, recognised ICT benefits have motivated numerous construction organisations to adopt and invest in this technology (Peansupap *et al.*, 2005). However, the uptake of this new technology in construction has lagged well behind most industries. In comparison to other major industries such as the aerospace or manufacturing industries, KPMG's annual report, "Building a technology advantage — Global Construction Survey" (2016) reveals that two-thirds of the 200-plus construction and engineering executives and major-project owners are not using advanced data analytics to monitor project-related estimation and performance.

The reasons for this slow uptake found by Peansupap *et al.*, (2005) that it is due to the unique characteristic of the construction including the complex nature of the construction industry, ICT immaturity levels, financial constraints, a poor availability of tools for evaluating benefits of using ICT, and a lack of understanding of the ICT implementation process. Blayse *et al.*, (2004) also identifies six key factors which have hindered technology adoption in comparison to other sectors. They are: clients and manufacturers; the structure of production; relationships between individuals and firms within the industry and between the industry and external parties; procurement systems; regulations/standards; and the nature and quality of organizational resources. In addition, Stewart *et al.*, (2004) supports that the deficit of technology adoption is a consequence of the temporary or one-off nature of construction projects, supply chain fragmentation, lack of client leadership, low level of technology awareness and training, necessary up-front investment, ongoing maintenance costs, and resistance to change.

In the UK, AEC sector including Small and Medium-sized Enterprises (SMEs) is considered as one of the most significant parts which contribute to the total UK economy (Myers, 2013). SMEs are widely considered to be the backbone of major economies around the world (Love *et al.*, 2004). In the UK, there are 950,000 SMEs, which generate about 80% of the production costs of the UK construction industry (Robson *et al.*, 2014). At the start of 2014, 99.3% of the UK's 5.2 million private sector businesses were small, and 99.9% were small or medium-sized (Department for Business Innovation & Skills, 2014)

However, BIM adoption concerns primarily large companies, whereas smaller ones are still slow to embrace the new technology (SmartMarket Report, 2012). The number of large companies adopting BIM is almost threefold the number of small ones doing so, the former making up 74% in 2009 and this figure rising to 91% in 2012. In contrast, BIM adoption in smaller firms in 2009 stood at just 25% of small firms, rising to 41% of small to medium firms.

In fact, SMEs are lagging behind in BIM adoption, losing out on winning not only publicly funded projects but also potentially private sector ones. It has emerged that 40 % of construction SMEs lose out on 90% of the public sector work they bid for, while more than half of construction SMEs claim to have identified a reduction in their rate of success in bidding for public sector contracts over the past five years (Federation of Master Builders, 2013). The latest survey conducted by the Electrical Contractor Association found that there are still large gaps in BIM adoption in the UK's construction industry. Eighty-nine percent of large organisations claimed that they were ready for BIM, whereas 54% of small companies' responses were "not ready at all" (Electrical Contractor Association, 2015).

Blackwell (2012) warns that if SMEs are still slow in grasping and adopting BIM as a transformative technology and process, they could well lose contracts in both the domestic and international markets. According to Harris (2013), as a result of losing out on business SMEs felt less competitive and innovative in comparison with their competitors (Harris, 2013). This trend may continue if SMEs do not pay attention to investing in new technology and reforming their organisations in order to meet with the requirements of the industry.

1.3. KNOWLEDGE GAP

So far, the adoption of BIM in the construction industry has generated huge numbers of workshops, conferences and research papers to investigate the positive effects of BIM in enhancing collaboration, coordination, integration, interoperability, and communication in all phases of building project (Succar, 2009). Efforts to support BIM adoption for project delivery by SMEs in the construction industry have included the development of BIM support groups, standards and protocols. BIM4SME for example seeks to provide SMEs with resources, best practices and knowledge to enable them to achieve BIM Level 2 (Bim4sme.org). The BIM Protocol created by the Construction Institution Council in 2013 aims to clarify issues related to legal agreements, including the obligations and rights of stakeholders on a BIM project (Bim4sme.org). The Publicly Available Specification (PAS) parts 2 and 3 and BS1192-4 have been developed specifically for information management for the capital/delivery phase of construction, the asset operation phase, and the exchange of information throughout the lifecycle of a facility (Bim4sme.org). In addition, a series of BIM frameworks have been developed to evaluate areas and identify factors for practical BIM effectiveness (Jung *et al.*, 2011) and for multidisciplinary collaboration (Singh *et al.*, 2011), optimising and simulating construction planning and scheduling (Song *et al.*, 2012), identifying individual BIM competencies (Succar *et al.*, 2013), and ensuring best value in construction projects (Porwal *et al.*, 2013; Liu *et al.*, 2015). However, these frameworks and efforts have so far had little impact on the adoption of BIM among SMEs. Additionally, the latest report of NBS in 2016 shows that 65% of the respondents agree that there have not been sufficient standards for BIM (NBS, 2016).

It appears that the surge of research seeking to increase BIM adoption has, so far, had limited success in convincing SMEs. This failure is largely due to lack of understanding of root causes, which has led SMEs to ignore the BIM agenda. The key reasons for not using BIM are complex and multifaceted. However, Kouider (2013) found that for SMEs not knowing what value they can achieve from their financial investment or how long it will take to see a return on the investment are two of the main barriers against BIM adoption. Indeed, BIM is perceived by SMEs to disrupt their work process, as well as having a significant impact on already scarce human and financial resources. Consequently, its implementation may result in potential benefits, but also brings several risks. SMEs find it difficult to weigh up the risks

and rewards that they may face when they invest in BIM (Kouider, 2013; Chien *et al.*, 2014). Amongst other concerns, such as a lack of relevant skills and BIM knowledge, SMEs seem worried about BIM affordability (Liu *et al.*, 2010; Eastman *et al.*, 2011; Migilinskas *et al.*, 2013), and as noted above return on investment is uncertain (Yang *et al.*, 2008; Azhar *et al.*, 2011; Azhar *et al.*, 2012; Won *et al.*, 2013). Despite various efforts and initiatives, a recent study conducted by NBS (2015) revealed that “BIM adoption is moving from being led by innovators and early adopters, towards being a more mature market, where the more mainstream are investigating and assessing the benefits of [adopting BIM]” (NBS, 2015).

Unfortunately, there is currently a lack of guidance and assistance for SMEs in how to adopt BIM in project delivery. Absence of standards and frameworks to evaluate the extent to which BIM can bring benefits to AEC through project delivery, especially for SMEs, results in low rates of BIM adoption (Liu *et al.*, 2010; Eastman *et al.*, 2011; Migilinskas *et al.*, 2013; Kouider, 2013). Indeed, SMEs, as a hard-to-reach group, require specific assistance to get them to adopt BIM.

1.4. PROPOSITION, AIM AND OBJECTIVES

1.4.1. Proposition

The central proposition of this thesis is that an improved understanding of risks and rewards associated with BIM to deliver construction projects among SMEs could result in better decision-making regarding BIM adoption amongst SMEs.

1.4.2. Aim and objectives

The aim of this study is to develop a decision support system (DSS) to help SMEs to broker risks and rewards of adopting BIM for project delivery. The proposed DSS will assist SMEs to make informed decisions about whether or not to adopt BIM to deliver building projects, based on several criteria such as stage of involvement, project value, source of funding and procurement route. This includes trading off the risks and rewards associated with each of these key factors affecting SMEs when they adopt BIM to deliver construction projects.

To achieve the aim of this study, the following objectives need to be met:

1. To critically review the challenges and issues related to adopting BIM in project delivery.
2. To analytically examine SMEs BIM adoption in the UK construction industry.
3. To develop and validate the conceptual framework to guide the design of the DSS.
4. To design and test a web-based DSS, based on the outcome of the framework validation.
5. To recommend the implications of the findings on SMEs, and future research.

1.4.3. Overarching research questions and appropriate research methods

The research endeavours to answer the central research question:

What are the factors that enable SMEs to maximise the benefits and minimise the risks associated with BIM adoption?

1.5. SUMMARY OF THE CONTRIBUTION TO KNOWLEDGE

The key contributions to knowledge are as follows (further details could be found in Section 8.3):

- Provision of an understanding of the key risks and rewards that affect SMEs when adopting BIM to deliver construction projects.
- Development of a comprehensive DSS, which enables SMEs to anticipate risks and rewards when adopting BIM to deliver construction projects.

1.6. STRUCTURE OF RESEARCH

The process of conducting the present study can be seen in *Figures 1 and 2* below.

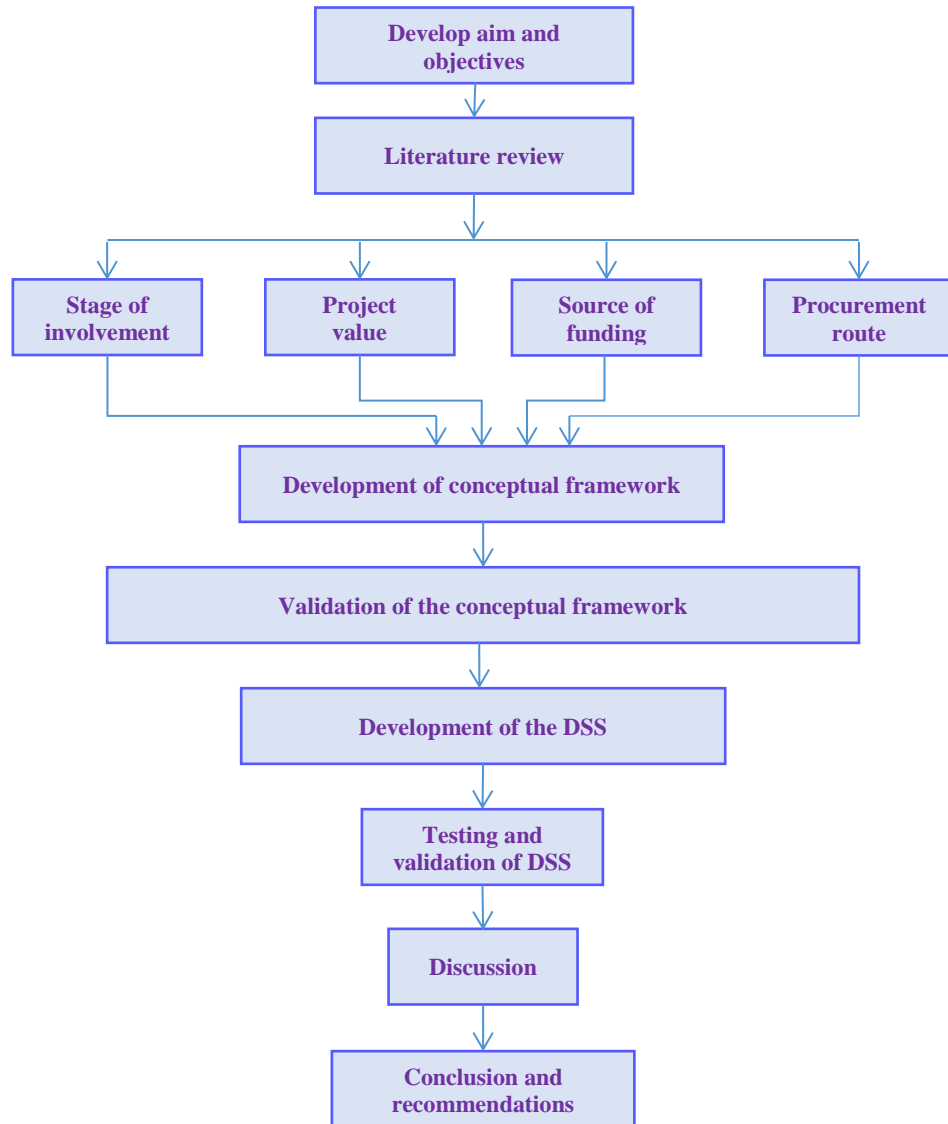
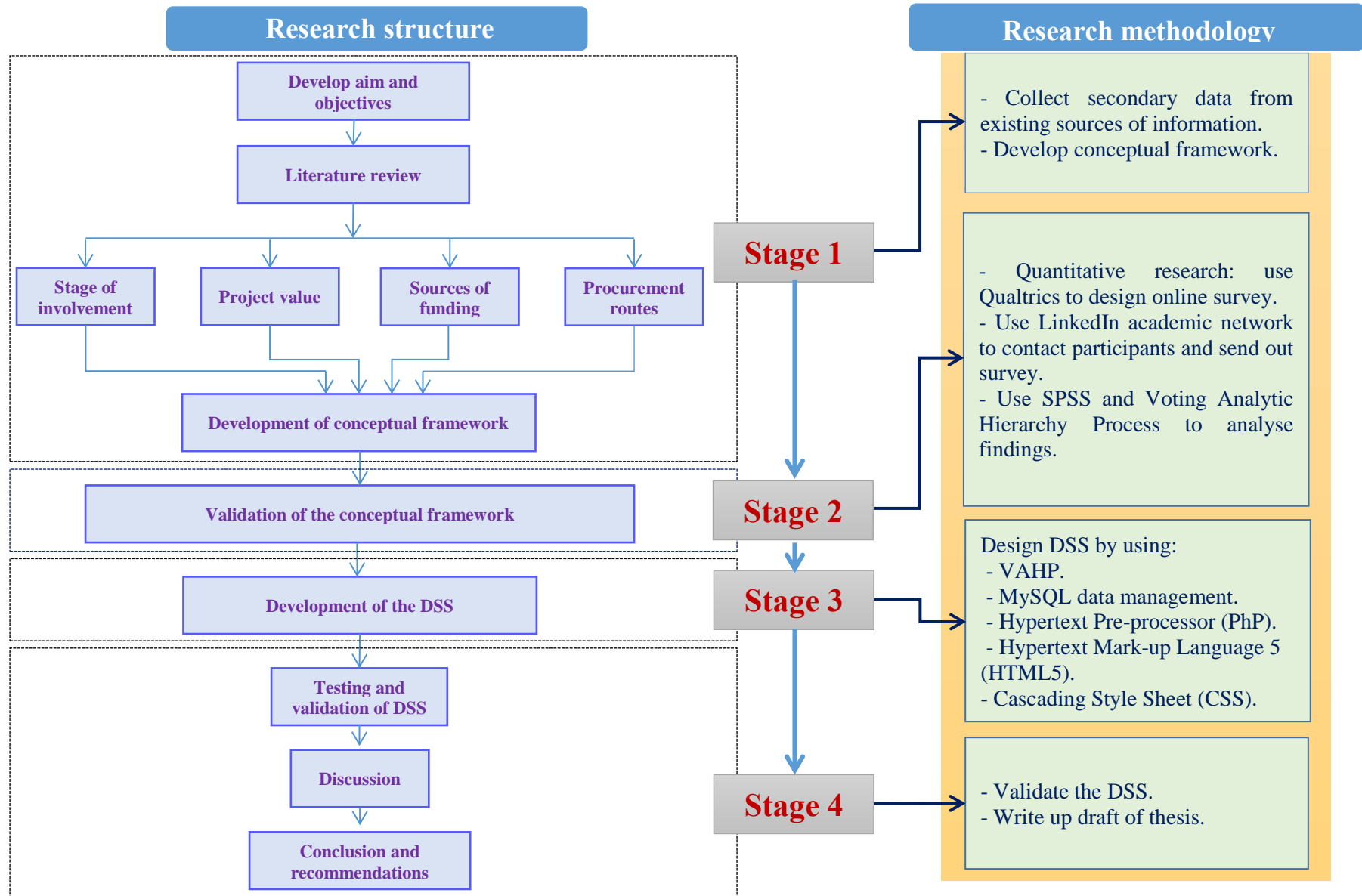


Figure 1. Flow chart of research structure

Figure 2. Process of conducting the study and its relevant methodologies



1.7. STRUCTURE OF THESIS

This thesis consists of 8 chapters. The outline of the thesis is presented in *Figure 3* below

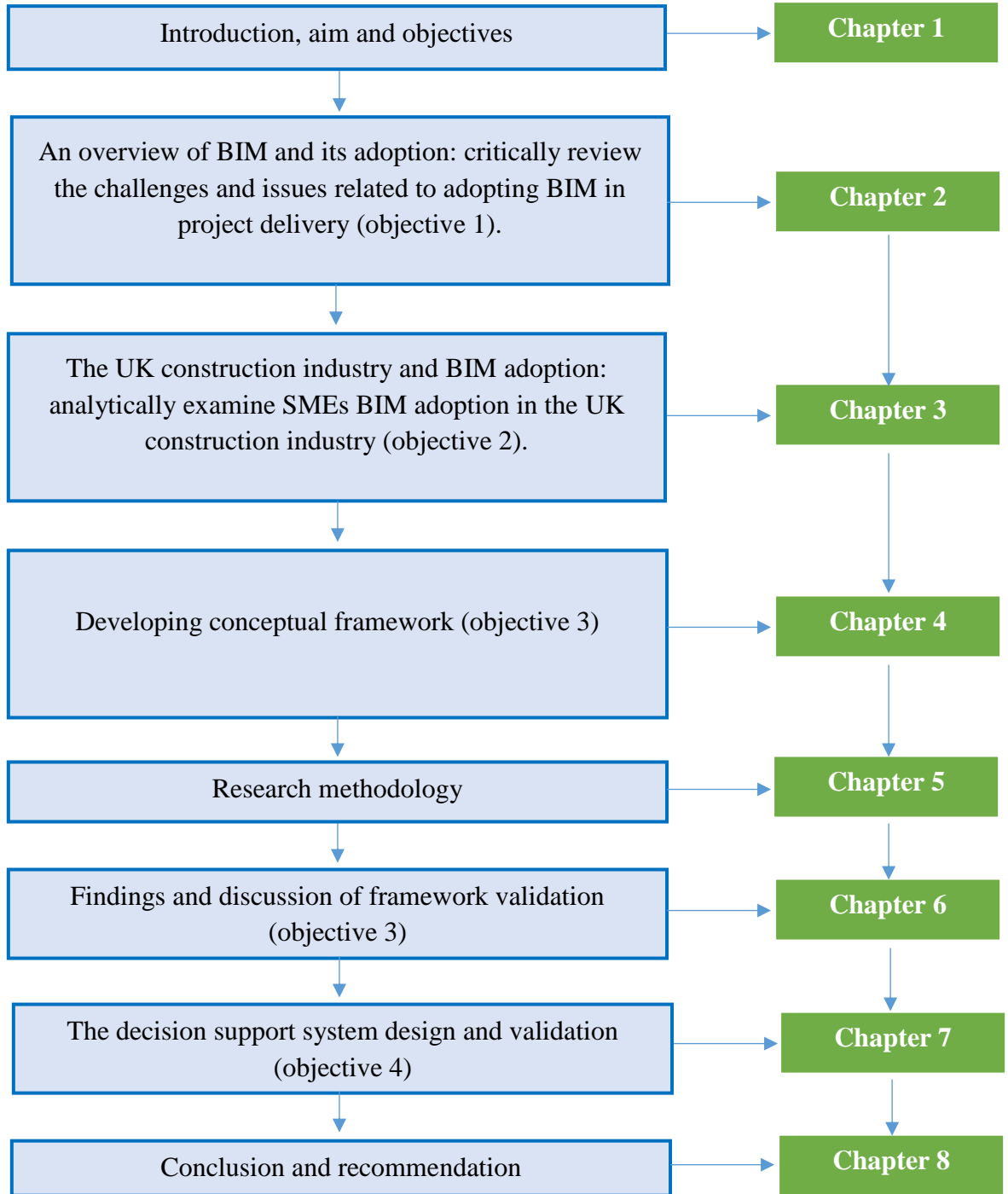


Figure 3. Structure of thesis

CHAPTER 2: AN OVERVIEW OF BIM AND ITS ADOPTION

2.1. INTRODUCTION

The terms BIM represents the current advances associated with technical and procedural innovation in the construction industry across the world. BIM appears to help in the generation, management and interactivity of facility data through the lifecycle of a project, with the aim of assisting the industry to minimise risks and maximise benefits during the progress of project delivery. To gain an overall view of BIM as well as understand its significant role in innovation in the construction industry, the aim of this chapter is to introduce the several different definitions of BIM as variously used within the construction industry (Section 2.2). In Section 2.3, the concepts of BIM are also examined. An investigation of BIM mandates and its adoption around the world is presented in Section 2.4. In order to illustrate the capabilities of BIM, a review of BIM best practice across the world is offered in Section 2.5. The key benefits of adopting BIM to deliver construction projects are outlined in Section 2.6, and Section 2.7 presents the issues and challenges associated with BIM adoption. Section 2.8 concludes the chapter.

2.2. BIM DEFINITION

BIM now is not a new concept in the construction industry across the world. It has become an initialism that attract the attention of many people in the AEC area. The miracle capability of BIM is presented through compliments as well as different definitions in the Table 1 below:

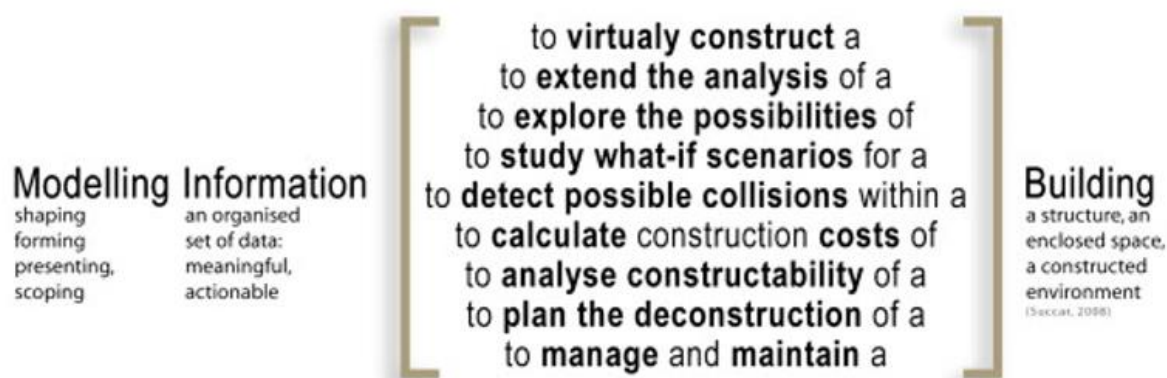
Table 1. The different definitions of BIM

BIM definition	References
<p>BIM is a process involving the generation and management of digital representations of physical and functional characteristics of a building. The resulting building information models become shared knowledge resources to support decision-making about a facility from earliest conceptual stages, through design and construction, through its operational life and eventual demolition. The time for a building owner to get involved with the BIM process is not at the end of the building project but from the very beginning.</p>	<p>Smith (2007)</p>
<p>BIM is a wonderful result of a revolutionary technology and process in the construction that has transformed the way the buildings are designed, analyzed, constructed, and managed.</p>	<p>Hardin (2009)</p>
<p>BIM is an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle.</p>	<p>Eastman <i>et al</i> (2011)</p>
<p>BIM is a sharing of information through the design, construction and whole life cycle of buildings, managing it in an integrated way by object modelling. The objects are components or elements of a building which are designed in 3D view and integrated layers of information including type of materials such as wall, floor,</p>	<p>Fewings (2013)</p>

<p>window, roof or information relevant to cost, time taken for construction, options for specification or even the maintenance information.</p>	
<p>BIM is a set of technologies and organization solutions that are expect to increase inter-organizational and disciplinary collaboration and coordination in construction industry and to improve the productivity and quality of design, construction, and maintenance of building.</p>	<p>Paavola et al (2014)</p>

In relation to BIM, there have been many available terms that researchers as well as organisations use to mention the massive ability of this approach to the construction industry. Succar (2009) collates the different connotations of multiple BIM terms as illustrated in *Figure 4* below:

Figure 4. Some common connotations of multiple BIM terms



Succar (2008 cited in Succar, 2009)¹

Also in this research, Succar (2009) had gathered some different wide used terms of BIM in both industry literature and researchers, which is presented in *Table 2* below:

¹ Reprinted from Automation Construction, 18 (3), Succar, B, Building information modelling framework: A research and delivery foundation for industry stakeholders, pp.357-375, Copyright (2009), with permission from Elsevier.

Table 2. Widely used terms relating to Building Information Modelling

Sample terms	Organisation or Researcher
Asset Lifecycle Information System	Fully Integrated & Automated Technology
Building Information Modelling	Autodesk, Bentley Systems and others
Building Product Models	Charles Eastman
BuildingSMART™	International Alliance for Interoperability
Integrated Design Systems	International Council for Research and Innovation in Building and Construction (CIB)
Integrated Project Delivery	American Institute of Architects
nD Modelling	University of Salford — School of the Built Environment
Virtual Building™	Graph iSOFT
Virtual Design and Construction & 4D Product Models	Stanford University— Centre for Integrated Facility Engineering
Other terms: Integrated Model, Object Oriented Building Model, Single Building Model etc.	

However, no matter what whether the terms are exact enough to describe about BIM ability in assisting delivering construction projects or not, BIM helps to spread knowledge domain within the Architecture, Engineering, Construction, and Operation (AECO) industry is undeniable (Succar, 2009). To further understanding about BIM as well as its concepts, a critical examining will be showed in the next section.

2.3. CONCEPT OF BIM

The wide spread development of BIM in recent years has attracted a large number of attentions from AECO industry. It emerges as a phenomenon to innovate the construction industry therefore players who participate in progress of project delivery have to change their way of thinking and working to be get involved into the BIM collaborating working environment. However, there have been still not many people understand entirely the concept of BIM as well as how BIM works within the industry.

The concept of BIM was first introduced to the industry in the early stage of 1970s which was defined as a “Building Description System” (Eastman, 1975). In this stage, the concept of BIM emerged as the result of the appearance of computer software products supporting modelling for buildings. However, by this time, progress towards BIM was restricted due to the high cost initiative and the dominant success of Computer Added Design (CAD) (Eastman *et al*, 2011). Over last decades, the gradual maturation of BIM has been recorded through the development of BIM software, complex projects conducted with BIM as well as the continuous increasing number of BIM users across the world. The progress of BIM maturation across the world is briefed by Shepherd (2004) and Thompson (2010) in the Table 3 below:

Table 3. The brief of international BIM timeline

Years	International BIM timeline
1970	Concept of BIM started to emerge.
1976	Scottish Special Housing Association saved 4% of construction cost using fully automated design, detailing and tendering tools.
1977	Oxford Regional Health Authority deployed comprehensive BIM to accelerate hospital design using OXSYS.
1981	GMW used RUCAPS to design the largest university building in the world.
1983	Royal Bank of Scotland, Islington was the first project to be model in 2D and in 3D and as thermal model and shown to client as animated walk through

1987	ArchiCAD from Graphisoft abled to create both 2D and 3D drawings on a PC.
1992	Autodesk released AutoCAD 12 for DOS.
1995	US chapter of BuildingSMART founded.
1996	UK chapter founded
1997	First version of IFC standard released. Bentley released its first BIM application to run on Micro Station.
2002	Autodesk acquired Revit Technology Corporation and changed its basic platform. Singapore launched CORENET e-submission as a collaborative digital tool for planning applications.
2003	IFC2x2 released. General Services Administration (GSA) set up its National 3D-4D-BIM programme.
2005	IFC became ISO PAS 16739 (public Available Specification).
2006	Bentley's MircoStation V8i BIM application released
2007	In Finland and Denmark BIM use required for public sector projects and in US, GSA also mandated BIM use.
2008	Revit 2009 released. Bridge Academy, Hackney: new £50 million 7-storey school building opens (project used BIM). Heathrow Terminal 5 opened, having achieved unprecedented saving through structured information sharing. Akershus Hospital opened in Norway BIM was a vital tool throughout the project.
2009	48% of the US industry using BIM

The quick development of new information technology products in 2000s has enabled AECO industry to interact with BIM frequently. The companies started thinking about facing problems of justifying their investments. The concept of BIM became the main focus of AECO industry and it was described by Eastman *et al* (2008) as the process of collaborative working based on 3D modelling. Unlike traditional method which used 2D CAD or even 3D-CAD solutions, BIM allows faster and more accurate modelling of structural elements and systems by carrying parametric object-based modelling technology. It provides an integration of data in a single collaborative 3D model that can be used in construction and maintenance phases of life cycle (Eastman *et al.*, 2008).

Realising the huge benefits of BIM in conducting construction project as well as the roles of BIM in helping to innovate the construction industry, Governments across the world have mandated their industries toward BIM aiming to improve the construction industry productivity and performance (SmartMarket Report, 2014). This has already helped to boost the increase in number of BIM users across the worlds. The mandate of BIM and current BIM adoption across the world will be discussed in next section

2.4. BIM MANDATES AND ITS ADOPTION

As BIM implementation are increasing across the world. Governments are stimulating its capability to minimise risks and maximize benefits the progress of delivering projects in AECO industry. Therefore, in last few years, BIM is achieving essential support from governments or even being enforced a compulsory requirement in the industry. The Table 4 below will summarise countries where BIM is high demand to use together with standards and policy initiative.

Table 4. BIM standardization and/or policy initiatives by country

Country	Organization	Standardization and/or Policy Initiative
USA	<ul style="list-style-type: none"> • U.S. General Administration (GSA) 	<ul style="list-style-type: none"> • National 3D-4D BIM Program in 2003 • BIM required in all final concept approval for all major projects since 2007 • 3D, 4D, and BIM technology deployment encouraged in all GSA projects • GSA BIM Guide Series
	National Institute for Building Science (NIBS)	<ul style="list-style-type: none"> • National Building Information Modelling Standard (NBIMS) on Building Energy Performance(BEP)
UK	UK government	<ul style="list-style-type: none"> • Model-based BIM (level 2) mandated on all public sector projects by 2016. • Commitment to BIM in Government projects over a 5-year time frame.
	BIM Task Group	<ul style="list-style-type: none"> • Support and assistance in transitioning to BIM and electronic delivery.

		<ul style="list-style-type: none"> • Information sharing environment (Operations Building Exchange COBie).
	AEC (UK) committee	<ul style="list-style-type: none"> • Unified standard for the Architectural, Engineering and Construction industry CAD & BIM in the UK
	British Standards Institute	<ul style="list-style-type: none"> • Information sharing standards created (PAS 1192:2)
Finland	Senate Properties	<ul style="list-style-type: none"> • Models meeting IFC standards in its projects mandated since 1 October 2007 • BIM Guide called Common BIM Requirement 2012, COBIM
		<ul style="list-style-type: none"> • BIM mandated for the lifecycle of their buildings.
Norway	Civil State Client Statbygg	<ul style="list-style-type: none"> • All Statbygg project using IFC/IFD based BIM by 2010. • Statbygg Building Information Modelling Manual released in 2007.
	Norwegian Homebuilders Association	<ul style="list-style-type: none"> • Norwegian Homebuilders Association BIM Manual.
Singapore	Building and Construction Authority (BCA)	<ul style="list-style-type: none"> • BIM e-submission system mandated for regulatory submissions in 2015. • Singapore BIM Guide
Hong Kong	Hong Kong Housing Authority	<ul style="list-style-type: none"> • Full implementation of BIM on all its housing development projects by 2014. • BIM standards, user guide, library component design guide and references.

South Korea	Korean Ministry of Land Infrastructure and Transportation (MLIT)	<ul style="list-style-type: none"> • BIM mandated for all projects over S\$50 million and for all public sector projects by 2016.
Australia	BEIIC (the Built Environment Industry Innovation Council)	<ul style="list-style-type: none"> • National Building Information Modelling Working Party reporting to BEIIC. • NATSPEC National BIM Guide developed in 2011

Adopted from Edirisinghe et al., (2015)

Besides, McGraw Hill Construction (2014) also proposes a list of countries where BIM is compulsory method for procuring construction projects. Details of BIM mandatory among these countries are presented in Table 5 below.

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Table 5. Countries with national mandates

Country	Name of mandate	BIM data required	Building sizes or budgets requiring BIM	Submittal file format	Reasons for establishing policy	Supporting materials	Date of original/current mandate	Future phase in plans
Denmark: Building & Property Agency under the Ministry of Climate, Energy and Building	Executive Order N0.18	Project lifecycle (architecture through O&M)	5M kroner and higher for national project 20M kroner and higher for regional and municipal projects	IFC, Native	<ul style="list-style-type: none"> - Reduce energy consumption in buildings - Improve productivity - Shorten coordination and communication among team members 		2007/ 2013	
Finland: Senate properties	Common BIM	Project lifecycle (architecture	All national public projects	IFC, Native	- Support making design and construction lifecycle process safe	Guidelines (updated in 2012)	2007/ 2012	

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	Requirement 2012	through O&M)			<ul style="list-style-type: none"> - Support making design and construction lifecycle process compliant with sustainable development - Utilize models for facility management 			
Norway: Statsbygg	Statsbygg BIM Manual 1.2.1	Architecture and handover data	All national public projects	IFC, Native	<ul style="list-style-type: none"> - Reduce errors and omissions - Improve communications and coordination - Gain efficiencies - Increase energy efficiency - Use cutting edge research, technologies and processes to improve the built environment 	BIM manual 1.2.1	2005/ 2013	Additional BIM data requirements expected by 2016
Singapore: Building and Construction Authority	BIM Road map and e-submission requirements	Architecture and engineering data	All new buildings over 20,000 sq.m	IFC, Native, 3D PDF or 3D DWF	<ul style="list-style-type: none"> - Increase construction industry productivity by 20% to 30% over the next decade - Achieve BIM use by 80% of Singapore's construction industry by 2015 	<ul style="list-style-type: none"> - Training - Financial incentives - Guidelines 	2012	All new buildings over 5,000 sq.m. in 2015

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					<ul style="list-style-type: none"> - Realise a highly skilled and technologically advanced construction sector led by progressive firms and supported by a skilled and competent workforce in 2020 	<ul style="list-style-type: none"> - Sample contract language - E-submission templates - Award programs for innovators 		
South Korea: Public procurement Services	BIM Guide version 1.2	Architecture and property data	All public buildings costing over \$27.6M	IFC, Native	<ul style="list-style-type: none"> - Increase energy efficiency - Reduce design errors - Reduce construction costs - Support efficient facility management 		2010	BIM required for all projects by 2016
United Kingdom: The Carbinet Office of Government	Government Construction Strategy	Project lifecycle (architecture though O&M,	All national public projects	COBie, Native, PDF	<ul style="list-style-type: none"> - Reduce construction costs - Reduce project delivery time - Make UK's design and construction industry more competitive globally 	BIM Task Group provides support for both the UK	2011	BIM requirements will apply in 2016

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Construction Board		defined in the UK as Level 2)			- Help UK meet carbon reduction targets for buildings	government and supply chain		
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It seems that, the efforts of countries in supporting and encouraging or even mandate BIM adoption in the construction industry for project delivery have obtained positive achievements. The recent evidences indicate that the number of BIM users around the world have recorded a significant increase over last few years.

According to a 2012 SmartMarket report (SmartMarket, 2012), BIM adoption in North America has rocketed, from 17% of organisations in 2007 to 71% in 2012. Besides, as regards levels of experience in BIM use, the number of organisations with five and more years' experience in BIM use double between 2009 and 2012: from 6% to 13% for those with five years' experience, and from 18% to 36% for those with more than 5 years' experience. In contrast, the number of users with two years' experience or less fell by half, or more, over the same period.

The current use of BIM is not only popular in construction industry but also in many other different sectors across the UK and the US. The 2012 SmartMarket report (SmartMarket Report, 2012) illustrates that BIM implementation has risen to over 50% of infrastructure projects in many different sectors

As for BIM awareness, Adrain (2013) conducted a survey in the UK, posted in the National BIM Report of 2013, which garnered the highest number of responses of any such survey to date, reflecting the important of BIM to the construction industry in 2012. The findings show that as many as 93% of respondents in 2012 were aware of BIM (39% "currently using" BIM, plus 54% "just aware of BIM"), while only 6% were "neither aware nor using" BIM (*Figure 5*).

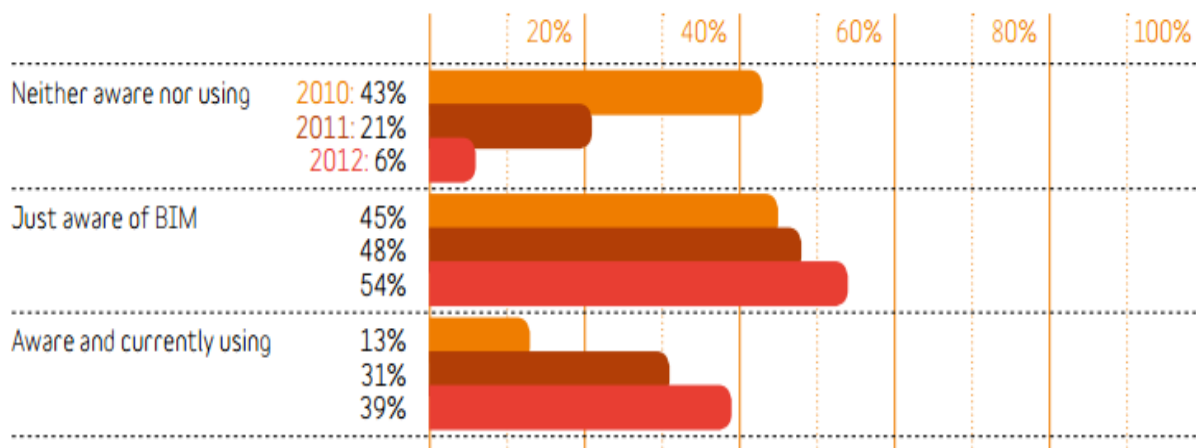


Figure 5. Awareness and use of BIM (Adrain, 2013)²

However, among those aware of BIM, not all were using BIM in their project in 2012. The survey shows that in 2012 only 43% were using BIM (though this does present an increase of 12% from the 2010 figure of 31%). The rest reported that they planned to use BIM within the next one to five years (Figure 6).

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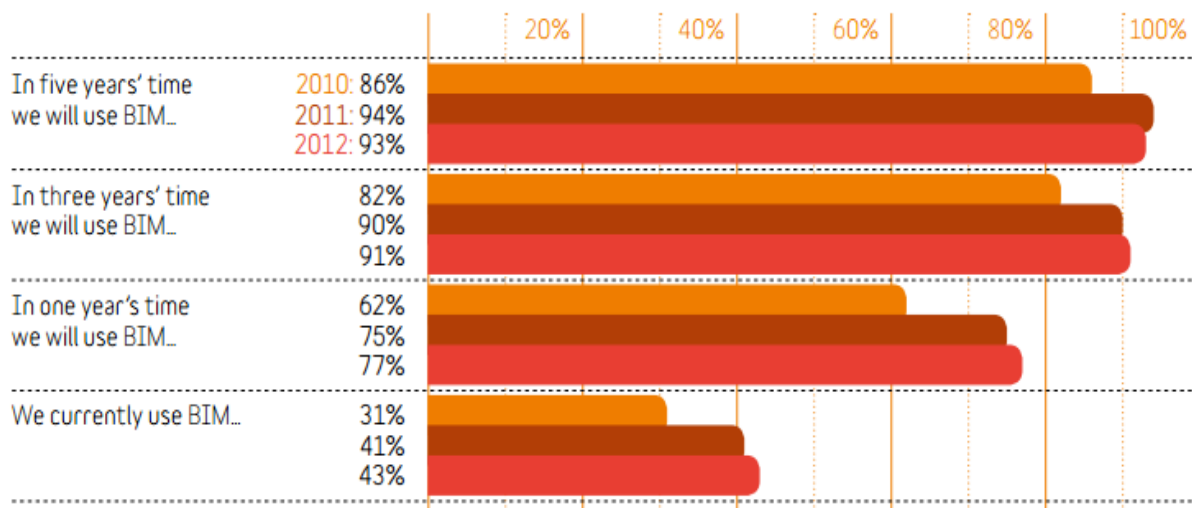


Figure 6. Projected use of BIM among those aware of it (Adrain, 2013)³

In the latest report regarding on BIM adoption in the UK posted in the National BIM Report 2016, Adrain found that 54% of responses are aware of and using BIM on at least some of their projects, 42% said they were just aware of BIM, and 4% were neither aware nor using *Figure 7*.

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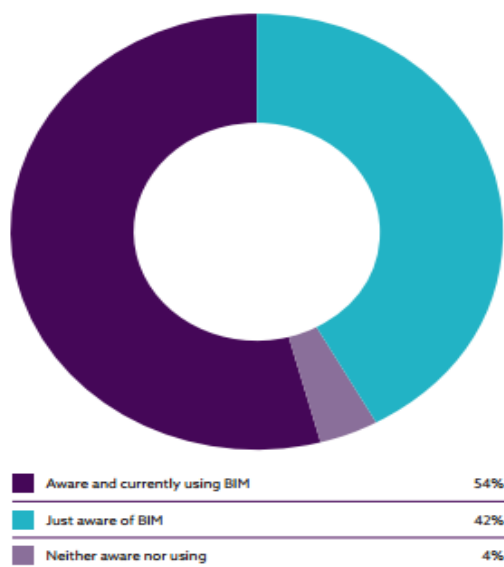


Figure 7. BIM usage and awareness (Adrain, 2016)⁴

In the report on the business value of BIM for construction in major global markets, SmartMarket Report (2014) shows that all countries investigated have BIM using from 1-5 years. In which, Brazil occupies the highest portion with 97%, followed by Australia & New Zealand with 89%, closely followed by UK, France & Germany with 88%.

Those figures arise the inference that BIM adoption amongst those countries has become a phenomenon of applying advanced technology to innovate the construction industry. The players in construction sector seem partly realising the benefits as well as risks that their organisations are going to deal with when BIM becomes a compulsory. However, the extent to which BIM can benefit as well as challenge firms are still questionable. Therefore, in order to convince players in the construction industry in addition to prove the roles of BIM in innovating construction industry, a consideration of BIM best practices which are reviewing of highlighted BIM projects is significant. This process will be presented in the next section.

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2.5. BIM BEST PRACTICES

The historical construction and architecture industry of the UK has ever witnessed plenty of unsuccessful project delivery which mainly results from mistake in appointing procurement method, contractor and suppliers. For example, some projects in the UK that all finished late and over budget including British Library, upgrades of the West Coast Main Rail Line, London Underground's Jubilee Line Extension, the Scottish Parliament building, the new Wembley Stadium and Bath Spa. Among them, Bath Spa is considered as the most delayed and disrupted project as a result of using wrong procurement and lacking collaborative working (Pryke, 2009)

Within the increasing development of technology, the construction industries around the world have been largely influenced and offered great benefits which cannot be achieved without supporting of advanced technology. One of the most famous projects in the UK which was supposed to be one of the biggest construction projects in European countries is the Heathrow Terminal 5 – T5 project which was controlled by British Airport Authority (BAA) and finished in 2008 (Potts, 2008).

As a £4.3bn five-year mega project, it is big and complex enough for BAA to think about adopting new technology in order to avoid cost and time overruns which was norm for mega project in the UK at that time (Pryke, 2009). By using technology to create 3D computer model and the adoption of integrated supply teams with equality between all members, it helps to generate significant benefits for all stakeholders. Besides, working on a single sharing model was able to cut off 10 per cent of the overall cost of this project Pott (2008).

Typically, collaboration working in single sharing model in T5 project is the process of using BIM in delivery the project. It helps to improve planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle (The National Building Information Modeling Standard (NIBS) 2008, cited in Eastman *et al.*, 2011). The success of T5 was due to the increase of transparency and creation of more integrated design and construction process supporting from BIM (Reddy, 2012) and the collaboration by different stakeholders at different stages to import, export, and update or modify information in the BIM model (Smith, 2007).

Another project which is also beneficial from BIM is Sutter Medical Center Castro Valley in the US, one of the best adopter of BIM implementation. It is a \$320 million, ~37 months; 230,000 sq. ft., and 130 beds project. The project was applied integrated project delivery method (IPD) together with BIM which helps to facilitate early collaboration during design and construction stages. In this project, 11 team members together shared in the project contingency funds and therefore jointly control their opportunity for gain or loss. The outcomes of this project are as follow (Eastman et al, 2011):

- IPD requires a shared commitment to the owner's goals; parties equally share the reward and risk.
- Owner driven.
- Target value design
- Integrated supply chain
- Lean practices
- Production level modelling
- Significant benefits
- Faster design
- Faster cost feedback
- Improved productivity
- Increased pre-fabrication
- Less rework
- On time
- Under budget

However, the most important advantages of BIM in this project are the opportunity to achieve the return on investment to all parties by using IPD method, which help to contribute to encouraging non-BIM user to rethink about adopting BIM in project delivery (Eastman *et al*, 2011).

The Table 6 below presents a brief review of some BIM practice projects as well as benefits that project participants achieve throughout adopting BIM to deliver construction projects.

Table 6. Some BIM best practice case study

Project name	Brief description	Benefits	Reference
<p>Shanghai China Tower,</p>	<ul style="list-style-type: none"> - Project value: €1,716 million. - Project size: 575,000m² of building space. - It is a 121-story transparent glass tower. - Once complete, the 632-meter Shanghai Tower will be the largest skyscraper in China as well as one of the most sustainable. - BIM required. - Targeting a LEED® Gold rating and a China 3 Star rating. - The project involves the collaboration of a 11 teams across the world. 	<ul style="list-style-type: none"> - By transforming to BIM process, it helps to set up new standards for information management of construction project in China - Integrated design enables to share the centre model to mechanical, electrical, and structural consultant team which helps to accelerates whole design process and engineers can access design data and geometric sizes directly from building model for calculation and analysis purpose. - Design communication improved. 3D virtual building helps better monitor construction and easier for the workers to understand complex construction drawing. 	<p>Autodesk (2012); McGraw-Hill Construction (2010)</p>

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		<ul style="list-style-type: none"> - Enhancing coordination amongst project teams especially subcontractors which lead to a better quality design and the avoidance of rework costs. - Saving 32 percent of building materials. - Significant improved construction efficiency and reduced on-site rework and material waste. 	
<p>Aylesbury Crown Court in Aylesbury, UK</p>	<ul style="list-style-type: none"> - Project value: £35 million. - Project size: 5,200 m². - Design by London offices of HOK with Turner & Townsend and AECOM. - BIM was required. 	<ul style="list-style-type: none"> - Decisions were made earlier in process and do not have to spend much time going back and forth at conceptual phase. - Detailed quality in model allow to check cost in real time effectively to keep client apprised of budget issues. - Changes can be made quickly for couple of weeks compared to traditional method which would have taken about two months. - Level of detail in the model help to identify spaces of the project easily. 	<p>McGraw-Hill Construction (2010)</p>

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		<ul style="list-style-type: none"> - Enabling sustainability through early energy analysis of building. - Enhancing contractors in bidding process. 	
<p>St Helens and Knowsley Hospitals Project in North West Sector, UK</p>	<ul style="list-style-type: none"> - Project value: £338 million. - Project size: 120,000m². - Type of Work: New build and refurbishment. - Design and construction: 2006 – 2009 - BIM required. 	<ul style="list-style-type: none"> - The team collaborative processes have enhanced to increase the quality of the data they exchange. - BIM generates a greater certainty of physical fit for off-site production - BIM enables the delivery of co-ordinated and complete construction information in a timely fashion. - Operation and maintenance information can be tracked during project process. 	BSI (2010)
<p>The Civil Engineering Research Building, National Taiwan University</p>	<ul style="list-style-type: none"> - Project value: 8,133,641USD. - Project size: 9,886m². - Completed in 2008. - BIM required. 	<ul style="list-style-type: none"> - Reduce errors at the design stage. - Improve the overall efficiency of design. - Provide the most cost-effective solutions. - Offer the most energy efficient solutions. 	Guo <i>et al.</i> , (2016)

Besides, throughout reviewing 10 different BIM projects, Eastman *et al* (2011) describes great benefits of BIM in project delivery according their different phase of involvement which can be seen in the Table 7 below.

Table 7. BIM best practice case study based on project involvement phase

Phase	Benefits	Project name									
		Aviva Stadium	Marriott Hotel	Sutter Medical Centre	Maryland General	Crusell Bridge	100 11th Avenue NYC	One Island East Office	Music Centre	Hillwood Commercial	Coast Guard
Integrated Design	Support for project scoping, cost estimation	x		x						x	x
	Early and accurate visualizations	x	x	x			x		x		
	Optimize energy efficiency and sustainability	x	x	x			x		x		
	Automatic maintenance of consistency in design	x	x	x		x	x	x	x		x
	Enhanced building performance and quality	x	x	x	x	x	x	x	x	x	x
	Accurate and consistent drawing sets	x	x	x		x	x	x	x	x	x
Construction execution/ coordination	Earlier collaboration of multiple design disciplines		x	x		x	x		x	x	x
	Synchronize design and construction planning	x	x	x		x	x	x	x		
	Discover errors before construction (clash detection)		x	x		x		x	x		
	Drive fabrication and greater use of prefabricated components	x	x	x		x	x				

	Support lean construction techniques		x	x	x	x					
	Coordinate/ synchronize procurement		x	x	x	x					
Operation	Lifecycle benefits regarding operating costs		x	x	x	x	x				
	Lifecycle benefits regarding maintenance		x		x				x		

In order to further understanding the significant roles of BIM in project delivery as well as encouraging the adoption of BIM in AECO industry, an examining benefit as well as barriers of adopting BIM to deliver construction projects is significant. The section below presents advantages that BIM awards project participants. In addition, barriers as well as attentions that stakeholders of BIM project need to pay attention on are also indicated.

2.6. BENEFITS OF BIM

It is obvious that, an adoption of BIM in conducting construction projects has brought stakeholders tremendous benefits in variety of aspects. Zuppa *et al* (2009) states that architects are more likely to see the benefits of BIM as enhancing coordination, productivity, and business operations. Likewise, contractors see improvements in scheduling, estimating, and drawing processing. BIM can be the significant approach to improve the interoperability within the supply chain including many different parties coming from different interests (Roger *et al*, 2012). The key factors of interoperability are effective communication, cooperation and integration between and among relevant departments in the organization to ensure that the tasks are well understood and implemented successfully. In other words, the management of design would not be isolated in the design department, but should involve the entire organisation, if commercially successful products are to be the outcome (Ughanwa, 1988). Therefore, Roger *et al* (2012) point out that in business process characteristics for using a BIM, the main efficiency is reducing costs, sharing information through interoperability and unlimited access leading to the integration of the various disciplines within the construction industry. In relation to procurement route, BIM is also acknowledged that it can be used for every procurement route and the level of benefits is varying according to the different procurement characteristics. As such, BIM with an integrated model development will increase the collaboration, communication and decrease the unforeseen risks across from small to large and complex projects (London *et al*, 2010).

In addition, BIM can be used for the purposes of visualization, greater use of off-site fabrication, code reviews, forensic analysis, facilities management, cost estimating, construction sequencing and conflict, conference and collision detection, which contribute to conducting project faster (Blake, 2012). The Co-operative Research Centre for Construction Innovation (CRC Construction Innovation, 2007) states that the key benefits of BIM can be concluded:

- The information can be shared easily, value-added and reused.
- The simulations feature can help to design better.
- Documents are exchanged quickly and easily.

However, regarding the construction industry, the two most significant benefits of BIM adoption in project delivery are the ability of added value and the return on investment.

The research of the British Council for Offices (BCO, 2013) indicates that the three most significant areas of value creation of using BIM in project delivery are De-risking construction, Building performance, and Operation and maintenance. As might be expected, BCO (2013) reveals that BIM coordinated design model enables stakeholders to effectively cooperate, accurately assess design risk and easily reduce the design risk allowance in the contract. Besides, the BIM process delivers fully coordinated design at an earlier stage of the process, significantly reducing uncertainty, offer enormous opportunities to reduce waste of materials and times, increase efficiency in the design construction and operational phases of a development. Whereas the traditional approach to design and construction, value is created and then destroyed at all stages of the process.

In addition, BIM also helps building performance has been improved significantly throughout accurate modeling of MEP (mechanical, electrical, plumbing) requirements. 3D modeling of all services and structure allows the design team to deliver a highly efficient building with actual requirements for servicing space identified rather than allowances being made.

Over longer term and short term, the greatest benefits of BIM have been identified by SmartMarket Report (2012) that in short term benefits, BIM can enable stakeholders to reduce document errors, omissions and reworks during the process of project delivery. Those findings are obviously suitable to characteristics of BIM as in comparison with traditional method of project delivery which is usually based on 2D drawing, BIM offers 3D virtual model that allows all components of the building as well as its information are clear presented. All clashes as well as unforeseen risks are also detected carefully before the real building comes into being constructed. Besides, in both long term and short-term benefits, BIM proposes organisations potential abilities of generating new services, new business and maintain repeat business. This benefit is essential because it can contribute to helping organisations to shorten the progress of getting the return on investment (ROI).

In the relation to the return on investment (ROI), many research findings indicate that ROI can be achieved through BIM adoption. BCO (2013) found that contractors as well as SME with strong BIM capability are able to capture a significant percentage of the value created through reducing risks and costs during construction.

SmartMarket Report (2014) reports that 75% of contractor participated in the research currently believe they have a positive ROI on BIM investments. It is interesting that the deeper levels of BIM engagement are showing the higher ROI on their BIM investment with 90% of contractors at very high BIM engagement have a positive ROI on their investment compare to only about 65% of low BIM engagement companies.

In order to maximise the potential value creation and ROI of using BIM, full coordination and collaboration by all parties from the initial stages is an absolute necessity. The real example of full this process is the integrated project delivery (IPD) method which has been applied successfully in many complex project and help cut construction cost by 20-30%, and in which all parties share in information, collaborate, and are rewarded according to their contribution to the project (BCO, 2013).

Throughout investigating data on 32 complex projects, Azhar (2011) indicates that the Stanford University's Centre for Integrated Facilities Engineering concludes the following benefits as a result from the progress of integration in conducting project:

- Up to 40% elimination of unbudgeted change.
- Cost estimation accuracy within 3% as compared to traditional estimate and up to 80% reduction in time taken to generate the cost estimate.
- A saving up to 10% of contract value through clash detection.
- Up to 7% reduction in project time.
- Up to 13% saving of project overall cost.
- Up to 70% cost saving for building maintenance.
- Quality and accuracy improvement.
- Document automation.
- Full integration for the AEC teamwork and the supply chain players.
- Enabled quick decisions and reduced risks

However, aside from benefits that stakeholders are able to achieve from adopting BIM to deliver construction project, they may also potentially face with challenges as well as issues associated with the transformation from traditional project delivery method to BIM. Those issues are indicated in section below.

2.7. CHALLENGES AND ISSUES RELATED TO ADOPTING BIM IN PROJECT DELIVERY

Along with massive benefits that BIM has positively influenced on the AECO industry, there are also some barriers that organisations need to consider when adopting BIM in practice. One such barrier preventing the adoption of BIM in project delivery is the cost initiative (Alreshidi *et al*, 2017). A considerable investment is required for the updating both software and hardware and for the training of staff to ensure that BIM can be implemented effectively. While return on investment will typically takes up to 4 years, companies will have to spend large amounts of money on initial startup costs (Beck, 2009). But this the clear eventual payback on this initial investment is corroborated by finding in the McGraw Hill (2009) on the business value of BIM, which found that 27% of surveyed contractors in the United States reported a return on investment of between 10-25%.

It may seem at first sight that the costs of investment in software and training do not usually appear overly cumbersome when compared to the overall cost of delivering a construction project; but in fact, in the case of BIM, the costs of investment on software and hardware upgrades is typically considered to be within the top four barriers to its wider adoption of BIM (McGraw Hill, 2008). For example, there is an increase in cost and time involved in converting the 2D drawings into a BIM model, and other additional financial management costs involved in adopting the BIM approach (Alreshidi *et al*, 2017). Rana *et al* (2013) point out that there is often concern and uncertainly over whether these additional costs will be borne by clients or shared among stakeholders.

Moreover, evaluation of the benefits of BIM adoption in project delivery is not easy, for a number of reasons. The said benefits can be sometimes tangible and sometimes be intangible and usually only take effect over the whole lifecycle of building project; the implementation of a new system may necessitate organizational changes; conflicts between parties may occur; and the individual skills of those using BIM may vary considerably (Joo *et al*, 2011).

Finally, the 2008 McGraw Hill survey (McGraw Hill, 2008) and Alreshidi *et al*. (2017) point out that lack of training is one of the greatest barriers to the wider adoption of BIM technologies. This is because BIM requires different ways of thinking about how designs are developed and building construction is managed, therefore the lack of trained staff will create

considerable obstacles to BIM adoption (Eastman, 2011). Lack of skills and knowledge in BIM in any given firm will mean that a careful analysis of responsibilities will be necessary within that firm: for example, if a decision is made to design a building using BIM, while the 2D drawing phase can be skipped, completing the design in 3D may require the deployment of modelers skilled in the use of BIM software (O'Brien, 2008).

Besides, issues associated with legality involving in the adoption of BIM in project delivery concerns identification of the ownership of BIM data (Alreshidi *et al*, 2017). Issues relating to ownership of a model are only apparent when BIM is used in a collaborative working environment, with many different parties contributing to producing and delivering the models. Specially, ownership becomes relevant when design teams each put their own elements into a model and make the model available to other parties (Azhar, 2008).

The key issue of concern for many information providers is that the open use of data in a BIM model will make it more difficult to protect intellectual property rights. When project members contribute their works in sub-models integrated into the central BIM model, licensing issues can arise, and should be considered carefully to avoid potential disputation over the possible use of the sub-models for other purposes or in other projects. Typically, equipment and material suppliers offer designs associated with their products for the convenience of the lead designer in the hope of encouraging the designer to specify that supplier's equipment. Now, while this practice may be good for business, licensing issues can nevertheless arise in the case of the vendor's design not being licensed in the location of the project (Thompson *et al*, 2007; Alreshidi *et al*, 2017).

BIM technologies provide stakeholders with the possibility to use a central 3D model throughout the project, for multidisciplinary collaboration. To enable this multiparty collaboration, it is essential to have both synchronous and asynchronous data access and control for the 3D model (Ku *et al*, 2011). Besides this, whereas traditionally data updates on the working progress of a project are usually collected daily as paper-based reports, by using BIM the process can be replaced with automatic updating through a digital model. Ongoing comparison between the actual work performed and the as-built data to plan schedule allows easy checking of any deviation between the two (Roh *et al*, 2011). However, it is necessary to address the issue of who will be responsible for the control of data entry into the model, and who will be responsible for any inaccuracies in it. This process is of considerable significance,

since the updating and control of BIM data involves a great deal of risk. Even minor errors result in problems which cause projects to fail or be delayed, especially when difficulties arise; and identifying who is to blame is a challenge (Thompson *at el*, 2007).

Finally, due to the fact that project stakeholders all share project information and each may add details to the project model, levels and limits of responsibility are blurred by the integrated concepts of BIM, so that risks and liabilities will likely be increased (Rosenburg, 2007).

2.8. CONCLUSION

The aim of this chapter has been to provide explanatory information associated with BIM, its adoption and its benefits, as well as the challenges that BIM users may need to deal with when participating in BIM construction projects. The wide-ranging, game-changing capabilities of BIM have been presented through some of the many compliments it has received in the literature and consideration of different scenarios such as the process of deploying and managing construction projects has demonstrated that BIM represents a revolution in technology, one that has changed the working style of the construction industry from its traditional way of functioning to a highly collaborative operational environment.

The concept of BIM was first introduced in the early 1970s as the result of the appearance of computer software products supporting modelling for building. BIM has been widely developed in the intervening years and has become a compulsory method for the conducting of construction projects in many countries across the world. The extremely powerful capabilities of BIM have been recorded through its application in the effective deployment of many different kinds of projects across the world. But alongside the huge number of benefits that BIM is able to offer project participants, the risks associated with adopting BIM to deliver construction projects also need to be taken into account in any comprehensive perspective of BIM in connection with the innovation in the construction industry.

The next chapter will investigate the UK construction industry's current BIM adoption, and its role in contributing to the development of the UK economy. This chapter will also highlight the important role of SMEs in the construction industry, and the necessity for them to move towards BIM adoption will be clarified.

CHAPTER 3: THE UK AEC SECTOR AND BIM ADOPTION

3.1. INTRODUCTION

This chapter begins with an investigation into the not inconsiderable role played by AEC sector in contributing to national economies worldwide (Section 3.2). The UK is no exception in this. The chapter continues by revealing current levels of BIM adoption in the UK AEC sector, as detailed in Section 3.3. The role of SMEs in the AEC sector in general and in the UK in particular are then examined in Section 3.4. The current use among SMEs of BIM to conduct construction projects is also uncovered (Section 3.5). From this investigation, the conclusion is drawn that there is a necessity for research as well as a need to develop a DSS to help SMEs to anticipate the risks and rewards of adopting BIM to deliver construction projects.

3.2. THE CONTRIBUTION OF AEC SECTOR TO THE NATIONAL ECONOMY

The AEC sector plays an important role in economic growth of any countries. The activities of this sector have generated a great importance to the achievement of the national economy development targets regarding on providing infrastructure and employment. The construction products provide the necessary public infrastructure and private physical structures for many productive activities such as services, commerce, utilities and other industries. It consists of hospitals, schools, townships, offices, houses and other buildings; urban infrastructure; highways, roads, ports, railways, airports; power systems; irrigation and agriculture systems; telecommunications etc. (Khan, 2008).

The output of AEC sector is major and is expected to be an integrated part of the country's national economy and industrial development (Anaman *et al*, 2007). Typically, the linkage between the value added by construction as a share in the Gross Domestic Product (GDP) and per capita GDP has long been recognized. It accounts for a sizeable proportion in the GDP of both developed and underdeveloped countries. Wibowo (2009) states that the share of the value added by construction as a percentage to GDP was found to be around 7%–10% for developing countries and 3–6% for more developed countries

This figure can be changed over years due to the development of the industry. Specifically, by investigating 39 countries across the world (Table 8) through the data available in United

Table 8. GDP per capita and GVA in construction for countries showing growth in GDP per capita period (1994–2000)

	GDP per capita (\$US) (1994)	% GVA in construction (1994)	GDP per capita (\$US) (2000)	% GVA in construction (2000)
Bangladesh	250	5.9	362	7.7
Indonesia	909	6.9	723	5.6
Sri Lanka	660	7	854	6.9
Honduras	622	5	919	5.7
Philippines	965	5.8	988	5
Bolivia	841	4.7	995	2.8
Bulgaria	1136	5.1	1508	3.6
Surinam	924	3.3	1584	10.1
Romania	1317	6.1	1635	5.3
El Salvador	1463	4.7	2103	4.5
Jamaica	1583	12.9	2801	10.4
Latvia	1140	7.9	2952	6.2
Lithuania	1970	8.8	3039	6.3
Belize	2459	7.2	3345	7.1
Panama	2870	4.4	3508	4.8
Estonia	1538	5.7	3569	5.8
Mauritius	3134	6.6	3886	5.4
Costa Rica	2485	2.3	3964	3.9
Czech Rep.	3507	6.8	4942	7.1
Venezuela	2719	4	5017	4.8
Mexico	4145	5.4	5805	4.9
Trinidad and T.	3791	9.2	6239	10.5
Barbados	6643	3.6	9721	5.8
Korea, Rep. of	8858	13.7	9782	8.2
Greece	7467	5.3	10680	6.9
Cyprus	9924	9	11231	7.7
Spain	12188	8	14054	7.4
Puerto Rico	11559	2.2	17069	2.9
Italy	17800	5.2	18653	4.9
Israel	14629	4.6	19521	4.8
Australia	18847	6.3	20298	5.5
Singapore	21681	7.4	22959	5.8
Netherlands	21896	5.2	23294	5.7
Finland	19201	4.7	22377	5.7
Hong Kong SAR	21642	4.9	23709	4.9
UK	17510	4.8	24058	5
Ireland	14694	4.6	25066	6
Denmark	28038	4.7	30141	4.9
USA	25127	3.8	34637	4.8

Ruddock *et al.*, (2006)⁵

Nations (1997, 2003) in both gross value added (GVA) and GDP per capita over the period (1994 – 2000), Ruddock *et al* (2006) founds that there have been changing over time toward increasing during this period. This change has generated positive impact on the growth of the national economy.

The AEC sector has been recognised as one of the industry that consumes considerable amount of resources and proposes significant environment emphasis. Typically, Klotz *et al* (2007) indicates that buildings can consume up to 36% of the total energy used. It also amounts to 30% of the raw materials and 12% of potable water consumed in the US. In the report conducted by

⁵ Taylor & Francis is pleased to offer reuses of its content for a thesis or dissertation free of charge contingent on resubmission of permission request if work is published

National Institute of Building Sciences (2007) also stresses that buildings consume 40% of the world's raw materials and facilities consume 40% of the world's energy which means that it can be potentially generate 40% of the carbon emissions and release to the atmosphere.

In addition, Gidado (1996) also states that the AEC sector is considered more complex and difficult to manage. This usually originates from the uncertainty which is associated with unfamiliar with local resources and environment; lack of detailed activities at construction site; and inadequate details of material; and adopting advanced technologies and the interdependence among them (Dubois et al, 2002).

In the UK, AEC sector is considered as one of the most significant parts which contribute to the total UK economy (Myers, 2013). Historically, this sector had ever experienced a serious concern when it was not well placed to meet challenges coming from both public and private clients who looked forward to providing construction infrastructure necessary for them to succeed in their business objectives. Consequently, this sector had suffered badly during the recession of the early 1990s. Typically, its output has dropped 39% during the period of 1990-1993; there were about half of million jobs had been lost in the industry the period of 1989 – 1993 and 35,000 small business had gone because of the bankruptcy (Adamson *et al.*, 2006). The reason for this weakness was found by Latham (1994) that the AEC sector was fragmented with a poor ability to adopt innovative solutions, deficit of communication as well as and lack of trust amongst players in the (AECO) players. In fact, the fragmentation in the AEC sector can cause significant impacts on building owners and operators. Eastman *et al.*, (2011) supports that the fragmentation amongst players in the USA's AEC sector generated approximately 10.6\$ billion additional costs in 2002. In addition to the fragmentation, the conservative nature of players in the industry is also assumed as a vital factor leading to low improvement of the industry. This includes the lack of changing working habits, adopting new technologies and concentrating on collaborative amongst stakeholders (Hardin, 2009; Arayici *et al.*, 2011).

Similar to other developing countries, the AEC sector in the UK has been negatively influence by lacking communication and interoperability. As a result, projects in this sector become more complex to manage due to the involvement of various kinds of participant during the progress of project delivery (Dulaimi *et al.*, 2002).

Realising the significant roles of its activities in the economy as well as the high spread increasing demands from both public and private sectors clients, the UK AEC sector have gradually improved and achieved significant results in contributing to the growing of the economy. According to the Office of National Statistics (2010), United Kingdom (UK) AEC sector employs more than 1.9 million people which account 4.5% of employment in the UK with annual output more than £83.5 billion in 2007. This figures continue to raise by 2012. According to Myers (2013), the AEC sector of the UK contributes gross value of almost £90 million to the UK economy and amounts to 6.7% of the UK GDP. The industry also employs around 2.93 million jobs which is equivalent to about 10% of total UK employment.

The Department for Business Innovation & Skill (2013) looks at the UK AEC sector as a composition of construction contracting industry; provision of construction related professional services; and construction related products and materials, which is detailed in *Figure 8* below.

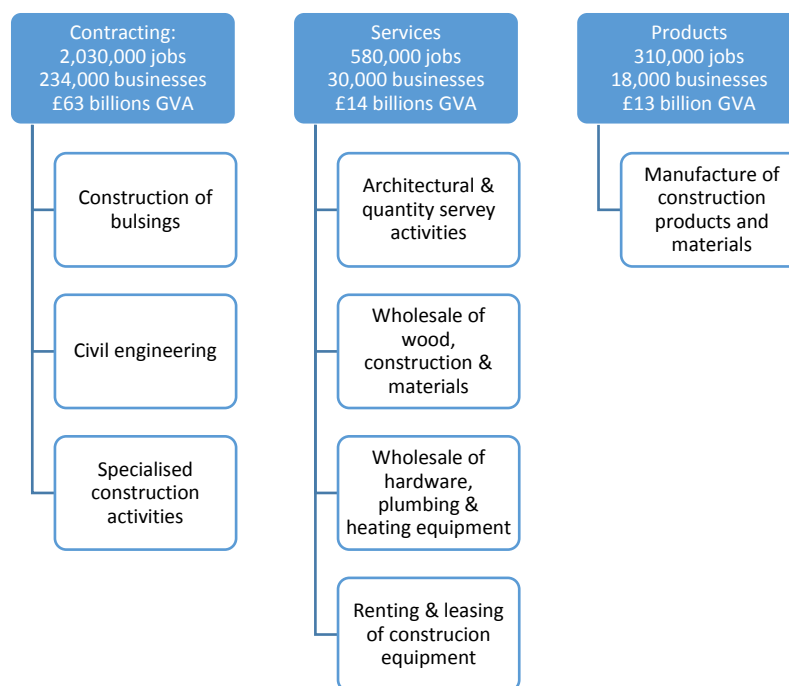


Figure 8. Composition of the UK construction sector, summarised from The Department for Business Innovation & Skill (2013) by author

In which, the contracting industry amounts to the largest sub-sector of the construction sector, which occupies about 70% of total VAG and almost 70% of the sector’s jobs. The construction products and services holds smaller in size but undertaking a core responsibility

in contributing to the industry's performance and generate substantial economic benefits The Department for Business Innovation & Skill (2013).

Within the ambition of promoting the sector to become one of the leading construction industries in the world, satisfying the requirement from clients as well as bring benefits to AECO players, the UK's government has set up important steps in the route of innovating the industry through adopting BIM technologies for their solutions. A more in-depth discussion of this progress will be presented in the next section.

3.3. BIM ADOPTION IN THE UK AEC SECTOR

In the UK, the BIM agenda was initially driven by Tony Blair New Labour Government who pushed forward the need to improve collaborative practices in construction. Sir John Egan commissioned by the Government to produce a report "Rethinking Construction", which concluded 'The movement would be a network through which members could collaborate with each other in developing construction techniques and skills and exchanging ideas for increasing efficiency and quality (Egan, 1998). This report sought to change the industry towards collaboration, focusing on information with a view to increase efficiency. The Egan report aimed to drive efficiency in the UK AEC sector, this push to efficiency is reflected in the overall aim of reducing the cost of Government construction projects by 15-20% (Cabinet Office, 2012)

The mandate to achieve 3D BIM level 2, and a 'cost reduction of 20% during the term of the current Parliament', was published within the UK Government Construction Strategic Report by the Cabinet office on 31 May 2011 (BIM Industry Working Group, 2011). *Figure 9* shows the maturity levels set by the BIM Industry Working Group within the document submitted to the Government in 2011 and helps take the ambiguity out of BIM. According to NBS (2014), details of BIM levels can be brief explain as below:

- Level 0:

- No collaboration.
- 2 CAD format.
- Output and distribution is via paper (or electronic prints) or a mixture of both.

- Level 1:

- No collaboration between different disciplines, each publishes and maintains its own data.
- Mixture of 3D CAD for concept and 2D for drafting.
- CAD standards are managed to BS 1192:2007.
- Electronic sharing of data is carried out from a common data environment (CDE)

- Level 2:

- Collaborative working, the collaboration comes in the form of how the information is exchanged between different parties – and is the crucial aspect of this level.
- All parties use their own 3D CAD models, but not necessarily working on a single, shared model. The information is shared through common file format. BIM software that each party used must be able to export to IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange).

- Level 3:

- Full collaboration between all disciplines through a central shared model.
- All parties can use and modify with a unique shared model.
- Fully open process and data integration by a collaborative model server.

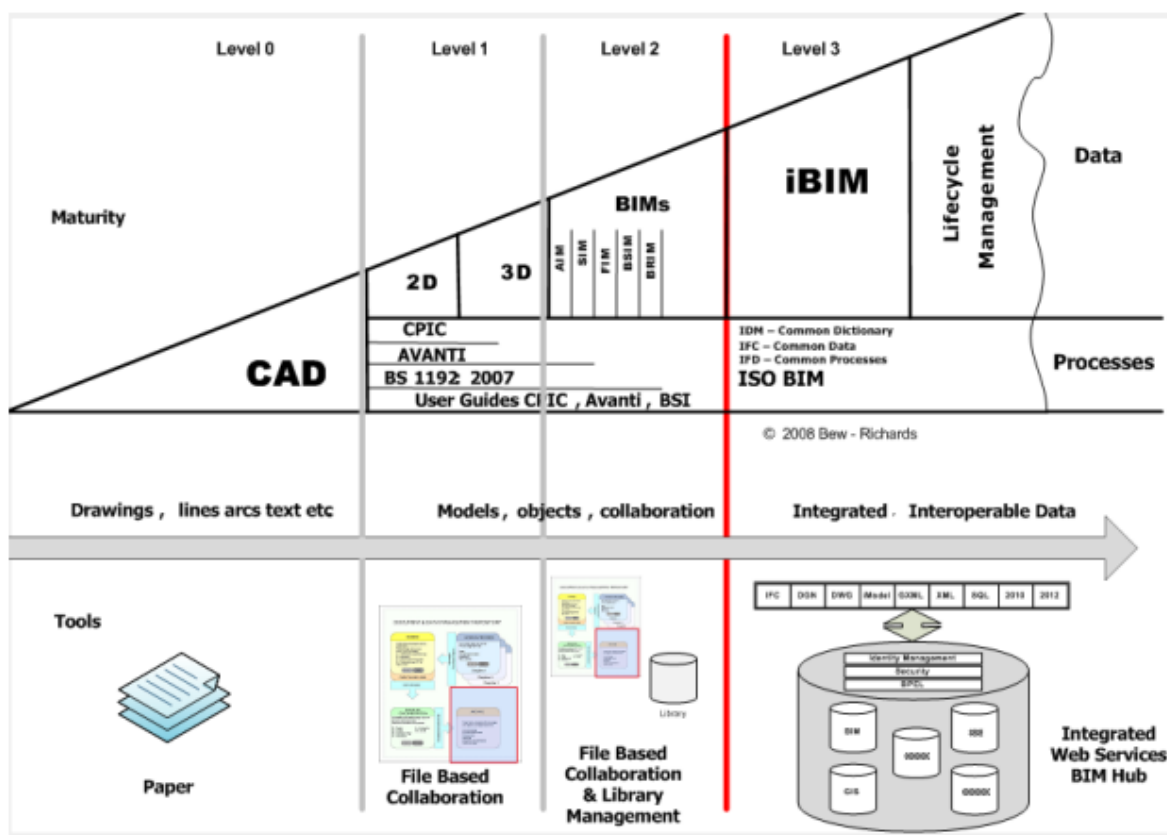


Figure 9. BIM maturity levels (Barlish et al., 2012).⁶

Basically, the BIM journey starts with CAD representing level 0 and the progress through the level of BIM shown on Figure 21. BIM is different to CAD in that the building is not merely designed it is also capable of being fully operated and maintenance through BIM technology. CAD 2D or even 3D drawing are graphic entities only, whereas the fundamental characteristics of BIM is the ability of carrying intelligent object based data which can contain details of the products and increase exchanging the flow of information in the model, collaborating by different stakeholders at different stages of the building lifecycle in terms of import, export, and update or modifying information in the BIM model (Smith, 2007). Therefore, using BIM in projects will help increase transparency and create a more integrated design and construction process, which will result in better quality buildings at lower cost and in a shorter time frame for completion (Reddy, 2012).

⁶ Reprinted from Automation in Construction, 24, Barlish, K., Sullivan, K, How to measure the benefits of BIM—A case study approach, 149-159, Copyright (2012), with permission from Elsevier

To encourage and support BIM adoption in the industry, the development of BIM support groups, standards and protocols has been implemented. Amongst them, BIM Task Group is considered as the official pioneer group which is supported by the Department for Business Innovation & Skill and Construction Industry Council. It aims to bring together expertise from industry, government, institutes and academia to strengthen the public sector's BIM capability and provide the information the industry needs to meet the government's BIM requirement (BIM Task Group, 2013). According to Designing Building Wiki (2016), this group consists of six core working parties involving to ensure BIM roadmap to be met the deadline by 2016. They are:

- Training and Education: Providing a long-term strategy to address the UK's inconsistent supply of BIM awareness and skills.

- COBie data set requirements: Documenting COBie 2.4 for use in the UK. It is a spreadsheet data format for the publication of a subset of building model information focused on delivering building information not geometric modelling.

- Plan of Works: The Construction Industry Council (CIC) Plan of Works group communicates a collective understanding of BIM amongst the Professional Institutions.

- BIM Technologies Alliance: An independent, non-product specific group facilitated by the Construction Industry Research and Information Association (CIRIA) focussing on providing generic advice and support to the Government.

- UK Contractors Group: The UKCG assists the BIM Task Group from a supply chain perspective.

- Construction Products Association: Working with the BIM Task Group to ensure that product data is available for design and construction and that operational data could be fed back to manufacturers.

In addition, The Construction Institution Council (CIC) was tasked with establishing a network of regional hubs to ensure up-to-date and consistent information is disseminated across the UK and allowing for local feedback to the BIM Task Group (Designing Building Wiki, 2016). In addition, BIM4SME is responsible for providing resources, best practices and knowledge to SMEs to get them to the BIM level 2 (Bim4sme.org).

Away from BIM support groups, it has been widely acknowledged that UK leads the way in terms of setting industry standards to enhance BIM adoption. In the report of SmartMarket Report published in 2014 about the business value of BIM for owners, McGraw Hill Construction (2014) indicates that 90% of BIM users (were asked) in the UK have standards and policies at their organisations for BIM execution, which can be implemented consistently with project teams. Some available standards and supporting documents for BIM adoption can be seen in Table 9 below.

Table 9. Review of existing standards and supporting documents for BIM adoption

Standard/ Document	Scope	Reference
BS 1192:2007	This standard was published in 1998 to provide a guide for structuring and exchange of CAD. It emphasizes on collaboration and effectiveness of reused data.	BSI (2008)
PAS 1192-2:2013	This Publicly Available Specification (PAS) was developed in 2013 and based on the existing code of practice for the collaborative production of architectural, engineering and construction information, defined within BS 1192:2007. This PAS focuses specifically on project delivery, where the majority of graphic data, non-graphic data and documents, known collectively as the project information model (PIM), are accumulated from design and construction activities. This PAS specifies requirements for achieving BIM level 2.	BSI (2013)
PAS 1192-3:2014	This PAS was developed in 2014 and is considered as the partner of PAS 1192-2 and mainly focus on information management for the operational phase of	BSI (2014)

	assets. This PAS specifies requirements for achieving BIM level 2.	
BS 1192-4:2014	This British Standard defines a methodology for the transfer between parties of structured information relating to Facilities, including buildings and infrastructure. It defines expectations for the design and construction project phases prior to handover and acquisition and the subsequent in-use phase.	(BSI, 2014)
PAS 1192-5:2015	This PAS specifies requirements for the security-minded management of projects utilizing digital technologies, associated control systems, for example building management systems, digital built environments and smart asset management.	(BSI, 2015)
CIC BIM Protocol	The BIM Protocol is a supplementary legal agreement that is incorporated into professional services appointments and construction contracts by means of a simple amendment. The Protocol creates additional obligations and rights for the employer and the contracted party. The Protocol is based on the direct contractual relationship between the employer and the supplier.	CIC (2013)
CIC Best Practice Guide for Professional Indemnity Insurance when using BIM	The Best Practice Guide has been produced support of the work of the BIM Task Group. The guide is directly addressed to the needs of insured parties – particularly consultants engaged in the production of definition information using Building Information Models. The aim of this best practice guide is to support the AEC sector’s take up of BIM Level 2 through summarising the key areas of risk which Professional	CIC (2013)

	Indemnity ('PI') insurers associate with level 2 BIM and what you can do about those risks as a prudent insured.	
NBS BIM Toolkit	The free-to-use NBS BIM Toolkit provides step-by-step help to define, manage and validate responsibility for information development and delivery at each stage of the asset lifecycle.	NBS (2016)
BIM2AIM document suite	The Ministry of Justice (MoJ) have launched a suite of documents on how to define, procure and deliver Level 2 Building Information Modelling (BIM) across their projects. The documents have been re-defined to assist the MoJ's supply chain by outlining a clear digital brief from tender and provide sufficient detail to enable data requirements to be packaged, procured and technically assessed on projects.	Ministry of Justice (2016)

In addition, the development of supporting groups, BIM standards as well as documents aiming to encourage and assist organisations in adopting BIM to deliver construction projects, a series of BIM frameworks has been also developed. It includes frameworks used to evaluate areas and to identify factors for practical BIM effectiveness (Jung *et al.*, 2011); ensure players work well in a multidisciplinary collaboration working environments (Singh *et al.*, 2011); optimise and simulate construction planning and scheduling (Song *et al.*, 2012); identify individual BIM competencies (Succar *et al.*, 2013); and ensure best value in construction projects (Porwal *et al.*, 2013; Liu *et al.*, 2015).

Consequently, BIM usage in the UK's AEC sector has recorded a significant increase over the last few years. The survey published by the National Building Specification (NBS) in 2013 shows that the percentage of industry using BIM rose from 13% in 2010 to 39% in 2012. Fifty-four percent of industry is not using BIM but is aware of it while 77% said that they would be using it in the next year (NBS, 2013). On 14 April 2016, the NBS (2016) published the sixth UK BIM study after 10 days the government mandate became a

compulsory requirement for minimum 3D BIM level 2. The report presents the view of more than 1000 AEC sector professionals across the UK. The findings indicate that 54% are aware of and using BIM (compared to 48% by 2015) whilst 42% were just aware of BIM. In a years' time 86% expected to be using BIM, and in 5 years, 97% (NBS, 2016).

Besides, in the SmartMarket Report in 2014 investigating about the business value of BIM for construction in major global markets, McGraw Hill Construction (2013) indicates that the percentage of contractors that have been using BIM from 1–2 years and 3–5 years are 47% and 41% respectively. In terms of BIM implementation with high and very high levels, this sector presents a dramatic increase, which is from 28% in 2013 to 66% by 2015. However, compared to other regions, the UK still occupies a very large percentage of low level of BIM engagement with 54%, ranked second highest, after Brazil holding 55% (McGraw Hill Construction, 2013). The large percentage of low level of BIM engagement in the UK explains for the impact of the government BIM mandates on the AEC sector as all public projects across the country have to be implemented with BIM at least level 2 by 2016. Typically, in another report about the business value of BIM for owners, McGraw Hill Construction (2014) compares the high and very high impact of government policies on owners' interest in BIM between the US and the UK, the results illustrate that over 67% of all UK owners are impacted by the mandate whereas the US's figure amounts to only 12%.

However, the number of BIM users in the UK's AEC sector are not growing evenly. There is evidence that BIM adoption concerns primarily large companies whereas small and medium sized enterprises (SMEs) are currently lagging behind and are losing out in winning construction projects. The next section will introduce about the SMEs as well as its current BIM adoption in the context of BIM mandates are becoming compulsory requirement in many countries across the world.

3.4. REVIEW ON SMEs

As was mentioned in the previous section, the common characteristics of AEC sector are complex and fragmentary, which consists of a large number of SMEs and fewer large companies, especially in developing countries (Langford *et al.*, 1991). Therefore, in any progresses of innovating AEC sector, a consideration on SMEs always attracts the attentions of the governments (Forstater *et al.*, 2006). Moreover, the definition of what constitutes to an SME has concerned the considerations from researchers and it has varied from one country or industrial sector to another. Ibrahim *et al.*, (1986) states that the most popular definition of SMEs is based on its characteristics. It includes the number of employees, turnover, asset size and capital requirement. Correspondingly, Anon (2005) proposes a similar definition of SMEs but more detail and simpler based on the European countries' standard under criteria regarding on the number of employees, annual balance sheet total or annual turnover. Typically, SMEs is divided into three groups detailed in Table 10 below:

Table 10. Definition of SMEs

Size of organisation	Number of employee	Annual balance sheet total or annual turnover
Micro	Less than 10	Less than or equal to €2 million
Small	Less than 50	Less than or equal to €10 million
Medium	Less than 250	Less than or equal to €50 million

Wedawatta *et al.*, (2010) reveal that a large number of SMEs are private owners or partnerships consisting of only the self-employed owner-manager, or companies encompassing only an employee director, which are group into the category of micro firms. Whist, the bulk portion of the remaining is small businesses, only a smaller portion are medium-sized. Due to the presence of many SMEs and less large businesses, a supply chain consisting of hundreds of organisations tend to deliver major construction projects (Stewart *et al.*, 2004).

SMEs are assumed as the backbone of many major economies across the world (Love *et al.*, 2004). The roles of SMEs in contributing to the development of the economies across the world are undeniable. Ayyagari *et al.*, (2007) indicates that SMEs employ up to 80 % of the world' workforce, generate about 54% of the global economy on average, and account for over 90 % of companies all over the world (Hsu *et al.*, 2012). By investigating 28 member countries of the European Union, Harty *et al.*, (2016) found that there are about 23 million SMEs which amounts to 99 % all companies and provide about 75 million jobs. In 2010, Canadian SMEs employed approximately 48% of the private sector workforce (Industry Canada, 2011) and 85% of new jobs were created by SMEs in the period 2002–2010 (Eurostat, 2012).

In the UK, there are 950,000 SMEs that generate about 80% of the production cost of the UK AEC sector (Robson *et al.*, 2014). At the start of 2014, 99.3% of the 5.2 million private sector businesses were small, and 99.9% were small or medium sized (Department for Business Innovation & Skills, 2014). According to the Federation of Small Business (2014 cited in Harty *et al.*, 2016), there are about 4.9 million business in the UK which employed 24.3 million people, and had the turnover of £3,300billion. SMEs accounts for 99.9 % of all private sector in the UK, 59.3% of private sector employment and 48.1% of private sector turnover. Therefore, they are a key driver for economic growth, innovation, employment and social integration

The differences between SMEs and large organisations are expressed in terms of resources limitation, and competitive and functional structure. Generally, SMEs usually lack personnel, finance and knowledge relevant to management and adopting new technology as well as effective strategies of development (Jutla *et al.*, 2002; Caskey *et al.*, 2001).

Kotey *et al.*, 2005 state that SMEs especially micro sized companies are usually have informal procedure managements which are only suit to informal business. Therefore, they generally tend to face with problems associated with ensuring health and safety standard as well as management (Eakin *et al.*, 2000; Vassie *et al.*, 2000). Also in these kind of organisations, the labour is usually cheap, temporary, and fewer staff compared to other kind of firms. Therefore, they are used to lack of high skill staff or difficult to train new working methods and technologies. When the industry requires its sectors to change in order to catch up with the development and the requirement of the country, SMEs usually find it difficult

to tackle barriers and limitations (Eurostat, 2012). This may account for differences in adopting new technologies between different sizes of companies as well as recent losing in competing with their rivals in among SMEs.

The next section will present an overview of recent innovations of SMEs in the UK to deal with changing of AEC sector as well as widespread demands from client both in public and private sectors, especially the demand of adopting BIM to conduct construction projects.

3.5. THE CURRENT USAGE OF BIM BY SMEs

The roles of SMEs in contributing to the development of national economies are significant. Typically, the construction supply chains consist of many parties and most of them are SMEs which encompass of materials, labour, information, plants, equipment etc. (Matmoko *et al.*, 2010). Furthermore, due to the limitations associated with their characteristics, SMEs are not able to conduct large and complex projects by themselves. Alternatively, they tend to cooperate with other organisations to delivery major construction projects (Stewart *et al.*, 2004). Consequently, the performance of the AEC sector especially large and complex projects has been significant impacted by SMEs' activities. Any failures or delays amongst SMEs can cause projects delayed which can lead to over budget problems. In fact, Matmoko *et al.*, (2010) agrees that SMEs have a vital impact on material flows and usually cause the delay which amounts up to 22% of the project duration amongst medium and large projects. Indeed, within the context of wide spread adopting BIM in AEC sector across the world in recent years, considering how BIM users growing amongst SMEs is essential because it can help the AEC sector to propose suitable policies to ensure the innovation is met with strategies (Boktor *et al.*, 2013). Notwithstanding the efforts to support BIM adoption amongst SMEs, the evidences indicate that BIM adoption primary concerns large companies and smaller companies are still slow in embracing the new technology (SmartMarket Report, 2012). The amount of large companies adopting BIM are almost threefold more than smaller ones, the former making up 74% in 2009 and this figure continuing to rise up to 91% in 2012, whereas BIM adoptions in small firms are just around 25% in 2009, followed by small to medium firms which account for 41% (SmartMarket Report, 2012).

In the UK, Jamieson *et al.*, (2012) indicate that SMEs feel ignored by policy initiatives and media, which help them to identify their roles in the context of BIM used as a new method to innovate the AEC sector. They find it difficult to foresee how BIM can help them to conduct construction projects typically determine risks and rewards that they may cope with. Besides, with a relentless emphasis on the use of BIM in early stages of projects, public sector, large-scale new-build projects and highly collaborative procurement have made a large number of SMEs in the industry feel that BIM is not for them (Jamieson *et al.*, 2012). Moreover, Ruikar *et al.* (2005) conclude that, implementation costs of a new technology are

a great barrier for SMEs, especially if SMEs' are always forced to adopt the change by spending a huge amount of money within a short duration.

Consequently, SMEs in the UK are lagging behind in BIM adoption and are losing out in winning publicly funded projects and potentially private sector ones too. It emerged that 40 % of construction SMEs lose out on 90% of the public sector work they bid for, while more than half of SMEs claim to have identified a reduction in their rate of success in bidding for public sector contracts over the past five years (Federation of Master Builders, 2013). The latest survey conducted by the Electrical Contractor Association found that BIM adoption in the UK's AEC sector still has large gaps amongst organisations. Eighty-nine percent of large organisations asked claimed that they were ready for BIM, whereas 54% of small companies' responses were "not ready at all" (Electrical Contractor Association, 2015).

Evidently, if BIM is to be the new methodology used by the industry to conduct construction projects then it has to accommodate all organisation sizes. However, the aforementioned figures indicate that adopting BIM amongst SMEs has, so far, not received enough attention by policy makers, the industry, and the research community. As a result, they have not fully recognised the benefits of using BIM in project delivery (Kouider, 2013). This field of study has also attracted little attention, which is reflected in the limited number of publications that directly reference the use of BIM within SMEs. Consequently, it emerged that SMEs are pessimistic about BIM and consider BIM discriminates against small independent practices in the built environment sector, notwithstanding the fact that BIM implementation could be more easily achieved in comparison with larger organisations (NBS, 2014).

Blackwell (2012) warns that SMEs could well lose contracts in both the domestic and international markets if they remain slow in grasping and adopting BIM as a transformative technology and process. Losing out on business results in the SMEs feeling less competitive and innovative in comparison with their competitors (Harris, 2013). This trend may continue if SMEs do not pay attention to investing in new technology and reforming their organisations in order to meet with the requirements of the industry.

In addition, public projects required the use of BIM by 2016 (British Standard Institute, 2013). This means that SMEs will be excluded from government business if they are not BIM compliant (HM Government, 2015). SMEs seem to favour private projects where no BIM mandate exists.

This sector is now a targeted area; the purpose being to “rescue” SMEs from losing business in the BIM environment. However, recent reports indicate that around two thirds of both public sector (65%) and private sector (70%) UK owners state that they will require BIM on their projects compared to 30% of US public owners and just 11% of US private sector ones (SmartMarket Report, 2014). Therefore, over-reliance on private sector works is not a viable option. These statistics ought to rouse SMEs from traditional approaches and encourage new strategies to adopt new technology and collaborative practices.

3.6. DECISION SUPPORT FOR BIM ADOPTION BY SMES

SMEs are finding it hard to make informed decisions about BIM adoption. There is currently a lack of guidance and assistance for SMEs in how to adopt BIM in project delivery. Absence of standards and frameworks to evaluate the extent to which BIM can bring benefits to AEC through project delivery, especially for the SMEs, results in low rates of BIM adoption (Liu *et al.*, 2010; Eastman *et al.*, 2011; Migilinskas *et al.*, 2013; Kouider, 2013). SMEs are known to be a hard to reach groups and require specific assistance to encourage BIM adoption. Consequently, this study seeks to bridge this gap and provide a decision support system (DSS) to give a theoretical foundation to the study of brokering risks and rewards in the adoption of BIM for project delivery.

Theoretically, good decision-making means outcomes in which relevant and appropriate information is yielded on the basis of selected criteria (Sauter, 1997). The term DSS denotes a computerized system designed specifically to help individuals to make decisions indeed, computer-based information systems such as DSSs typically affect or are intended to affect how people make decisions (Silver, 1991) and hence its structure and the way it is designed. According to Kivijarvi (1997), DSSs were first introduced in the 1970s, and were distinct from other, then current information systems in terms of their structure, development and application. They have since then been applied in a variety of disciplines and areas of research, including finance, marketing and production. Power *et al.* (2015) state that there are five kinds of DSS, namely:

- Communications-driven DSSs, which are central to communications technologies supporting decision-making;

- Data-driven DSSs, providing access to large data stores and analytics to create information;
- Document-driven DSSs, using documents to provide information for decision making;
- Knowledge-driven DSSs, in other words expert systems or recommendation systems;
- Model-driven DSSs, which use quantitative models for functionality and have been called both model-oriented DSSs and computationally-oriented DSSs

Pomerol *et al.* (2000) and Sauter (1997) note that it does not matter what kind a DSS is, as long as it incorporates the following four characteristics:

- Firstly, a DSS must include database management, which will give a multi-criteria DSS the potential to store, retrieve and update information easily.
- Secondly, a DSS must be able to facilitate the development and evaluation of a model of a choice process. This means that the DSS should allow decision makers to translate data into information.
- Thirdly, a DSS should avoid focusing on a very small number of alternatives or using over-simplistic models for alternatives.
- Finally, a DSS must provide a good user interface, to help decision makers use it and interact with it easily.

The developments of the DSS for this study started with developing the conceptual framework which is presented in the next chapter.

3.7. CONCLUSION

It can be seen that the AEC sector plays an important role in the economic growth of any country in the world. The activities and output of this sector can be of great importance to the achievement of national economic development targets. But as is the case with other industries, this industry is difficult to manage especially when it adopts advanced technologies. The UK's AEC sector underwent a difficult phase in both public and private sectors in the early 1990s, when output dropped by 39%. The causes of these difficulties were the fragmentation of the industry combined with a poor ability to adopt innovative solutions, deficits in both communication and interoperability, and a lack of trust between AECO players. Realising the significant role of construction activities, the UK government has improved this sector by forcing industry players to use BIM to deliver projects. To encourage and support BIM adoption in the industry, the development of BIM support groups, standards and protocols has been implemented.

As an important part of the AEC sector, the role of SMEs in the national economy is undeniable. However, this sector reports that it feels ignored by the very policy initiatives and media that have been put in place to help them identify their roles in the context of BIM use as a new method to innovate in the AEC sector. SMEs in general find it difficult to foresee how BIM can help them to conduct construction projects normally, and to determine the risks and rewards that they may be obliged to cope with, while guidance and frameworks to assist SMEs are currently lacking. Consequently, SMEs in the UK are lagging behind in BIM adoption and are losing out in winning not only publicly funded projects but also potentially private sector contracts too.

Therefore, it is of significance to develop guidance as well as frameworks to support SMEs in deciding whether or not to adopt BIM in their organisations. The next chapter will present the process of developing the DSS to assist SMEs in foreseeing the risks and rewards of adopting BIM to deliver construction projects.

CHAPTER 4: DEVELOPING CONCEPTUAL FRAMEWORK

4.1. INTRODUCTION

In the first part of this chapter (Section 4.2), a review of BIM publications across the world is presented. Also, a number of relevant BIM frameworks are investigated, with the aim of assisting the present author to establish a basic background perspective as to how such frameworks have been developed. Key criteria affecting BIM adoption amongst SMEs are identified in Section 4.3; these include Involvement phase, Project value, Funding source, and Procurement route. In order to show in detail the risks and rewards associated with each criterion in the conceptual framework, a profile of risks and rewards is given in Section 4.4. The conceptual framework of this study and its workflow diagram is presented in Section 4.5. The chapter is concluded in Section 4.6

4.2. A REVIEW OF CURRENT BIM ADOPTION FRAMEWORKS

In last decades, an unprecedented growth in the adoption of technology has been witnessed in order to assist organisations and companies to enhance their competitiveness and innovation. Alongside this trend, a growing body of research has been established to conduct and develop models of technology adoption. For instance, the Technology Acceptance Models (TAM) offer decision makers whether to accept or reject a particular innovation, or the extent to which that innovation is integrated into the appropriate context. However, Innovation Diffusion Models (IDM) have been concerned with how an innovation spreads through a population (Rogers, 1995; Straub, 2009; Oliveira *et al.*, 2011; Folkinshteyn *et al.*, 2016). At an organisational level, these models are usually examined based on individual characteristics of the leader, internal characteristics of organisational structure, and external characteristics of the organisation (Rogers, 1995; Oliveira *et al.*, 2011). In addition, Stewart *et al.*, (2004) also identifies reasons for the poor diffusion of IT as well as barriers to effective IT implementation in construction industry. Those are found in many different levels ranging top-down from industry, organisation, and project level (Figure 10).

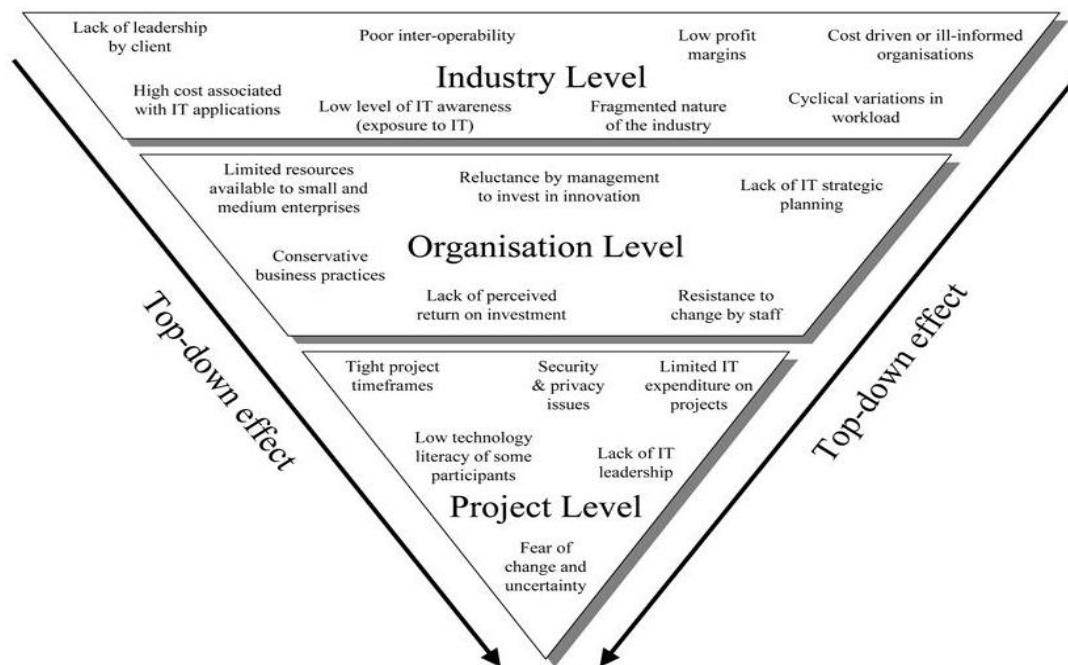


Figure 10. Tiered IT implementation barriers⁷ (Stewart *et al.*, 2004)

⁷ Reused with permission from © Emerald

Since BIM has become a phenomenon and attracted the attention of governments across the world, the global construction industry has been dramatically innovated and seems to be moving forward to a new chapter in which traditional working methods in project delivery are replaced by collaborative and coordinative procurement (Eastman *et al.*, 2011). In accordance with compulsory legalities associated with BIM adoption by governments (McGraw Hill Construction, 2014), there has been a huge quantity of research related to BIM, including books on the subject, journal publications, conference proceedings, BIM standards and guidelines, research reports, Master's and Doctoral theses, and magazine publications, all published order to help actors in the construction industry across the world to adopt BIM to deliver projects. Badrinath *et al.* (2016) found that in the past 25 years there have been more than 1,500 such BIM publications by global BIM researchers from 65 countries. Whereas researchers in Asian countries have paid more attention to process simulation and monitoring, those in North American and European markets have been concerned with standardization and building information services. This may be because of market maturity, as well as the fact that these countries are already realizing the basic benefits of BIM, and workflows which are now moving towards deeper interoperability and process standardization. In terms of the research direction of these studies, process simulation and monitoring occupies the highest percentage, accounting for 22% of publications, followed by building information services (16%) and standardization (14%). There are relatively very few publications focusing on organisational adoption, which is addressed in only 6% of BIM publications across the world (Badrinath *et al.*, 2016). This finding is in agreement with a study conducted by Jamieson *et al.* (2012), which indicates that SMEs consider themselves ignored by policy initiatives and feel that BIM is not for them. Lack of standards and frameworks for analysing the risks and rewards of adopting BIM in project delivery, especially for SMEs, results in low rates of BIM adoption (Liu *et al.*, 2010; Migilinskas *et al.*, 2013; Kouider, 2013).

In fact, it is essential to be able to benefit from available BIM tools and frameworks. By reviewing current frameworks associated with BIM research areas, or even simply by exploring existing knowledge and experience surrounding the issues being investigated, many lessons can be learned; much knowledge and understanding can be gained through analysing how these frameworks have been developed, what their contributions are, and how

they are validated and disseminated to users (Succar, 2009). With this in mind, Table 11 below presents some of the published attempts to foster the adoption of BIM in conducting projects.

Table 11. A review of relevant BIM frameworks

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Sample Representation	Abbreviation
	<p>Framework for practical implementation of BIM</p> <p>A review of the existing literature associated with computer-integrated construction (CIC) and BIM was performed in order to investigate the role of BIM from a global perspective. The authors propose a BIM framework focusing on practicability for real-world projects. The framework consists of three dimensions in a hierarchical structure comprising six major variables, namely data property, relation, standards, utilisation, perspective and construction business function. This framework can provide a basis for evaluating promising areas and identifying driving factors for practical BIM effectiveness.</p>
	<p>Using the MD CAD model to develop a time-cost integrated schedule for construction projects.</p> <p>Time and cost in construction projects are two critical factors which determine the success of project delivery. This research seeks to develop a scheduling system model that will help to generate time-cost integrated schedules for construction projects. This model as an extension of three BIM applications: the Multi-Dimensional (MD) CAD model, the Object Sequencing Matrix (OSM), and Generic Algorithms (GAs). It provides sufficient detailed and meaningful information for project delivery, and thereby assists in the effective management of construction projects in terms of cost and time. It helps to reduce overheads and errors, and improves project performance by generating flexible and efficient schedules.</p>

Figure 11. Framework for practical implementation (Jung et al., 2010)⁸

Figure 12. The procedure of project information processing (Feng et al., 2010)⁹

⁸ Reprinted from Automation in Construction, 20(2), Jung, Y., Loo, M, Building Information Modeling (BIM) framework for practical implementation, 126-133, Copyright (2010), with permission from Elsevier.

⁹Reprinted from Automation in Construction, 19, Feng, C, W., Chen, Y, J., Huang, J, R, Using the MD CAD model to develop the time–cost integrated schedule for construction projects, 347-356, Copyright (2010), with permission from Elsevier.

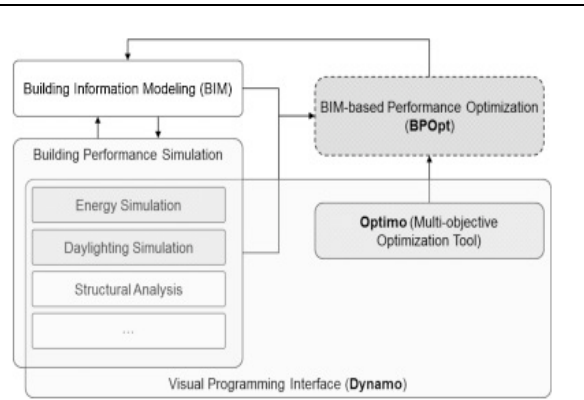


Figure 13. The overview of BPOpt framework (Asl et al., 2015)¹⁰

BPOpt: A framework for BIM-based performance optimisation

This framework enables designers to explore design alternatives using an open-source, visual programming user interface on top of a widely used BIM platform, to generate models of building design options, assess the environmental performance of these models through cloud-based simulation, and search for the most appropriate design alternatives. The BPOpt framework helps designers (both those with and those without extensive parametric modelling and computer programming experience) to use a novel BIM-based visual programming interface to perform a broad variety of simulation-based analyses for design optimisation. The framework was developed as a result of observing gaps in the existing literature associated with multidisciplinary optimisation in the process of performance based design.

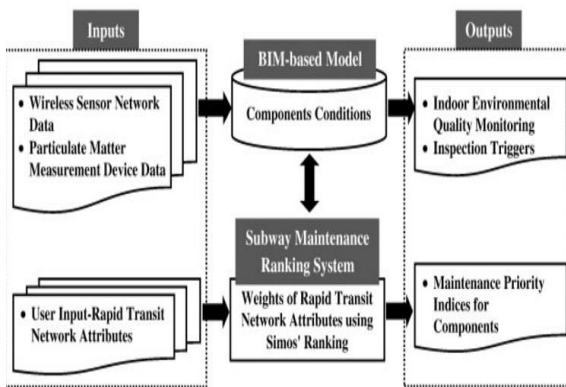


Figure 14. Schematic diagram for the developed framework (Marzouk et al., 2014)¹¹

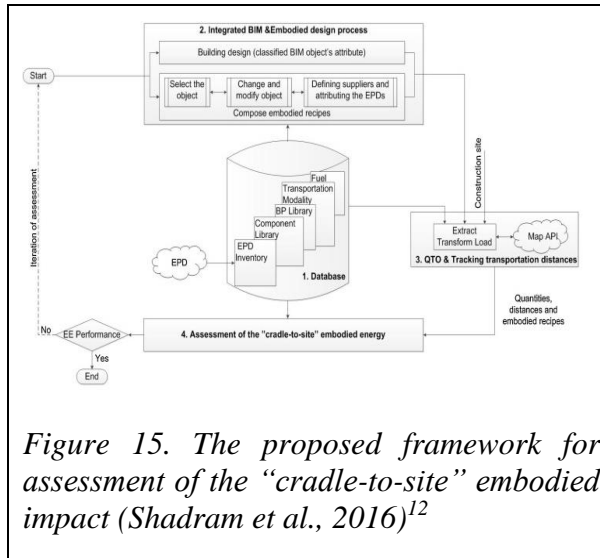
BIM-based framework for managing the performance of underground tube (subway) stations

The framework was developed to facilitate observation of indoor environmental quality and determine maintenance priority indices for inspected components. Within it, a rating system uses Simos' ranking method to determine the weights of different components contributing to the whole level of service as well as to maintenance priority indices. The maintenance priority indices are determined based on the conditions stored in the BIM-based model and on the weights of attributes. Maintenance priority indices (MPIs) can be calculated globally or locally throughout the whole rapid transit system. This research has developed a metric allowing asset managers to consider different funding scenarios by foreseeing the priority of different components in the network.

¹⁰ Reprinted from Energy and Buildings, 108, Asl, M.R., Zarrinmehr, S., Bergin, M. and Yan, W, BPOpt: A framework for BIM-based performance optimization, 401-412, Copyright (2015), with permission from Elsevier.

¹¹ Reprinted from Automation in Construction, 41, Marzouk, M. and Abdelaty, A, BIM-based framework for managing performance of subway stations, 70-77, Copyright (2014), with permission from Elsevier.

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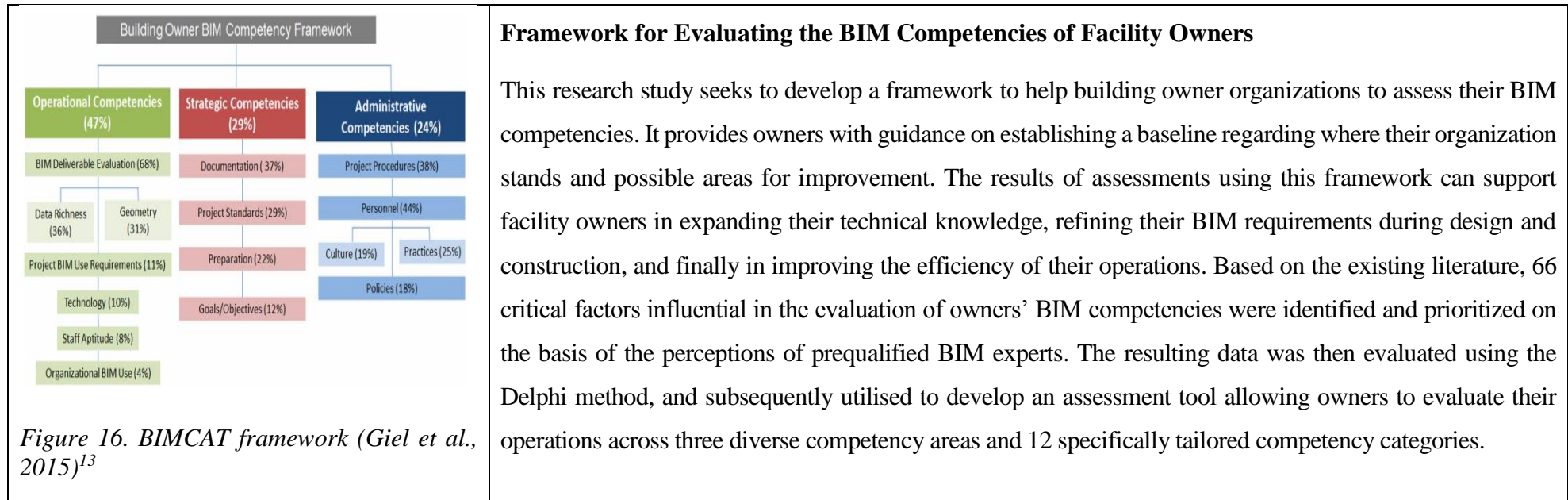
An integrated BIM-based framework for minimizing embodied energy during building design

This framework has been designed to increase interoperability at the design stage of project delivery. It supports design decisions and enables assessment of the embodied energy related to building environment supply chains. Typically, through choice of appropriate criteria it allows selection of low embodied impacts during the design stage of buildings

The framework also integrates extract transform load technology into BIM to enable an automated or semi-automated assessment process. A prototype has been developed to enhance the accessibility of the framework.

Figure 15. The proposed framework for assessment of the "cradle-to-site" embodied impact (Shadram et al., 2016)¹²

¹² Reprinted from Energy and Buildings, 128, Shadram, F., Johansson, T. D., Lu, W., Schade, J., Olofsson, T, An integrated BIM-based framework for minimizing embodied energy during building design, 592-604, Copyright (2016), with permission from Elsevier.

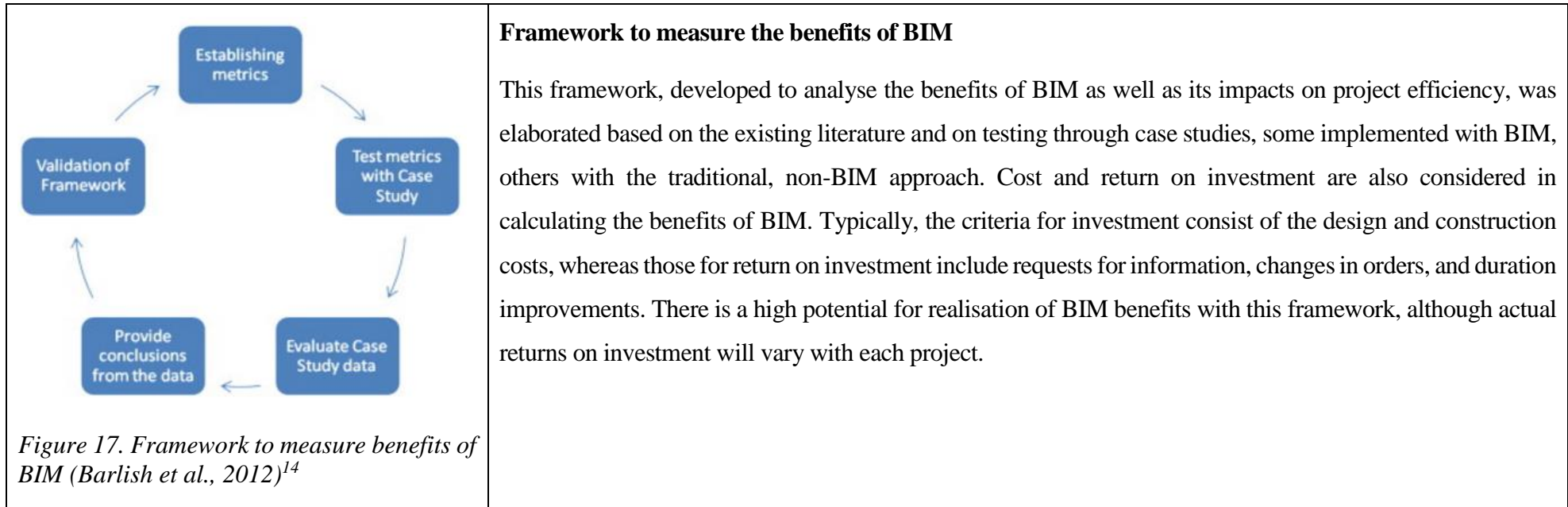


Framework for Evaluating the BIM Competencies of Facility Owners

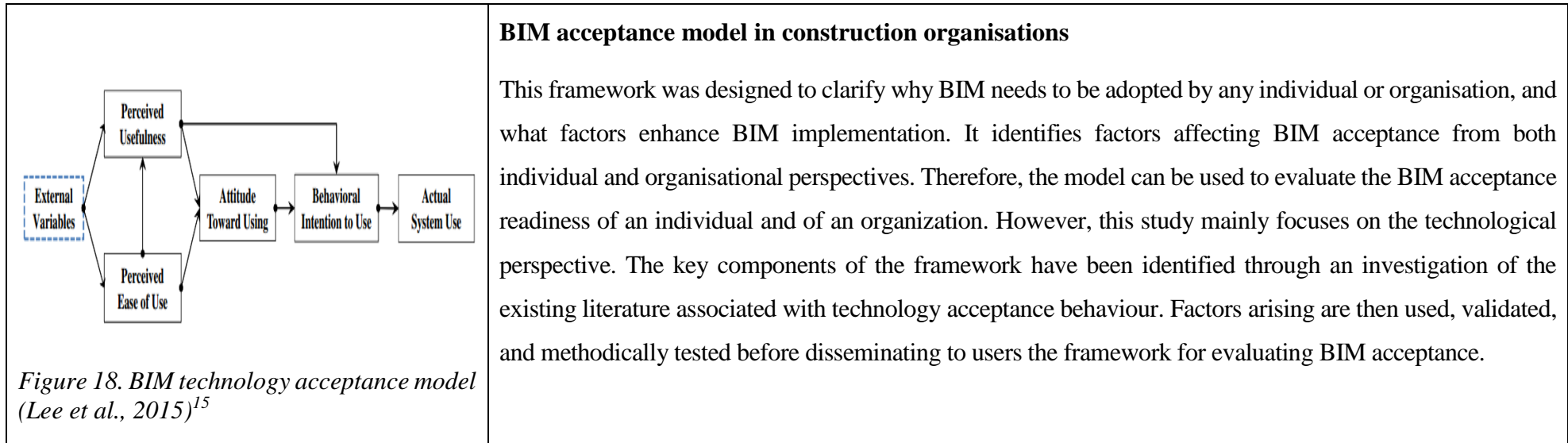
This research study seeks to develop a framework to help building owner organizations to assess their BIM competencies. It provides owners with guidance on establishing a baseline regarding where their organization stands and possible areas for improvement. The results of assessments using this framework can support facility owners in expanding their technical knowledge, refining their BIM requirements during design and construction, and finally in improving the efficiency of their operations. Based on the existing literature, 66 critical factors influential in the evaluation of owners’ BIM competencies were identified and prioritized on the basis of the perceptions of prequalified BIM experts. The resulting data was then evaluated using the Delphi method, and subsequently utilised to develop an assessment tool allowing owners to evaluate their operations across three diverse competency areas and 12 specifically tailored competency categories.

Figure 16. BIMCAT framework (Giel et al., 2015)¹³

¹³ Reused with permission from ASCE. This material may be downloaded for personal use only. Any other use requires prior permission of the American Society of Civil Engineers



¹⁴ Reprinted from Automation in Construction, 24, Barlish, K., Sullivan, K, How to measure the benefits of BIM—A case study approach, 149-159, Copyright (2012), with permission from Elsevier.



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The above listed BIM frameworks are representative of the small number of published research studies associated with BIM adoption. In some respects, they differ in terms of conceptual depth, terminology, and target audience, but in overall terms they all share the same objective, which is to demonstrate the applicability of BIM to improving construction project delivery.

As a result of this review of eight relevant frameworks, several important lessons regarding the development of models or frameworks have been learned. Firstly, the frameworks have been developed to address gaps in knowledge. Secondly, they can be modified from existing models, or developed anew from scratch. Thirdly, their components are usually derived from the existing literature associated with current matters needing to be investigated or addressed. Fourthly, after development the frameworks need to be validated to ensure the soundness of the information and knowledge that they aim to contribute. And finally, their accessibility may be increased if they are developed as tools or prototypes which can then be easily disseminated to users.

The following sections focus on the identification of factors affecting BIM adoption, and on the development of the conceptual framework

4.3. KEY FACTORS AFFECTING BIM ADOPTION AMONG SMEs

In the light of the experience gained from reviewing relevant BIM frameworks as mentioned in the previous section, and following the suggestion of Succar (2009), in order to establish the framework for this study it is essential to identify key factors that affect SMEs in adopting BIM to deliver construction projects.

A two-step approach was adopted to the selection of relevant articles to be included in the study. For the first step, it was decided to screen the literature to identify sources describing and discussing the development of developing methodologies for BIM adoption frameworks. The journals searched were *Automation in Construction*, *The ASCE Journal of Computing in Civil Engineering*, *Advanced Engineering Informatics*, and *The Journal of Information Technology in Construction*. Other relevant sources were located in the UWE library, and in a number of other online databases. A total of more than 490 citations were identified relevant to the issues being investigated. Articles not addressing the research focus were excluded, while those meeting the inclusion criteria were retrieved in full. The literature once extracted was critically appraised and discussed, and a narrative approach was then selected to synthesise the data.

The final studies were scrutinised and nineteen articles were identified. A systematic literature review of these studies established links between BIM adoption and four main factors: involvement phase, project value, source of funding, and procurement route (see Table 12). For each main component, a series of attributes were also identified. These factors paved the way for the development of the conceptual framework.

Table 12. Key factors affecting BIM adoption, as noted by various researchers

Reference	Involvement phase			Project value			Source of funding		Procurement route		
	Design stage	Construction stage	Operation stage	<£5m	≥£5m, ≤£50m	≥£50m	Public	Private	Traditional	Two-stage design and build	Integrated project delivery
Al-Hammad <i>et al.</i> , 1997	x	x	x								
Bryde <i>et al.</i> , 2013	x	x	x	x	x	x	x	x			
Negendahl, 2015	x	x	x			x	x	x			x
Succar, 2012	x	x	x								
Arditi <i>et al.</i> , 1999	x	x	x								
Oti <i>et al.</i> , 2015	x	x	x								
Eastman <i>et al.</i> , 2011				x	x	x			x	x	x
Eadie <i>et al.</i> , 2015									x	x	x
Luu <i>et al.</i> , 2013									x	x	x
Volk <i>et al.</i> , 2014						x	x	x			
Liu <i>et al.</i> , 2010				x	x	x					
Azhar <i>et al.</i> , 2011				x	x	x					
Yang <i>et al.</i> , 2008				x	x	x					
Byrne <i>et al.</i> , 2011									x	x	x
Cox <i>et al.</i> , 2011									x	x	x
Hogg <i>et al.</i> , 2007									x	x	x
Hughes <i>et al.</i> , 2006									x	x	x
Migilinskas <i>et al.</i> , 2013				x	x	x					
Won <i>et al.</i> , 2013				x	x	x					

4.3.1. Involvement phase

The involvement phase refers to the timing of the engagement in project delivery that will allow an SME to maximise rewards and minimise risks when adopting BIM to deliver projects (Al-Hammad *et al.*, 1997; Negendahl, 2015; Succar, 2012). The involvement phase of project delivery is divided into three stages: the design stage, the construction stage, and the operation stage.

The design stage is a combination of strategic decision making, preparation and brief, concept design, and technical design. This is considered the most important stage of project delivery because decision making, assigning resources to parties, and allocating risks and rewards are made during this phase (Penttilä *et al.*, 2007; Abrishami *et al.*, 2014; Bryde *et al.*, 2013; Negendahl, 2015; Succar, 2012). It is recognised that the involvement of key disciplines at the early stages of a project will result in optimum benefits for project delivery (Lahdenperä, 2012). However, it is essential to be aware that design work should be started earlier in the BIM model than in traditional methods. Indeed, the design work needs to be started before project launch decisions are made, otherwise the project owner will obtain neither validation, nor evaluation, nor information from analysis (as these are all BIM-based) to support his project decision.

It is in the construction stage that the contractor completes operations according to the conditions of the contract. This is the stage when work starts on site and visible progress is made (Fewings, 2013). The process of coordinating human resources, materials, and machines is deployed at this stage (Li *et al.*, 2012), and project teams can use BIM to monitor project progress through 4D planning, organising coordination meetings, integrating RFIs, changing orders and punching list information into the BIM models (Oti *et al.*, 2015). However, the project team must continuously update the BIM model so that it reflects the most up-to-date information, which can then later on be used by facility managers for building operations and maintenance (Azhar *et al.*, 2012).

The operation stage refers to the handover of the building and the conclusion of the building contract. The undertaking of maintenance work in accordance with the schedule of services is assigned to this stage (Becerik-Gerber *et al.*, 2011). Within the BIM model, all information associated with facilities that has been involved in any of the planning, design, and

construction stages is then leveraged downstream to facilitate operation maintenance (Oti *et al.*, 2015). Newton *et al.* (2012) report that 85% of the life cycle cost of a facility occurs after construction is completed, and that in the United States about \$10 million per year is lost due to lack of access to information and other issues associated with maintenance. Traditionally, the involvement of all parties at the construction and maintenance/operation stages has less influence on project quality and outcomes, as key decisions are taken at earlier stages of the process. The adoption of BIM, in contrast, permits all parties to be involved at all stages, and enables operational and maintenance organisations to shift their working methods and working environments from the traditional to the highly collaborative.

4.3.2. Project value

The construction industry is experiencing a major trend change towards projects of increasing complexity (Naoum, 2003). Project values vary from less than £5m for small projects, to £5m–£50m for medium projects, and more than £50m for large projects. Procurement choice is dependent on the complexity or size of projects and is guided by the need to ensure completion on time and within budget (CIOB, 2010). According to NBS (2014), small-sized projects are associated with organisations that are slower to adopt new technology and have fewer staff than larger enterprises. This type of organisation struggles to win business, especially in the current highly competitive environments.

Medium-sized projects are usually derived from a breakdown of complex projects delivered by groups of SMEs. Each SME can be assigned a suitable unit of the project with a tight schedule of performance (Hatmoke *et al.*, 2010). Thus, managing the collaborative performance of SMEs in conducting medium-sized projects is of significant concern. Similarly, managing parties participating in large-sized projects also needs to be considered carefully. The general rule is that the larger the scope of the project, the more complex participation will be (Volk *et al.*, 2014). There has therefore been an assumption that using BIM on small scale projects (e.g. less than £5m) may be less likely to yield significant benefit compared to projects on a larger scale (Bryde *et al.*, 2013).

4.3.3. Source of funding

It can be stated categorically that clients are key drivers of performance improvement and innovation, constituting the most important factor in achieving project delivery and project success in almost all industries; and the construction industry is no exception (Walker, 2007). The important role played by clients is highly significant to stakeholders because it can affect all stages of a construction project, from conception to project maintenance (McCabe, 2007). Clients typically employ a variety of criteria to assess whether a bid for their project by a given contractor or supplier should be accepted or rejected (Holt *et al.*, 1993). This is because any error in contractor selection can contribute to project failure; while at the same time, mere quality, and completion on time and within budget, are not sufficient to guarantee full client satisfaction and repeat business for a given contractor or supplier (Egemen *et al.*, 2006). The potential client of the construction industry is vast, and clients may be of several types. However, they can be classified into two overall groups, public and private clients, who may therefore also be considered as two main sources of project funding (Jaafar *et al.*, 2012).

The private sector consists of private housing, such as residential, apartment, and development projects (Walker, 2007); and private sector commercial properties, including retail stores, manufacturing plants, businesses, restaurants, and warehouses (National Statistical Bulletin, 2014). Private clients are characteristically increasingly well-informed and knowledgeable about how to enter into the building process (SmartMarket Report, 2014), and they tend to expect the best value from contractors and suppliers. This has led to a shift in the contractor selection process, from a “lowest-price-wins” approach to what can be termed “multi-criteria selection practices”, especially since the implementation of BIM (Wong *et al.*, 2010).

In contexts where BIM in project delivery is compulsory in the public sector, SMEs seem to favour private projects where no BIM mandate exists. This sector is now a targeted area, the purpose being to rescue SMEs from losing business in the BIM environment. However, recent reports indicate that around two thirds of UK owners in both the public sector (65%) and the private sector (70%) state that they will require BIM on their projects, compared to a mere 30% of US public owners and just 11% of owners in the US private sector (SmartMarket Report, 2014). Therefore, over-reliance on private sector work is not a viable option. It is to be hoped that such statistics as these will rouse SMEs from their reliance on

traditional approaches and encourage them to adopt new strategies, new technology and new, collaborative practices.

The public sector client, primarily government, is seen to be the initiator of major developments in social amenity projects. It is this type of client that is involved in the construction of buildings such as schools and colleges, hospitals, universities, fire stations, prisons and museums (Office for National Statistics, 2014). Public clients are not individuals but sophisticated structures consisting of numerous different individuals and groups of people, who often have opposing interests and objectives. These individuals can influence the formation of project teams and therefore have an impact on the choice of procurement system (Briscoe *et al.*, 2004). Since this sector is considered to have been the main driver of the BIM agenda (British Standards Institute, 2013), the construction industry has witnessed considerable change, construction projects shifting from traditional working methods towards the highly collaborative BIM model, with the aim of reducing government construction project costs by 15% to 20% (Cabinet Office, 2012). This has also had significant impact on AECO players, especially SMEs, which are at risk of loss of public sector contracts if they do not or cannot adopt BIM due to limitations associated with their SME characteristics such as lack of resources, lack of appropriately skilled staff, or lack of knowledge of the necessary pre-qualification steps or the issue of preferred bidder status (CIOB, 2010). It is recognised that while cost is often seen as a barrier to BIM entry, especially for small organizations, the real challenge lies in the need to change processes and practices (Porwal *et al.*, 2013).

4.3.4. Procurement route

Procurement in construction projects is defined as a process whereby clients make decisions about how they will build (Hogg *et al.*, 2007). The procurement stage plays a significant role in the success of any building project (Squires *et al.*, 2011). Any selection of an inappropriate procurement system may lead to project failure (Chua *et al.*, 1999). Essentially, construction procurement is an array of considered risks that need to be examined carefully by stakeholders. Each procurement route has developed its own characteristics to suit different sizes and types of project (Nahapeit *et al.*, 1985). As a general rule, the traditional procurement method is most suited for delivering small-sized projects, whereas Design and Build is the method used for projects of medium size, and Integrated Project Delivery (IPD)

is used for large and complex projects (CIOB, 2010). In the context of BIM integration, no significant changes are necessary in terms of project delivery methods. Porwal *et al.* (2013) indicate that all project delivery methods appear as modifications or slight variations of existing ones, and the three most widely used procurement methods with BIM are the Traditional method, Design and Build, and IPD.

In traditional procurement, the client appoints consultants to design the project in detail. The tender documents are then prepared, including drawings, work schedules, and bills of quantities. Constructors are then invited to submit tenders for the construction of the project (Hogg, 2007). The advantages of this procurement method are that the project cost can be estimated, planned and monitored by the quantity survey from the pre-contract stage, which can lead to an outstanding level of price certainty for the client (Hogg, 2007). Besides, due to the fact that clients visit the architects in person for advice when they need a building, these architects are able to invite consultant engineers, landscape architects and other experts to participate in the project by advising on or designing subsystem projects. The architects are able to consult appropriate contractors and suppliers for the project, and subcontractors may be invited to submit competitive tenders for subsystems in which they are specialised (Franks, 1998).

However, Franks (1998), Hogg (2007) and Cox *et al.*, (2012) indicate that these traditional procurement methods also have certain disadvantages. Client requirements are likely to change during the construction process, a factor which bills of quantities and relevant contracts need to take into account. Owing to the fact that the design is fully developed before the bills of quantities or the subsequent tender are produced, such variations by the client create a risk of project delay or project disruption. Moreover, communication and collaboration between stakeholders is not well-developed, which can lead to a range of difficulties in executing the project, especially in terms of solving problems or identifying the responsibilities of parties when elements of the project experience failure. Finally, by virtue of the characteristics described above the traditional procurement method is not suitable for large and complex projects which require advanced professional management systems, structures and skills.

The two-stage Design and Build method was developed to eliminate the liability gap between design and construction within the Traditional method. The client benefits from

single point responsibility by making the contractors solely responsible for design, construction and problem-solving during the building lifecycle (Hogg, 2007). The requirements of clients are accurately specified, and certainty of final project costs can be achieved, with these costs usually less than when using other types of procurement system (Masterman, 2002). In addition, the significant advantage of this method compared to the Traditional method is the possibility of increasing communication between parties and integrating the contractor contribution to design and project planning (Franks, 1998; Masterman, 2002).

Although this procurement method can avoid certain disadvantages that the Traditional system faces, Hogg (2007) and Franks (1998) indicate other disadvantages of the Design and Build method that may affect a project when it comes into operation. First of all, the role of the client in controlling the design will be reduced to a greater or lesser extent, depending on the approach adopted to design and building. Secondly, the evaluation of different design alternatives contained in the contractor's proposal is more complex, and the different designs are hard to compare. Finally, reductions in levels of cost information make it difficult to manage the cost of the project.

With the IPD procurement route, the early involvement of key parties is advocated (Lahdenperä, 2012). The IPD route, according to the American Institute of Architects (AIA), is a "project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimise efficiency through all phases of design fabrication and construction" (AIA, 2007). IPD seeks to improve construction productivity by using a combination of partnering concepts and lean thinking to improve communication, eliminate waste, reduce costs, address expectations and generate value for all parties involved (Hardin, 2009). The AIA (2007) argues that IPD helps parties understand the outcome of projects by means of early and open sharing of project knowledge and streamlined project communication. Thus, it helps to improve the ability to control costs and manage budgets effectively. The United Kingdom's Office of Government Commerce (OGC) estimates that IPD can help save up to 30% of construction costs where integrated teams promote continuous improvement over a series of construction projects (OGC, 2007). IPD achieves significant improvements in six performance areas: quality, schedule, project changes,

communication among stakeholders, environmental issues, and financial performance (Asmar *et al.*, 2013). Decker (2009) supports this positive view of IPD, stating that this project delivery method uses rational contract principles to harness all of the strengths and capabilities of the client, the designers and the contractors, and to focus them principally on one unique goal, the efficient delivery of the project as a whole.

4.4. A SUMMARY OF RISK AND REWARD PROFILE

A profile of risks and rewards was developed in order to demonstrate the potential risks and rewards associated with the criteria being investigated. These risks and rewards were identified through investigation of the relevant literature associated with framework criteria. Details of the risks and rewards related to the framework criteria are presented in the Tables below:

Table 13. Rewards associated with framework's criteria

Potential benefits of BIM to SMEs		Reference
1	Better customer services	SmartMarket Report, 2012; Business Innovation & Skill, 2013; Hartmann <i>et al.</i> , 2010; Oti <i>et al.</i> , 2015
2	More business in future	Allison, 2010; Succar, 2012; Zuppa <i>et al.</i> , 2009; SmartMarket Report, 2012; Oti <i>et al.</i> , 2015
3	Improved cooperation and coordination in project delivery	Eastman <i>et al.</i> , 2008; Eastman <i>et al.</i> , 2011; Oti <i>et al.</i> , 2015
4	More opportunities to compete with larger organisations	Oti <i>et al.</i> , 2015; Allison, 2010; Succar, 2012
5	Improved communication between parties and relationships upstream and downstream	Fewing, 2013; Oti <i>et al.</i> , 2015; Eastman <i>et al.</i> , 2011; Paavola <i>et al.</i> , 2014; Akcamete <i>et al.</i> , 2011; Fewings, 2013
Rewards associated with design stage		Reference
6	Reduction of time required to carry out design activities	Kassem <i>et al.</i> , 2015; Eastman <i>et al.</i> , 2011; Sanguinetti <i>et al.</i> , 2012; Bryde <i>et al.</i> , 2013; Negendahl, 2015

7	Improved predictability of construction and performance issues	Goucher <i>et al.</i> , 2012; Succar, 2012; Eastman <i>et al.</i> , 2011; Negendahl, 2015; Bryde <i>et al.</i> , 2013; Oti <i>et al.</i> , 2015
8	Significant improvement in ability to control cost of design changes	Al-Hammad <i>et al.</i> , 1997; Eastman <i>et al.</i> , 2011; Negendahl, 2015; Succar, 2012; Oti <i>et al.</i> , 2015
9	Collaboration between architect, contractor, and engineers allowing for better decision making, which helps to improve quality and mitigate risk	Eastman <i>et al.</i> , 2011; Al-Hammad <i>et al.</i> , 1997; Bryde <i>et al.</i> , 2013; Negendahl, 2015; Oti <i>et al.</i> , 2015
10	Increased accuracy and consistency from the early stages and subsequent stage of the design production phase	Eastman <i>et al.</i> , 2011; Al-Hammad <i>et al.</i> , 1997; Bryde <i>et al.</i> , 2013; Negendahl, 2015
Rewards associated with construction stage		Reference
11	Early planning allows team members to use materials more efficiently, creating less waste	Eastman <i>et al.</i> , 2011; Bryde <i>et al.</i> , 2013; Oti <i>et al.</i> , 2015
12	Change in orders are minimised	Eastman <i>et al.</i> , 2011; Bryde <i>et al.</i> , 2013; Al-Hammad <i>et al.</i> , 1997; Succar, 2012; Oti <i>et al.</i> , 2015
13	Construction can be completed on schedule and on budget	Oti <i>et al.</i> , 2015 Eastman <i>et al.</i> , 2011Succar, 2012;
14	Uncertainty over construction is reduced	Bryde <i>et al.</i> , 2013; Eastman <i>et al.</i> , 2011; Negendahl, 2015; Succar, 2012; Oti <i>et al.</i> , 2015; Al-Hammad <i>et al.</i> , 1997
15	Fully coordinated design helps to reduce potential risk on site	Jalaei <i>et al.</i> , 2015; Negendahl, 2015; Oti <i>et al.</i> , 2015; Eastman <i>et al.</i> , 2011; Al-

		Hammad <i>et al.</i> , 1997; Bryde <i>et al.</i> , 2013; Succar, 2012
Rewards associated with operation/maintenance		Reference
16	Better operations and facilities management	Bryde <i>et al.</i> , 2013; Eastman <i>et al.</i> , 2011; Negendahl, 2015; Al-Hammad <i>et al.</i> , 1997; Succar, 2012; Oti <i>et al.</i> , 2015
17	As-built spaces and systems utilized as a starting point for maintenance and operations and as well as a database for possible future retrofits	Eastman <i>et al.</i> , 2011; Al-Hammad <i>et al.</i> , 1997; Bryde <i>et al.</i> , 2013; Succar, 2012; Oti <i>et al.</i> , 2015
18	Linking of building model to energy analysis to improve energy efficiency and sustainability	Succar, 2012; Oti <i>et al.</i> , 2015; Eastman <i>et al.</i> , 2011; Al-Hammad <i>et al.</i> , 1997; Bryde <i>et al.</i> , 2013; Negendahl, 2015
19	Use of BIM helps organizations to schedule all maintenance management activities in both the long-term and the short-term	Oti <i>et al.</i> , 2015; Eastman <i>et al.</i> , 2011; Bryde <i>et al.</i> , 2013; Negendahl, 2015; Succar, 2012
20	BIM modeling helps organizations to better manage condition, history and specifications of facilities and equipment	Al-Hammad <i>et al.</i> , 1997; Eastman <i>et al.</i> , 2011; Succar, 2012; Bryde <i>et al.</i> , 2013; Negendahl, 2015; Oti <i>et al.</i> , 2015
Rewards associated with projects less than £5 million		Reference
21	Greater opportunities to offer greater value	Negendahl, 2015; Liu <i>et al.</i> , 2010; Azhar <i>et al.</i> , 2011; Yang <i>et al.</i> , 2008; Migilinskas <i>et al.</i> , 2013; Won <i>et al.</i> , 2013
22	Easier and faster to switch from CAD to BIM	Azhar <i>et al.</i> , 2011; Bryde <i>et al.</i> , 2013; Yang <i>et al.</i> , 2008; Negendahl, 2015; Liu <i>et</i>

		<i>al.</i> , 2010; Migilinskas <i>et al.</i> , 2013; Won <i>et al.</i> , 2013
23	Quicker delivery	Yang <i>et al.</i> , 2008; Migilinskas <i>et al.</i> , 2013; Bryde <i>et al.</i> , 2013; Negendahl, 2015; Liu <i>et al.</i> , 2010; Azhar <i>et al.</i> , 2011; Won <i>et al.</i> , 2013
24	Greater profits	Won <i>et al.</i> , 2013; Bryde <i>et al.</i> , 2013; Azhar <i>et al.</i> , 2011; Yang <i>et al.</i> , 2008
25	Fewer employees	Azhar <i>et al.</i> , 2011; Migilinskas <i>et al.</i> , 2013; Won <i>et al.</i> , 2013
Rewards associated with projects between £5 million and £50 million		Reference
26	Waste reduction	Bryde <i>et al.</i> , 2013; Yang <i>et al.</i> , 2008; Migilinskas <i>et al.</i> , 2013; Won <i>et al.</i> , 2013
27	Lower than usual cost growth of packages for service installation	Liu <i>et al.</i> , 2010; Azhar <i>et al.</i> , 2011; Yang <i>et al.</i> , 2008; Won <i>et al.</i> , 2013
28	Saving in spending on administrative and coordinating staff time	Bryde <i>et al.</i> , 2013; Yang <i>et al.</i> , 2008; Won <i>et al.</i> , 2013
29	Improvement in ability to control cost projects	Migilinskas <i>et al.</i> , 2013; Azhar <i>et al.</i> , 2011; Won <i>et al.</i> , 2013
30	Faster return on investment	Bryde <i>et al.</i> , 2013; Azhar <i>et al.</i> , 2011; Yang <i>et al.</i> , 2008; Migilinskas <i>et al.</i> , 2013; Won <i>et al.</i> , 2013

Rewards associated with projects greater than £50 million		Reference
31	Significant waste reduction	Negendahl, 2015; Liu <i>et al.</i> , 2010; Azhar <i>et al.</i> , 2011; Migilinskas <i>et al.</i> , 2013; Won <i>et al.</i> , 2013
32	Significantly lower than usual cost growth in packages for service installation	Liu <i>et al.</i> , 2010; Azhar <i>et al.</i> , 2011; Yang <i>et al.</i> , 2008; Won <i>et al.</i> , 2013
33	Significant savings in spending on administrative and coordinating staff time	Migilinskas <i>et al.</i> , 2013; Won <i>et al.</i> , 2013; Negendahl, 2015; Liu <i>et al.</i> , 2010; Azhar <i>et al.</i> , 2011
34	Improvement in ability to control cost projects	Migilinskas <i>et al.</i> , 2013; Azhar <i>et al.</i> , 2011; Won <i>et al.</i> , 2013
35	Significantly faster return on investment	Bryde <i>et al.</i> , 2013; Yang <i>et al.</i> , 2008; Migilinskas <i>et al.</i> , 2013; Won <i>et al.</i> , 2013
Rewards associated with projects Funded by public sector		Reference
36	Greater opportunities to win public projects	Bryde <i>et al.</i> , 2013; Negendahl; Volk <i>et al.</i> , 2014; McCabe, 2007; Walker, 2007; Egemen et al, 2006; Walker, 2007; Wong et al., 2010
37	Closer relationships with contractors and suppliers	Bryde <i>et al.</i> , 2013; Negendahl; Volk <i>et al.</i> , 2014; McCabe, 2007; Walker, 2007; Egemen et al, 2006; Walker, 2007; Wong et al., 2010

38	Offered repeat business	Bryde <i>et al.</i> , 2013; Negendahl; Volk <i>et al.</i> , 2014; McCabe, 2007; Walker, 2007; Egemen et al, 2006; Walker, 2007; Wong et al., 2010
39	Increased business due to enhancement of company's visibility in market place enhanced	Bryde <i>et al.</i> , 2013; Negendahl; Volk <i>et al.</i> , 2014; McCabe, 2007; Walker, 2007; Egemen et al, 2006; Walker, 2007; Wong et al., 2010
40	Improved satisfaction of public client's requirements	Walker, 2007; Bryde <i>et al.</i> , 2013; Negendahl; Volk <i>et al.</i> , 2014; McCabe, 2007; Wong et al., 2010
Rewards associated with projects Funded by private sector		Reference
41	More opportunities to win more business due to enhanced company's visibility in market place	Negendahl; Volk <i>et al.</i> , 2014; McCabe, 2007; Walker, 2007; Wong et al., 2010
42	More opportunities to win larger projects	Volk <i>et al.</i> , 2014; McCabe, 2007; Bryde <i>et al.</i> , 2013; Walker, 2007; Wong et al., 2010
43	More opportunities to participate in public projects	McCabe, 2007; Bryde <i>et al.</i> , 2013; Negendahl; Volk <i>et al.</i> , 2014; Walker, 2007
44	More opportunities to be offered repeat business	McCabe, 2007; Walker, 2007; Egemen et al, 2006; Walker, 2007; Wong et al., 2010
45	Improved customer satisfaction	Bryde <i>et al.</i> , 2013; Negendahl; Volk <i>et al.</i> , 2014; McCabe, 2007; Walker, 2007; Egemen et al, 2006; Wong et al., 2010

Rewards associated with projects adopts IPD		Reference
46	Reduction in disputation	Eadie <i>et al.</i> ,2015; Hughes <i>et al.</i> , 2006; Hogg <i>et al.</i> , 2007; Luu <i>et al.</i> , 2013; Negendahl, 2015
47	Sharing risks and rewards	Byrne <i>et al.</i> , 2011; Cox <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015
48	Improved quality and safety	Byrne <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Cox <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015
49	Improvement in design and construction times and certainty of completion	Byrne <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Luu <i>et al.</i> , 2013; Negendahl, 2015
50	Better working environment	Byrne <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Hogg <i>et al.</i> , 2007; Cox <i>et al.</i> , 2011
Rewards associated with projects adopt Design and build		Reference
51	Reduction of overall project cost	Byrne <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015
52	Reduction of overall project completion time	Byrne <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015
53	Improvement in build ability	Eastman <i>et al.</i> , 2011; Cox <i>et al.</i> , 2011; Byrne <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015

54	Reduction in claims due to bringing together of design and construction and high degree of collaboration between parties	Byrne <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015
55	Better project quality	Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Hughes <i>et al.</i> , 2006; Hogg <i>et al.</i> , 2007; Cox <i>et al.</i> , 2011; Negendahl, 2015
Rewards associated with projects adopts Traditional procurement		Reference
56	Greater cost certainty	Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015; Byrne <i>et al.</i> , 2011
57	Low preparation cost	Byrne <i>et al.</i> , 2011; Hughes <i>et al.</i> , 2006; Hogg <i>et al.</i> , 2007; Cox <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015
58	Improved designed changes and better cost management process	Hogg <i>et al.</i> , 2007; Cox <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015
59	Higher tender quality	Cox <i>et al.</i> , 2011; Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015
60	Shortened lengthy time from inception to start on site	Cox <i>et al.</i> , 2011; Hughes <i>et al.</i> , 2006; Hogg <i>et al.</i> , 2007; Eastman <i>et al.</i> , 2011; Eadie <i>et al.</i> ,2015; Luu <i>et al.</i> , 2013; Negendahl, 2015

Table 14. Risks associated with framework's criteria

Potential risks of BIM to SMEs		Reference
1	Inability to bid for publicly funded projects from 2016	Federation of Master Builders, 2013; Harris, 2013; SmartMarket Report, 2014
2	Risk of losing business with private clients	Harris, 2013; SmartMarket Report, 2014; Federation of Master Builders, 2013
3	Lagging behind competitors in terms of BIM readiness	Harris, 2013; Electrical Contractor Association, 2015; Federation of Master Builders, 2013; SmartMarket Report, 2014
4	Disruption to working patterns	Thompson <i>et al</i> , 2007; Ku <i>et al</i> , 2011; Azhar, 2011
5	Loss of visibility in the market place due to lack of professional working style	Ku <i>et al</i> , 2011; Newton <i>et al</i> , 2012; Elmualim <i>et al</i> , 2014
Risks associated with design stage		Reference
6	Unclear protocol for data sharing upstream and downstream to various parties	Azhar, 2011; Azhar <i>et al</i> , 2012
7	Failure to detect clashes	Leite <i>et al.</i> , 2011; Monteiro <i>et al.</i> , 2013; Jalaei <i>et al.</i> , 2015; Kassem <i>et al.</i> , 2015
8	Model not updated along with progress reviews	Chien <i>et al.</i> , 2014; Tsipouri <i>et al.</i> , 2009; Hergunsel, 2011; Kassem <i>et al.</i> , 2015
9	Risks associated with the inaccuracy of cost estimates from model quantities	Chien <i>et al.</i> , 2014; Tsipouri <i>et al.</i> , 2009
10	Delay in model submission and approval	Chien <i>et al.</i> , 2014; Tsipouri <i>et al.</i> , 2009; Hergunsel, 2011; Kassem <i>et al.</i> , 2015

Risks associated with construction stage		Reference
11	Inaccurate onsite construction information due to failure to detect errors in the model during the design stage	Kassem <i>et al.</i> , 2015; Monteiro <i>et al.</i> , 2013;
12	Failures in opening the model due to incompatibility of different software platforms	Azhar, 2011; Azhar, 2012; Elmualim <i>et al.</i> , 2014; Chien <i>et al.</i> , 2014
13	Ineffective and incompatible transition between design and constructability	Chien <i>et al.</i> , 2014; Thompson <i>et al.</i> , 2007
14	Duplication of content in the model affecting construction pricing	Azhar, 2011; Azhar, 2012; Elmualim <i>et al.</i> , 2014; Chien <i>et al.</i> , 2014
15	Failure to update the designed model to incorporate the BIM changes made during construction	Azhar, 2011; Azhar, 2012; Elmualim <i>et al.</i> , 2014; Chien <i>et al.</i> , 2014
Risks associated with operation/maintenance		Reference
16	Operation cost overrun	Su <i>et al.</i> , 2011; Chien <i>et al.</i> , 2014; Thompson <i>et al.</i> , 2007
17	Operational revenues below expectation	Su <i>et al.</i> ,2011; Thompson <i>et al.</i> , 2007
18	Low operating productivity	Su <i>et al.</i> ,2011; Chien <i>et al.</i> , 2014; Thompson <i>et al.</i> , 2007
19	Maintenance more frequent than expected	Chien <i>et al.</i> , 2014; Thompson <i>et al.</i> , 2007; Dey <i>et al.</i> , 2010
20	Maintenance costs higher than expected	Su <i>et al.</i> ,2011; Chien <i>et al.</i> , 2014; Thompson <i>et al.</i> , 2007

Risks associated with projects less than £5 million		Reference
21	High initial cost for investment	Beck, 2009; Ku <i>et al</i> , 2011; Newton <i>et al</i> , 2012; Elmualim <i>et al</i> , 2014
22	Unfamiliarity with working to tight schedules	Haron, 2013; Clevenger, 2012; Gerbov, 2014
23	Difficulty of execution in comparison with large projects	Ritz <i>et al.</i> , 2013
24	Lack of BIM experience	Ku <i>et al</i> , 2011; Azhar, 2011
25	Lack of demand from clients	Marshall <i>et al</i> , 2000; Lusek, 2006; Wong <i>et al</i> , 2000
Risks associated with projects between £5 million and £50 million		Reference
26	Complexity and difficulty of management	Bryde <i>et al.</i> , 2013; Ritz <i>et al.</i> , 2013
27	High initial cost for investment	Beck, 2009; Ku <i>et al</i> , 2011; Newton <i>et al</i> , 2012; Elmualim <i>et al</i> , 2014
28	Failures in communication between parties due to technical risks	Chien <i>et al.</i> , 2014; Tsipouri <i>et al.</i> , 2009; Hergunsel, 2011; Kassem <i>et al.</i> , 2015
29	Lack of trust between parties	Thompson <i>et al</i> , 2007; Ku <i>et al</i> , 2011; Azhar, 2011
30	Potential project delay due to variable BIM competencies among parties	Azhar, 2011; Newton <i>et al</i> , 2012; Azhar, 2012; Elmualim <i>et al</i> , 2014

Risks associated with projects greater than £50 million		Reference
31	More complexity and difficulty of management	Bryde <i>et al.</i> , 2013; Ritz <i>et al.</i> , 2013
32	High initial cost for investment	Beck, 2009; Ku <i>et al.</i> , 2011; Newton <i>et al.</i> , 2012; Elmualim <i>et al.</i> , 2014
33	Failures in communication between parties due to technical risks	Chien <i>et al.</i> , 2014; Tsipouri <i>et al.</i> , 2009; Hergunsel, 2011; Kassem <i>et al.</i> , 2015
34	Lack of trust between parties	Bryde <i>et al.</i> , 2013; Jamieson <i>et al.</i> , 2012
35	Potential project delay due to variable BIM competencies among parties	Azhar, 2011; Newton <i>et al.</i> , 2012; Azhar, 2012; Elmualim <i>et al.</i> , 2014
Risks associated with projects Funded by public sector		Reference
36	Risk of loss of public contracts due to failure to satisfy client requirements	Federation of Master Builders, 2013; Harris, 2013
37	Risk of disruption of relationship with contractors and supplier's due to differing levels of BIM knowledge and BIM deliverability	Azhar, 2011; Newton <i>et al.</i> , 2012; Azhar, 2012; Elmualim <i>et al.</i> , 2014
38	Lack of legal framework on using BIM	Thompson <i>et al.</i> , 2007; Rosenburg, 2007; Azhar, 2011; Ku <i>et al.</i> , 2011
39	Lack of BIM experience in public project delivery	BCO, 2013; Newton <i>et al.</i> , 2012; Azhar <i>et al.</i> , 2012
40	Lack of knowledge regarding BIM documentation	Ku <i>et al.</i> , 2011; Newton <i>et al.</i> , 2012; Azhar <i>et al.</i> , 2012

Risks associated with projects Funded by private sector		Reference
41	Risk of loss of private contracts due to increase the requirements of client with BIM	Blackwell, 2012; SmartMarket Report, 2014
42	Lack of opportunities to win larger projects due to low BIM competency	Newton et al, 2012; Azhar, 2012; Elmualim et al, 2014
43	Failure to win public projects due to lack of experience in these kinds of projects	CIOB, 2010; Harris, 2013
44	Lack of BIM experience in project delivery	BCO, 2013; Newton et al, 2012; Azhar et al, 2012
45	High initial investment	Beck, 2009; Ku et al, 2011; Newton et al, 2012; Elmualim et al, 2014
Risks associated with projects adopts IPD		Reference
46	Risks of loss of contracts due to failure to satisfy requirements to deliver BIM project.	Azhar, 2011; Newton et al, 2012; Azhar, 2012; Elmualim et al, 2014
47	Risk of interrupted communication between parties	Chien et al., 2014; Tsipouri et al., 2009; Hergunsel, 2011; Kassem et al., 2015
48	Difficulty of setting a lifecycle cost benchmark against traditional arrangements	Love <i>et al.</i> , 2008; Thompson <i>et al</i> , 2007
49	Lack of BIM experience in project delivery	BCO, 2013; Newton et al, 2012; Azhar et al, 2012
50	Different BIM competencies between parties	Newton <i>et al</i> , 2012; Azhar, 2012; Elmualim <i>et al</i> , 2014

Risks associated with projects adopt Design and build		Reference
51	Greater potential for disputes among parties	Cox et al, 2012; Masterman, 2002
52	Risk of creating significant cost management issues	Cox et al, 2012; Masterman, 2002
53	Difficulty in comparison of tenders	Cox et al, 2012; Masterman, 2002
54	Risk of differences in degree of BIM knowledge and BIM capacity among parties	Cox et al, 2012; Masterman, 2002
55	Risk of disconnect between project stakeholders in the design and construction process and occupiers utilising the data from these models	Cox et al, 2012; Masterman, 2002
Risks associated with projects adopts Traditional procurement		Reference
56	Disputation between parties due to fragmentation between design and construction	Hogg, 2007; Franks, 1998; Cox et al, 2012; Masterman, 2002
57	Project delays in cases of failure of clash detection	Hogg, 2007; Franks, 1998; Cox et al, 2012; Masterman, 2002
58	Lack of ability to negotiate prices	Hogg, 2007; Franks, 1998; Cox et al, 2012; Masterman, 2002
59	Lack of ability to apply BIM in large project	Hogg, 2007; Franks, 1998; Cox et al, 2012; Masterman, 2002
60	Risk of unskilled consultants	Hogg, 2007; Franks, 1998; Cox et al, 2012; Masterman, 2002

4.5. THE CONCEPTUAL FRAMEWORK AND ITS WORKFLOW DIAGRAM

Frameworks are generally developed to assist and guide research efforts, to enhance exchange of information or knowledge, and to consolidate relevant concepts into a descriptive or predictive model (Jung *et al.*, 2011; Naumann *et al.*, 1986; Kirs *et al.*, 1989). Any BIM framework must be comprehensive enough to address all relevant BIM domains and implementation challenges as well as to present key issues of project management in a systematic manner (Jung *et al.*, 2010). Within the context of this study, there has been no systematic effort to date to bring together the results of research into BIM adoption by SMEs. Consequently, this present research seeks to bridge this gap and provide a conceptual framework that will provide a theoretical foundation for the study of brokering risks and rewards in the adoption of BIM for project delivery. This proposed BIM application framework targets SMEs, to help them better understand the potential risks and rewards associated with adopting BIM to deliver construction projects.

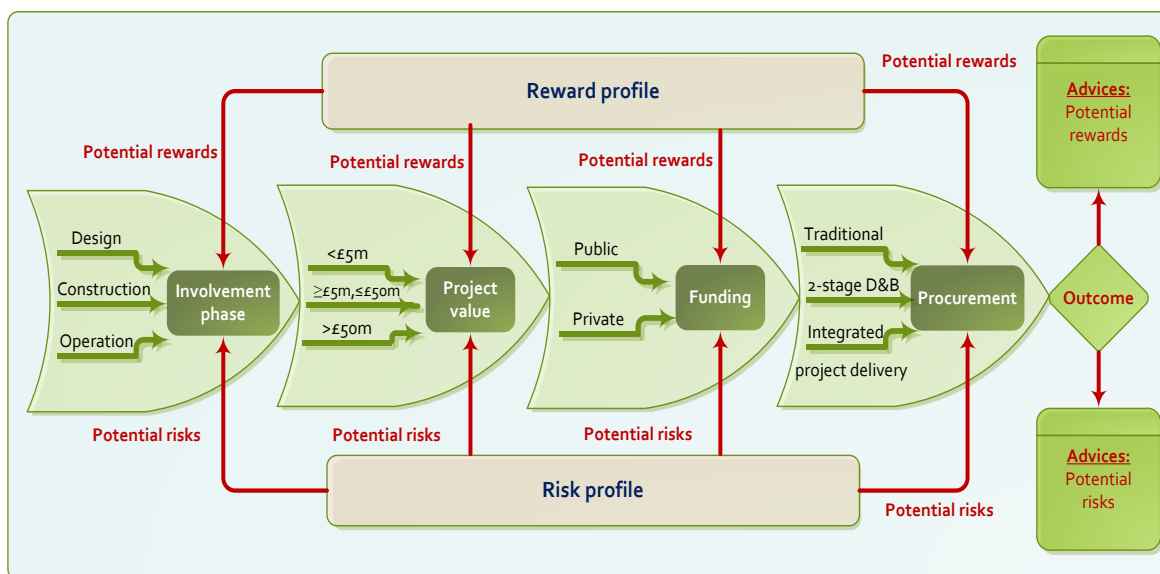


Figure 19. Conceptual framework to help in the analysis of the risks and rewards for SMEs of adopting BIM

Notwithstanding the proliferation of literature examined, no studies to date have attempted to develop a framework that postulated criteria for brokering the risks and rewards associated with BIM adoption by SMEs for project delivery. Nevertheless, the increasingly widespread use of BIM in the construction industry today (Shepherd, 2004) coupled with the lack of engagement of SMEs with a BIM agenda (Federation of Master Builders, 2013) have created

a need to develop a conceptual model. Any such model would then require testing to ascertain if its prevailing assumptions can form the basis for the development of an accepted theory in this field of study.

The conceptual framework of this study is illustrated in *Figure 19*; it was built on the foundation of the key factors illustrated in Table 12, which were synthesised from the existing literature in this field to address the current knowledge gap. The framework outlines the entire context that SMEs consider when they adopt BIM to deliver construction projects. It emerges that there are four broad areas in BIM adoption that have an impact on SMEs:

- The involvement phase, which includes the design stage, the construction stage, and the operation /maintenance stage.
- The project value, which can be further divided into three categories: projects of less than £5 million, projects between £5 million and £50 million, and projects of more than £50 million.
- The source of funding, that is to say either public sector or private sector funding of projects.
- The procurement route, which may be the Traditional method, two-stage Design and Build, or Integrated Project Delivery.

In addition, the risks and the rewards associated with each criterion have also been synthesised from the existing literature and stored in the risk and reward profiles. They can then be used to determine the potential risks and rewards linked to each criterion. In this way, depending on users' selections, different risks and rewards are generated, thus providing an informed basis for decision-making regarding the best course of action for BIM adoption. These potential risks and rewards are assessed in terms of their likelihood of occurrence and level of impact on an SME.

The workflow diagram for the framework is illustrated in *Figure 20*. This shows a process with a total of five steps used to anticipate the risks and opportunities involved in using BIM in project delivery. These steps start with identification of the involvement phase (e.g. the design stage). The framework then addresses project value (e.g. \geq £5m or \leq £50m), procurement route (e.g. two-stage D&B), and source of funding (e.g. public) as criteria to generate a final recommendation at the end of the assessment process. The framework also

allows SME users to generate interim reports at each step of the process. These reports include a presentation of risks and rewards at every step of the process (indicated by broken lines). The risks and rewards are calculated on the basis of the weight of the criteria. Risks and rewards associated with the criteria are also validated and then used as informative output in the final report of the assessment process.

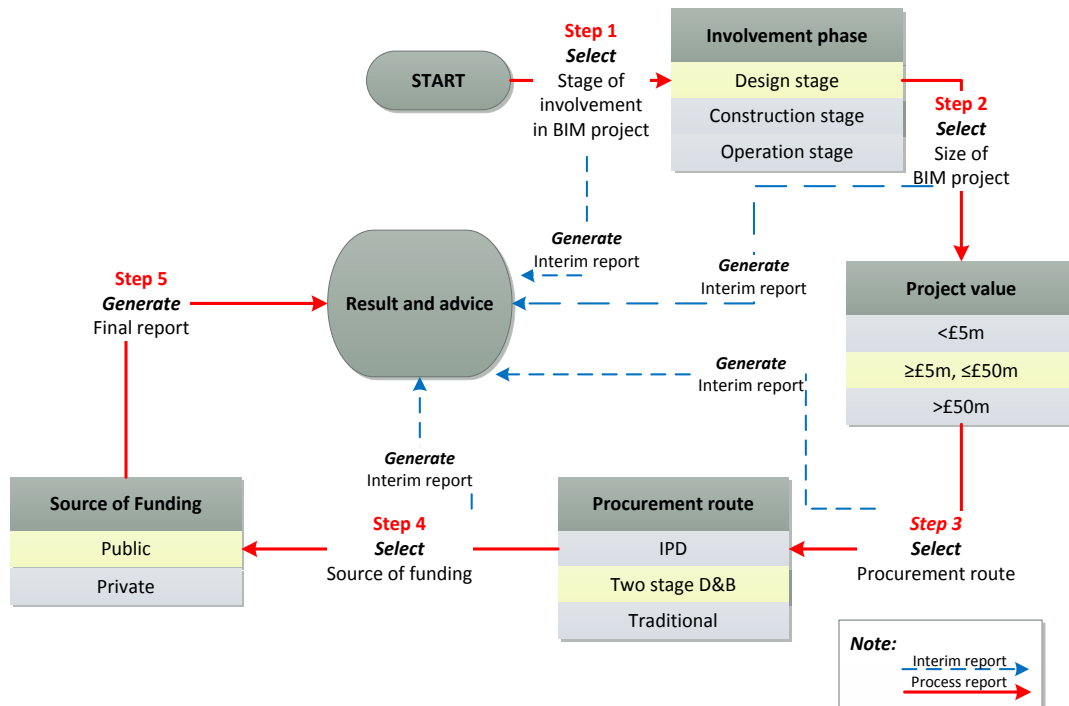


Figure 20. The workflow diagram of the framework

This present research has identified four main factors, comprising eleven sub-factors, affecting BIM adoption amongst SMEs. There is therefore a total of fifty-four situations that SMEs can refer to, to anticipate risks and rewards for their organisations. Details of alternatives are presented in Table 15 below:

Table 15. Summary of selections

Involvement phase	Project value	Source of funding	Procurement route	Index
Design	≥ £50m	Public	IPD	1
			Two-stage design and build	2
			Traditional procurement	3
		Private	IPD	4
			Two-stage design and build	5
			Traditional procurement	6
	≥ £5 m, < £50m	Public	IPD	7
			Two-stage design and build	8
			Traditional procurement	9
		Private	IPD	10
			Two-stage design and build	11
			Traditional procurement	12
	<£5m	Public	IPD	13
			Two-stage design and build	14
			Traditional procurement	15
		Private	IPD	16
			Two-stage design and build	17
			Traditional procurement	18
Construction	≥ £50m	Public	IPD	19
			Two-stage design and build	20
			Traditional procurement	21
		Private	IPD	22

			Two-stage design and build	23	
			Traditional procurement	24	
			IPD	25	
	≥ £5 m, < £50m	Public		Two-stage design and build	26
				Traditional procurement	27
				IPD	28
		Private		Two-stage design and build	29
				Traditional procurement	30
				IPD	31
	<£5m	Public		Two-stage design and build	32
				Traditional procurement	33
				IPD	34
Private			Two-stage design and build	35	
			Traditional procurement	36	
			IPD	37	
Operation/ maintenance	≥ £50m	Public	IPD	37	
			Two-stage design and build	38	
			Traditional procurement	39	
		Private		IPD	40
				Two-stage design and build	41
				Traditional procurement	42
	≥ £5 m, < £50m	Public		IPD	43
				Two-stage design and build	44
				Traditional procurement	45
		Private		IPD	46

			Two-stage design and build	47
			Traditional procurement	48
	<£5m	Public	IPD	49
			Two-stage design and build	50
			Traditional procurement	51
		Private	IPD	52
			Two-stage design and build	53
			Traditional procurement	54

4.6. CONCLUSION

As a consequence of a systematic review of studies associated with the context of this study, four key criteria were identified involvement phase, project value, source of funding, and procurement route. These criteria consist of 11 sub-criteria in total. They are the involvement phase (the design stage, the construction stage, and the operation /maintenance stage), the project value (projects of less than £5 million, projects between £5 million and £50 million, and projects of more than £50 million), the source of funding (public sector, private sector), and the procurement route (traditional method, two-stage design and build, integrated project delivery). These emerged as significant factors affecting SMEs BIM adoption.

The conceptual framework and its workflow diagram was developed, based on an in-depth analysis of the existing and emerging peer reviewed literature in this field. The profile of risks and rewards, which are relevant to each criterion of the conceptual framework were also identified.

The framework validation is a significant step to ensure framework validity. The next chapter will present the methods used in this present research to validate the conceptual framework. This validation also constitutes the primary data collection for this research.

CHAPTER 5: RESEARCH METHODOLOGY

5.1. INTRODUCTION

In the previous chapter, the conceptual framework was developed. The purpose of this present chapter is to provide an explanation of the research methodology as well as a justification for the research methods adopted for the validation of the conceptual framework. It also explains the testing of the DSS.

The chapter is divided into four main sections. After the current introduction (Section 5.1), Section 5.2 deals with deciding the research design of this study, and includes identification of stance adopted with regard to research philosophy (Section 5.2.1) and the research approach taken (Section 5.2.2). Research strategies and time horizons are presented in Section 5.2.3, and in Section 5.2.4 the research methods used to collect data. Section 5.2.5 addresses the questionnaire design and survey implementation for this study, while the decision as to sample size is the focus of Section 5.2.6. Data analysis methods and the resolution of ethical issues are dealt with in Sections 5.2.7 and 5.2.8 respectively. The chapter is concluded in Section 5.3.

5.2. RESEARCH DESIGN

Considered the backbone of, or “blueprint” for, any research process is its research design, which helps researchers and readers to see how a study is organised and conducted through a particular set of methods, and the procedures used to measure the variable or variables specified in the study (Gorard, 2013). A good research design allows researchers to obtain “the best research data possible” (Toledo-Pereyra, 2012). Research design usually deals with issues that seek to answer the following fundamental questions (Crotty, 1998):

- What epistemology informs the research?
- What theoretical perspective lies behind the methodology in question?
- What methodology governs our choice and use of methods?
- What methods do we propose to use?

To answer these questions, Crotty (1998) suggests that research design should consider the following elements:

- Theoretical perspective (which is concerned with the philosophical stance taken by the research, which may for example be positivism, interpretivism, critical inquiry, or postmodernism);
- Epistemology (which refers to the theory of knowledge embedded in that theoretical perspective, for example objectivism, subjectivism, or constructionism);
- Methodology (the strategy or plan of action that links methods to outcomes, and which can include experimental research, survey research, ethnography, phenomenological research, grounded theory, action research, or discourse analysis);
- Methods (the techniques and procedures to be used, for instance questionnaires, interviews, focus groups, case studies, statistical analysis, or cognitive mapping).

An alternative, though similar, research model proposed by Kagioglou *et al.*, (1998) is known as *nested approach methodology*. In this model, the research design consists of three layers:

- Research philosophy, responsible for guiding the researcher's approach and the research techniques used;
- Research approach, which concerns the organising of research activities, and data collection to ensure achievement of research aims;
- Research techniques, referring to the methods used to collect data, including case studies, action research, surveys, experiments, interviews, questionnaires, focus groups, and observation.

Besides the two models of research design mentioned above, a third, the six-layer research model often known as the research onion, has attracted attention among researchers. Developed by Saunders *et al.*, (2003), and described in *Figure 21*, the research onion model covers all the aspects mentioned in the models established by Crotty (1998) and Kagioglou *et al.*, (1998), as well as providing a solid structure for research design that can be adapted to the aims of the particular research in question.

Given these strengths, this present study has adopted the onion model for the presentation of its research methodology design. It is hoped that it will enable the researcher to show clearly the structure of the design of this research, ensuring the achievement of the research's aim and objectives. The six layers of the onion model (research philosophy, research approaches, research strategies, time horizons, method choices, and data collection methods) offers researchers typical methods from which they may select the most appropriate according to the nature of their study. Details of the selections adopted for this present research from the layers of the model are presented in the Sections below.

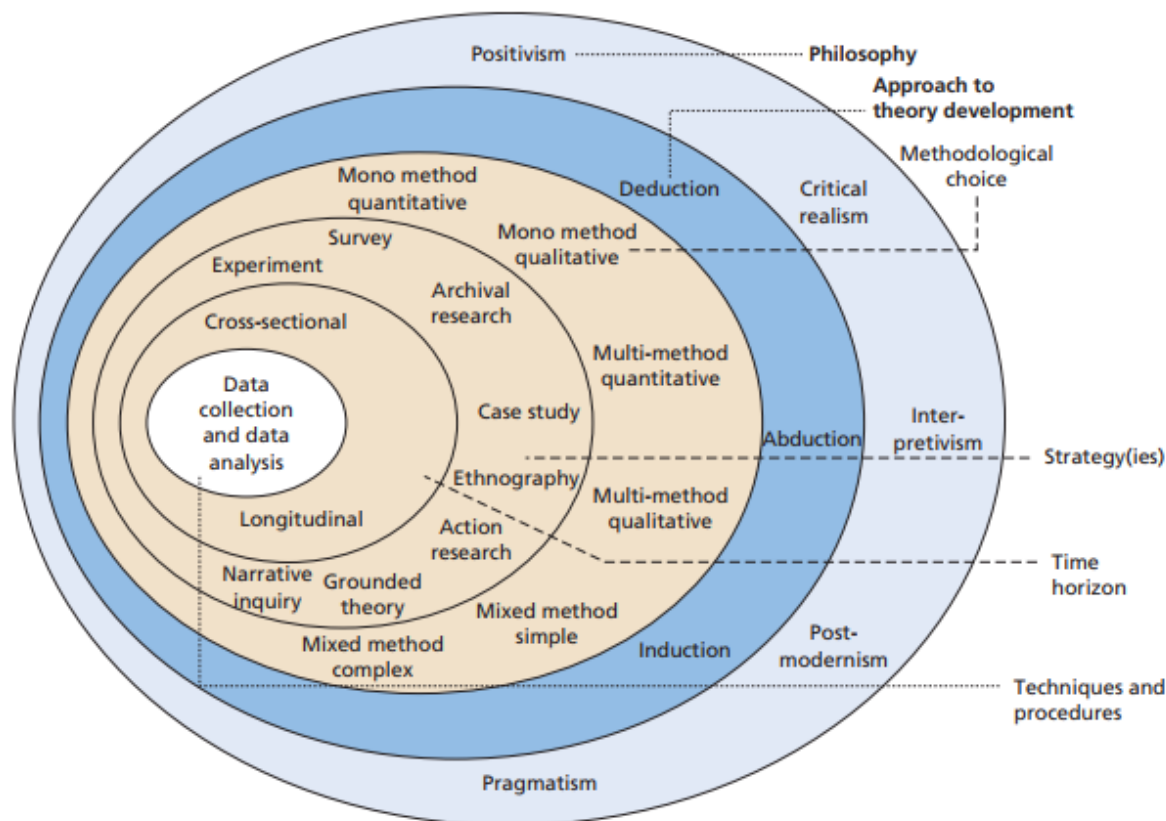


Figure 21. The onion model, reused with permission from © 2015 Mark Saunders, Philip Lewis and Adrian Thornhill¹⁶

5.2.1. Research philosophy

As indicated in the outer ring of the model, Saunders *et al.*, (2003) state that research philosophy refers to the development of knowledge and the nature of that knowledge. Depending on the nature of their philosophical assumptions, researchers can be categorised as either positivist or constructionist (Easterby-Smith *et al.*, 2002). Positivists contend that the world is actually concrete and external and therefore their exploration can only be based upon observed and captured ‘facts’ through direct data or information. Conversely, the constructionist school of thought holds that the world is neither objective nor exterior, but rather based on a social construct in which people create and interact (Easterby-Smith *et al.*, 2002). William (2011) notes that constructivism is also known as interpretivism, idealism, or relativism, and is a view of the world as a creation of the mind; whereas the positivist

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considers the world around him/her to be real. This comparison between positivist and relativist approaches as made by William (2011) is illustrated in *Table 18* below:

Table 16. The comparison between positivist and relativist

Issue	Positivist	Relativist
Philosophical basis	Realism: the world exists and it is real	Idealism: the world exists but differently according to the observer's way of thinking
The role of research	To explore universal laws and generalisations	To reveal different interpretations of the world as made by people
The role of the researcher	Neutral observer	Part of the research process
Theoretical approach	Rational, using deductive and scientific methods	Subjective, using inductive methods and value-laden data
Methods	Experiments or mathematical models and quantitative analysis, used to validate, reject or refine hypotheses	Observations and qualitative analysis, used to seek meaningful relationships and the consequences of their interactions. Analysis of language and meaning
Analysis of society	Search for order – society being governed by a uniform set of values and	Search for dynamics, with multiple values leading to complex interactions –

made possible only by society being made possible
acceptance of these values by negotiation

Easterby-Smith *et al.*, (1997) emphasise that identification of the research philosophy is very important because it can help researchers to determine their research methods and eliminate limitations in the early stages of the study. Put simply, the choice of research philosophy will inform the research design. The selected research philosophy will also determine the relevant epistemology, ontology, and axiology.

Typically, as Saunders *et al.*, (2003) define them, axiology is associated with value judgements relating to the fields of aesthetics, ethics and justice; while ontology is concerned with the nature of reality and the assumptions made about its nature, and epistemology is concerned with what constitutes acceptable knowledge in a field of study. Positivism and interpretivism are the most widely used research philosophies associated with epistemology. Interpretivism refers to a search for explanations of human action by understanding the way in which the world is comprehended by individuals; whereas positivism refers to a search for general laws and cause-effect relationships by rational means (Sexton, 2003). There is a strong relationship between positivism and quantitative research methods (Liu *et al.*, 2003; William, 2011).

Given the nature of the present study, the positivist stance is deemed the most appropriate research philosophy. By investigating BIM and its role in the construction industry, the present research will be able to identify the potential risks and rewards for SMEs of adopting BIM to deliver construction projects. The outcomes of the research promise to provide informative intelligence that will be of considerable use in deciding whether or not adopting BIM to deliver construction projects.

5.2.2. Research approach

It can be seen from the second layer of the onion model above that there are two principle research approaches, the deductive and the inductive. In the deductive approach, the theory and hypothesis are developed first, followed by the research strategy to test the hypothesis. Conversely, the inductive approach begins with the analysis of data (Saunders *et al.*, 2003).

Although each approach has its potential and its limitations, Creswell (2003) proposes that if there is a rich literature available on a research topic, and if it is possible to define a theoretical framework, then that topic is more amenable to a deductive approach.

This present study falls into this category, and therefore the deductive approach has been adopted. In this research study, the factors that influence SMEs as to whether or not to on adopt BIM to deliver construction projects were identified from the existing literature. Available frameworks associated with the research topic were also reviewed, with a view to assisting the researcher to grow ideas in the development of the conceptual framework for this study.

An important factor to consider is that the appropriacy of a research approach can be also affected by the characteristics of the data. Gill *et al.*, (2002), Creswell (2003), and Fellows *et al.*, (2003) indicate that research approaches can be classified into three groups, according to the research methods adopted – quantitative, qualitative, or mixed – and that choice of methods will depend on the characteristics of the data. In this present research, the quantitative research approach is adopted, seeking to use quantitative methods to test whether experts in the field of BIM for SMEs are in agreement with the various categories and variables included in the conceptual model. These categories and variables, emerging from the synthesis in the literature review (Chapters 2 and 3) need to be validated by a representative sample of experts, thus improving the reliability and validity of the proposed DSS.

5.2.3. Research strategies and time horizons

The third and fourth rings of the research onion represent research strategies and time horizons for a research study. Research strategies, also known as the research process, begin with an identification of issues and problems that the research needs to address, as well as a consideration of how the research process should be designed (William, 2011). The research aims and research objectives are then generated according to the characteristics of these issues and problems. Yin (2003) points out a strong relationship between research strategies and research questions, the former usually established to achieve the aims of the research study through a series of research questions or objectives. With this in mind, the research strategies of this present study were indicated in Section 1.5, and illustrated in *Figures 1* and *2* below of this section.

Depending on the nature of the research questions that are set, appropriate data needs to be collected, and suitable analysis methodologies need to be adopted. William (2011) states that research strategies are usually designed to answer the following types of question:

- “What” questions, addressing the research topic and what the research sets out to do;
- “Why” questions, addressing the reasons for, and the necessity of, the research;
- “How” questions, addressing the ways in which the research will be carried out;
- “When” questions, addressing the programme of work, and the time-frame of the research.

As detailed in the next Section, the quantitative research method was adopted to seek answers to these questions – answers which will provide a framework for conducting the research itself.

Regarding time horizons, illustrated by the fourth ring of the research onion, research studies are usually grouped into two types: cross-sectional or longitudinal. According to Saunders *et al.*, (2003) and Sekaran (2003), research that investigates a particular phenomenon at a particular time is cross-sectional, while research that examines changes and developments of a phenomenon over a period of time is longitudinal – for example social research into child development, health, and education. The disadvantages of longitudinal research are indicated by Patrick *et al.*, (2005):

- Difficulty in choosing participants when they are aware of the necessary long-term commitment;
- Difficulty in keeping in touch with sample groups;
- High rate of withdrawal;
- High cost of recruiting participants due to the long-term nature of the research;
- Suitability only for social research.

Mann (2003) writes of cross-sectional studies that besides being popular and relatively quick they enable research into multiple outcomes, while not themselves differentiating between cause and effect or between points in a sequence of events.

Consequently, reflecting on the nature of this present research, which investigates principally the risks and rewards of using BIM to deliver construction projects, the cross-sectional time horizon can be seen to be the best choice for this doctoral study. Due to time limitations and the focus of the literature review on BIM implementation, this study focuses on SMEs across the UK only; and its outcomes and solutions thus apply principally to SMEs in the UK.

The next section will present data collection methods and techniques used in this study.

5.2.4. Research methods

Research methods are sets of tools and techniques that are used to conduct research through doing different practical tasks to achieve the aim of the research (Walliman, 2011). The primary research method in this study uses a process known as framework validation. Framework validation entails checking that a system complies with its own requirements and is free from failures or incorrect behaviour (Ferreira *et al.*, 2009; Collofello, 1998), by obtaining objective evidence establishing that the system will perform its intended functions. Consequently, validation of the conceptual framework will help to determine the level of robustness and usefulness of the criteria in enabling SMEs to maximise their benefits and minimise their potential risks. The validation of a system is mostly a concern at the system level, focusing on whether or not the system can do what the user wants and is suitable for a specific intended use or application (Upadhyay, 2012). Therefore, validation of the conceptual framework will help to ensure that the potential DSS will have full functionality, and will work as intended, to help SMEs to anticipate the risks and rewards of adopting BIM. As the aim of the present study is to design a DSS mainly to assist SMEs, and to make sure that this DSS will meet their current requirements, the participants for framework validation were limited to companies with BIM experience working in the UK, including project managers, designers, constructors, sub-contractor and operators etc., who have all worked in a context where BIM has been adopted to deliver construction projects. In this way, the conceptual framework could be validated carefully across its working process and functionalities. In addition, the potential risks and rewards mentioned in the conceptual framework could also be considered fully by those who have worked with BIM in conducting construction projects.

It is essential to note that research methodology is one of the most significant factors contributing to the success of any research project. It provides the procedural approaches used in a study, shows how appropriate the chosen methods are, and puts forward a rationalization of the use of those methods over others. The methodology also provides a good link between the literature reviewed and the research findings of the study (Yin, 1994). There are many methodologies that might be adopted to evaluate the conceptual framework of this present study; they are divided into two main groups, qualitative and quantitative methodologies, as detailed below:

5.2.4.1. Qualitative research method

Qualitative research consists of a set of interpretive, material practices including for example field notes, interviews, conversations, photographs, recordings, and memos to the self (Denzin *et al.*, 2005). Such research usually describes people's behaviour, actions or even points of view regarding the issue in which they are interested, for example through descriptions and explanations of both the perspectives and the behaviour of research participants (Patton, 1992). Information gathered can be classified as belonging to one of two categories: exploratory research and attitudinal research (Naoum, 1998). Exploratory research consists of describing a particular situation about which researchers want to know in depth but have only limited knowledge and need to have a clear idea of the problems involved. Attitudinal research, in contrast, is usually used to evaluate the ideas or statements of a person or even a group of people according to attributes, variables, factors or questions designed by researchers. The main forms of qualitative research are the individual interview, focus groups, direct observation and case studies (Hancock, 1998).

Amaratunga *et al.*, (2002) state that the key benefits of qualitative methods consist in allowing researchers to make in-depth studies, obtaining more detailed information and greater understanding of the topic of study. However, the disadvantage of such methods lies in the time-consuming nature of data collection, which precludes their use in cases where the research requires large samples (Flick, 2009).

5.2.4.2. Quantitative research method

Quantitative research is defined as “*an inquiry into a social or human problem, based on testing a hypothesis or theory composed of variables, measured with numbers, and analyzed with statistical procedures to determine whether the hypothesis or theory holds true*”

(Creswell, 2003). It is a popular research method used in studies where the researcher needs to collect data on a large scale, rather than simply a behavioral or small scale survey (Brannen, 1992).

SJI (1999) write that the most popular quantitative research methods are experiments and surveys. A researcher will select the most effective type of method depending on the nature of the research. The most popular of quantitative research methods is the survey technique; this method, involving the use of questionnaires to collect large amounts of data, is considered highly flexible, as it can be conducted online, face-to-face or by telephone. It is this technique that is the most appropriate in this present study, and so will be used to collect quantitative data. The advantages and disadvantages of the various survey methods are compared by Rubin *et al.*, (2009), as detailed in *Table 17* below:

Table 17. Advantages and disadvantages of survey methods

Types of survey	Advantages	Disadvantages
Online survey	<ul style="list-style-type: none"> - Low cost - Assurance of anonymity for respondents - Wide geographical coverage - Low processing cost 	<ul style="list-style-type: none"> - Low response rate - High rate of uncompleted questions - Greater bias of respondents - Lack of opportunity to clarify answers - Need for questions to be simple and easy to understand
Personal survey	<ul style="list-style-type: none"> - High flexibility questioning process - High response rate - Situation easy to control - Greater quantity of information obtained 	<ul style="list-style-type: none"> - Higher cost than online - Lack of anonymity - Time-consuming nature - Bias of potential interviewers

Telephone survey	<ul style="list-style-type: none"> - Moderate cost - High response rate - Fast data collection 	<ul style="list-style-type: none"> - Hesitancy to discuss sensitive data - Less opportunity to provide supplementary information - High likelihood of respondents completing
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The next section presents methods adopted to collect data through framework validation and DSS validation processes.

5.2.4.3. Research method adopted

The nature of the research objectives has a strong influence on the choice of research method (Creswell, 2009). In order to decide the most appropriate method for this study, a comparison between qualitative and quantitative research methodologies was drawn up, following Amaratunga *et al.* (2002), as detailed in *Table 18* below:

Table 18. Comparison between qualitative and quantitative methods

Criterion of comparison	Qualitative method	Quantitative method
Alternative labels	Constructivist, naturalistic-ethnographic or interpretative	Positivist, rationalist or functionalist.
Scientific explanation	Inductive	Deductive
Data classification	Subjective	Objective
Objective	<ul style="list-style-type: none"> To understand original reasons and motivations. To investigate insights into a problem To generate ideas and hypotheses for later quantitative research. 	To evaluate data and generalise results from a sample population of interest.

	To uncover prevalent trends in thought and opinion.	To measure the occurrence of various views and options in a chosen sample.
Sample	A small number of representative cases. Respondents selected to fulfil a given quota or requirement.	A large number of cases representing the population of interest. Randomly selected respondents.
Data collection	Participant observation, semi- and unstructured interviews, focus groups, conversation and discourse analysis.	Structured interviews, self-administered questionnaires, experiments, structured observation, content analysis/ statistical analysis.
Outcome	Exploratory and/or investigative. Findings not totally conclusive, and cannot be used to make generalisations.	Usable to recommend a final course of action.

It can be stated that, qualitative methods can alternatively be labelled constructivist, naturalistic-ethnographic or interpretative, these being the paradigms they arise from; quantitative methods, on the other hand, are associated with to the positivist, rationalist or functionalist paradigms. Qualitative methods are suitable for application to subjective data, and their scientific reasoning is inductive, whereas quantitative methods are applicable to objective data, and employ deductive reasoning. Qualitative methods are appropriate for enquiries that seek to understand original reasons and motivations, to investigate insights into a problem, to generate ideas and hypotheses for later quantitative research, or to uncover

prevalent trends in thought and opinion. Quantitative methods, on the other hand, are more appropriate for enquiries that seek to evaluate data and generalise results from a sample population of interest, or to measure the occurrence of various views and options in a chosen sample. As for samples, a small number of representative cases might be appropriate for qualitative research, where respondents have been selected to fulfil a given quota or requirement; whereas quantitative methods are more suitable for large numbers of cases and randomly selected respondents representing the population of interest. Data collection methods in qualitative research can include participant observation, semi and unstructured interviews, focus groups, and conversation and discourse analysis; while for quantitative research data collection methods might include structured interviews, self-administered questionnaires, experiments, structured observation, and content analysis or statistical analysis. And finally, whereas the outcomes of qualitative research methods are generally exploratory and/or investigative, with findings that are not totally conclusive and cannot be used to make generalisations, the outcomes of quantitative methods on the other hand can generally be considered reliable, and so can be used for example to recommend a course of action.

From the literature reviewed for this present study, the conceptual framework and research design were developed. Given that the objective of the study is to ensure that the framework as well as the DSS can help SMEs to clarify and anticipate the risks and rewards of adopting BIM to deliver construction projects, careful consideration was given to the appropriacy of research methodologies, and to the comparison above, and accordingly the quantitative research method was adopted to collect primary data for this present study. The aim of this activity was to validate the criteria of the conceptual framework as well as the risks and rewards associated with each criterion. In addition, after careful comparison of survey methods as illustrated in Table 18, the online survey method was also adopted.

The main reason for adopting a quantitative research methodology for this research, and the online survey in particular, is the fact that the framework validation requires the participation of a large number of BIM users in various professions across the UK. With this number of participants, the findings can be considered representative of the entire UK construction industry, and sufficiently reliable to decide the outcomes of the framework and to ensure that the framework provides valuable and instructive information about BIM to SMEs. Such

an objective could not be achieved by means of a qualitative methodology, due to the necessary limitations on participant numbers, and to the fact that such methodologies can be difficult to employ

As for the online survey, in spite of its comparative limitations (see Table 18 above) this method was considered the most suitable for the present research because it is easy to deploy, and its use via a free online survey system allows savings of time and money. Furthermore, the researcher is easily able to select and send questionnaires to participants through professional BIM social media groups such as Facebook, Yahoo, and LinkedIn. Also, the data collected was easily analysed through the “Export Data” function of the online survey system used.

As for the survey procedure for this present study, structured questionnaires were designed and sent out via the online survey system to BIM users across the UK, to collect quantitative data in order to validate the conceptual framework of the research. The data collected was then analysed by statistical methods to evaluate the conceptual framework addressing the risks and rewards for SMEs of adopting BIM in construction project delivery.

The DSS was then developed based on the completed conceptual framework, with a sufficient number of the most important criteria and their attributes relating to issues about which SMEs are concerned when they adopt, or consider adopting, BIM to deliver construction projects. To visualize the outcome of the framework as well as to demonstrate how DSS can help SMEs to anticipate the risks and rewards of BIM adoption, the DSS was developed based on web application technology. This was then sent out to validate on the internet. Once again, a quantitative method was adopted, given its potential to save the researcher time and money on testing and to create new opportunities for SMEs to interact with a new framework relating to the benefits of BIM, which it is hoped may help them to reach a new perspective regarding BIM investment for their company.

The design of the survey, and its implementation to collect data for the process of framework validation, are detailed in the next section.

5.2.5. Questionnaire design and survey implementation

At this stage, an online structured questionnaires survey was designed to collect data for framework validation. Before the survey went on live, an initial pilot study was conducted

with six BIM users. The purpose of this pilot study was to ensure that the evaluation of each criterion of the framework was meaningful, fit for purpose, and easy to follow. Feedback from the participants assisted in the adjustments of the criteria and in the design of the framework. The details of the questionnaires can be seen in Appendix I.

In this survey, rank order questions were selected, and the Qualtrics platform was used to provide an individual token system for survey management. This ensured that participants could not undertake the survey twice, and all data was securely stored in an online MySQL database.

The rank order question type allows participants to rank a set of items against each other. This type of question has the benefit of requiring respondents to identify how elements or choices compare to each other and determines the most important ones to them (Cao *et al.*, 2015). Respondents had the opportunity to classify the criteria from the most to the least important by dragging and dropping the available choices into an appropriate order. They were asked to rank elements within a situation to ascertain the most and the least important attributes of BIM implementation in project delivery in terms of their impacts and likelihood of occurrence. The survey consisted of six sections, as detailed in *Table 19* below:

Table 19. Details of survey design

Section	Assessment criteria	Tasks
1. Personal information	<ul style="list-style-type: none"> - Role within organisation - Length of professional experience - Length of BIM experience - Size of organisation that they are working for 	In this section, respondents were asked to provide details about their role in their organisation, the length of their professional and BIM experience, and the size of their organisation.
2. Key factors	<ul style="list-style-type: none"> - Involvement phase 	Participants were asked to rank factors from the most to the least likely to allow

	<ul style="list-style-type: none"> - Project value - Source of funding - Procurement route 	<p>an SME to maximise the benefits and minimise the risks when adopting BIM.</p>
3. Stages of involvement	<ul style="list-style-type: none"> - Design stage - Construction stage - Operation/maintenance stage 	<p>Participants were asked to rank the stages of involvement in project delivery, from the most to the least likely to allow an SME to maximise benefits and minimise risks when adopting BIM.</p> <p>In addition, they were required to rank the risks and rewards associated with each stage of involvement, from the most to the least, in terms of their likelihood of occurrence and level of impact on an SME.</p>
4. Project value	<ul style="list-style-type: none"> - Less than £5 million - Between £5 million and £50 million - Greater than £50 million 	<p>Participants were asked to rank in terms of their value projects from the most to the least likely to allow an SMEs to maximise the benefits and minimise the risks when adopting BIM.</p> <p>They were also required to rank the risks and rewards associated with project value, from the most to the least, in terms of their likelihood of occurrence and level of impact on an SME.</p>
5. Source of funding	<ul style="list-style-type: none"> - Public funded projects - Private funded projects 	<p>Participants were asked to rank sources of funding from the most to the least likely to allow an SME to maximise the benefits and minimise the risks when adopting BIM.</p>

		They were also required to rank the risks and rewards associated with sources of funding, from the most to the least, in terms of their likelihood of occurrence and level of impact on an SME.
6. Procurement route	<ul style="list-style-type: none"> - Traditional - Two-stage design and build - Integrated project delivery 	<p>Participants were asked to rank procurement methods from the most to the least likely to allow SMEs to maximise the benefits and minimise the risks when adopting BIM.</p> <p>They were also required to rank the risks and rewards associated with each procurement method, from the most to the least, in terms of their likelihood of occurrence and level of impact on an SME.</p>

Participants in the survey were limited to companies with BIM experience, working in the UK, and were largely selected from the main BIM groups to be found on LinkedIn. These groups included BIM4SME (857 members), BIM Architecture (18,214 members), and BIM Experts (41,281 members). Before the survey went live, three pilots and three semi-structured interviews were conducted with personnel with BIM experience to ensure that there was uniform understanding of the research issues and that the content of the questionnaire was clear.

The sample size of this study decided through formula mentioned in the next section.

5.2.6. Deciding sample sizes

To determine the sample size, Czaja *et al.* (1996) suggest that the sample size *ss* can be calculated using the following formula:

$$ss = \frac{Z^2 * e(1 - e)}{c^2}$$

where:

z = Z score: 1.96 - the most common confidence intervals

c = 10% - confidence interval, expressed as a decimal

e = 50% - the worst case percentage picking choice, expressed as a decimal

As a result,

$$ss = \frac{z^2 * e(1-e)}{c^2} = \frac{1.96^2 * 0.5(1-0.5)}{0.1^2} = 96.04$$

However, there are currently 950,000 SMEs in the UK construction industry (House of Commons, 2015), so the new sample size should be:

$$new\ ss = \frac{ss}{1 + \frac{ss - 1}{pop}} = \frac{96.04}{1 + \frac{96.04 - 1}{950.000}} = 96.03$$

This result suggests that 96 responses are needed for a valid sample size.

To allow for a poor response rate, 20–30% above the sample size appears to be the norm (Takim *et al.*, 2004). Therefore, the sample size of this present survey was determined as follows:

$$ss = \frac{96.03}{0.2} = 480 \text{ participants}$$

In order to ensure the achievement of the responses target, this number was doubled to 960. As indicated in Section 5.2.4.3, the conceptual framework and DSS validations are conducted through online structured surveys. This sample size was targeted for the conceptual framework and DSS validation.

The next section proposes methods used to analyse data after being collected from the framework validation survey.

5.2.7. Data analysis methodology

There are two different methods used to analyse data of this study. The Voting Analytic Hierarchy Process (VAHP) was selected to analyse data collected from conceptual

framework validation process, whereas, the descriptive statistics method was used to describe and present data collected from the survey conducted to validate the DSS.

Details of adopting VAHP data analysis method are presented in the next section.

5.2.7.1. The analytic hierarchy process

The Analytic Hierarchy Process (AHP) is a MCDM approach which was developed by Thomas Saaty in 1996 (Ata *et al.*, 2008). It is a structured technique designed for dealing with complex decisions (Marjanavie *et al.*, 2010), a theory of measurement through paired comparisons that relies on the judgement of experts to derive priority scales (Saaty, 2008). Basically, AHP is a method of breaking down complex and unstructured problems into smaller and consistent parts (variables) which are then arranged into a hierarchical order. Subjective judgements as to the relative importance of each variable are then translated into numerical values which can be processed and compared over the entire range of problems. The results can then be used to guide decision makers in choosing the most appropriate outcome by noting the highest score variables (Saaty, 1995).

According to Saaty *et al.* (1989), AHP comprises three separated stages deriving from the following three principles: hierarchy construction, priority setting and logical consistency. As to the first of these principles, because the human mind cannot perceive simultaneously every factor affected by an action or the connections between these factors, complex systems need to be broken down into simple structures, and thus hierarchies can serve as significant tools to assist decision makers in dealing with the complexity of decision-making problems, by constructing frameworks consisting of different large elements, separate yet at the same time connected.

With regard to the priority setting principle, priorities (or weights) can be established from paired comparisons between elements belonging to the same hierarchy level. Thus, all the criteria at the same hierarchical level are compared in pairs with respect to the corresponding elements at the next highest level, establishing a matrix of paired comparisons.

Typically, for each criterion C , an n -by- n matrix A of paired comparisons is established. The elements A_{ij} ($i, j = 1, 2, \dots, n$) of the matrix A are numerical entries and represent the element I over the element j with respect to the corresponding element in the next highest level. Therefore, the matrix A takes the following form:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

where

$$a_{ii} = 1 \quad a_{ij} = a_{ji} \quad a_{ij} \neq 0$$

In order to calculate relative priorities among the n elements of the matrix A , the principal Eigen vector of the matrix is computed and normalized to what is termed the priority vector (v , with $\sum v_i = 1$).

Regarding the logical consistency principle, it should be noted that a degree of inconsistency can arise when elements are compared. To check the degree of inconsistency in particular cases, the λ_{max} (maximum or principal Eigen value) of each matrix of paired comparisons is calculated. If the inconsistency is too high, it will be necessary to reformulate the assessments by means of new paired comparisons (Toro *et al.*, 2000).

According to Saaty (2000), the scoring of alternatives and criteria can be performed by using a paired comparison method, specifically a nine-point scale ranging from 1 to 9 as described in table below:

Intensity of importance	Definition	Explanation
1	Equally important	Two factors contribute equally.
3	Somewhat more important	Experience and judgment slightly favour one over the other.
5	Much more important	Experience and judgment strongly favour one over the other.

7	Very much more important	Experience and judgment very strongly favour one over the other. The relative importance of one is clearly demonstrated in practice.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

It is to be assumed that when an attribute A is absolutely more important than an attribute B and is rated at 9, this means that attribute B must be absolutely less important than A and is therefore set at 1/9. Paired comparisons are carried out in order for all elements to be taken into account (usually not more than 7), and the matrix is established to support the calculations (Yang *et al.*, 1998).

The steps involved in AHP are identified by Bouyssou *et al.* (2006) and Cox *et al.* (2013) as follows:

1. The decision-makers/stakeholders are required to compare criteria in paired attributes in the order of their relative importance.
2. The weights of the criteria are calculated from the paired comparisons as Eigen vectors corresponding to the Eigen value of the matrix.
3. The Eigen vectors are normalised to 1.
4. Steps 1 to 3 are repeated for comparison of the alternatives.
5. The overall score of each alternative is finally calculated using the equation below (Cox *et al.*, 2013):

$$V(a_j) = \sum_{i=1}^n w_i v_i(a_j) \quad (1)$$

where:

$V(a_j)$ = the total score of each alternative j.

w_i = the weight of criterion i .

$v_i(a_j)$ = the normalisation of alternative j with respect to criterion i (for example).

n = the number of criteria.

6. A sensitivity analysis is conducted and the alternative with the highest score is selected.

7. The whole analysis is reported.

AHP is one of the most popular methods of MCDM, having been employed in many different frameworks, and experience has shown it to have numerous advantages. First of all, it is easy to use since its paired comparisons can enable decision makers to weight coefficients and compare alternatives with relative ease (Hester *et al.*, 2013). Besides, AHP permits criteria to be structured hierarchically so that stakeholders can better focus on specific criteria and sub-criteria when allocating weights and can easily adjust the analysis in size to accommodate decision making problems (Alessio *et al.*, 2009). Another important strength of AHP is that it allows the evaluation of quantitative as well as qualitative criteria and alternatives, on the same preference scale of nine levels. Moreover, although it requires sufficient data to properly perform the necessary paired comparisons, it is not data intensive (Hester *et al.*, 2013). Finally, in comparison with other methods such as TOPSIS or ELECTRE II which have limitations in terms of controlling inconsistencies, in AHP the consistency of judgement of decision makers is measured carefully (Esnaf, 2011).

Aside from its strengths, AHP does nevertheless evince certain disadvantages that should be considered. Hester *et al.* (2013) note that the paired comparisons approach could lead to inconsistencies in judgement and ranking criteria, and the supplementing of alternatives at the end of the process could cause the final ranking to collapse or reverse. In addition, if all elements are compared to all others at all hierarchy levels, the number of paired comparisons in the matrix will be too great $[N(N-1)/2]$; and when the number of criteria and alternatives are increased, implementation of this method will become impossible (Esnaf, 2011). Indeed, this method is not considered the most suitable for this present research, given that its DSS is potentially conducted online. Ease of use and simplicity of calculation are factors that need to be considered to increase the accessibility of the DSS.

5.2.7.2. Multi-attribute utility theory

In the field of management science research and applications, MCDM is always the best choice, several decision-making methodologies having been developed for different decision-problem structures and decision-maker preferences. Alongside AHP, Multi-Attribute Utility Theory (MAUT) is another highly popular decision making methodology, one that is used in many different research industries (Wellenius *et al.*, 2008). MAUT is essentially an extension of Multi-Attribute Value Theory, or MAVT (Keeney *et al.*, 1974) and is a “more rigorous methodology for incorporating risk preferences and uncertainty into multi-criteria decision support methods” (Loken, 2007). It provides a solution for use in cases where uncertainty is not included explicitly but can be analysed *ex post facto* through sensitivity analysis; it is thus very helpful in analysing very large numbers of alternatives (Charles *et al.*, 1997).

Kahraman (2008) states that MAUT and Multi Attribute Decision Making (MADM) both well-known, can be viewed as alternative methods that can be applied to “combine the information in a problem’s decision matrix together with additional information from the decision maker to determine a final ranking, screening, or selection among the alternatives”. The MADM general pay-off matrix proposed by Kasie (2013) is shown below:

		x1	x1	.	.	.	x1
		A1	A1	.	.	.	A1
w1	C1	a ₁₁	a ₁₂	.	.	.	a _{1n}
w1	C2	a ₂₁	a ₂₂	.	.	.	a _{2n}
.
.
.
w1	Cm	a _{m1}	a _{m2}	.	.	.	a _{mn}

where:

m = the number of decision criteria

n = the number of alternatives

C_1, \dots, C_m = the decision criteria/alternatives

A_1, \dots, A_n = the n -finite alternatives

a_{ij} = the score performance of the alternatives A_i ($i=1 \dots n$) against the criteria C_j ($j=1 \dots m$), or the marginal utility of attribute i with respect to alternative j .

w_1, \dots, w_m = the normalised weights assigned to the criteria

x_1, \dots, x_n = the values associated with the alternatives after evaluation with m criteria

The total score x_i for each decision alternative A_i against each criterion C_j in the matrix above can be calculated by the following formula:

$$X_i = \sum w_j a_{ij} \quad (2)$$

Criteria are ranked according to their level of importance and scores are assigned to them to indicate their relative importance. To reflect the values of alternatives by comparing the importance of attributes, a simple multi attribute ranking technique (SMART) was suggested by Edwards *et al.* (1994), and named SWART. This involves the use of swing, which in the process of comparing the importance of the criteria also investigates how utility values of alternatives change from the worst to the best utility level.

In order to identify the utility value a_{ij} of an alternative with respect to an attribute, the most popularly applied method is proportional scoring (Levin *et al.*, 2001). This means the linear re-scaling of each alternative to a common utility scale which ranges from 0 to 1. The highest potential score for any alternative is 1, while the lowest is 0. The proportional scoring utility function is shown in the following equation (Levin *et al.*, 2001):

$$a_{ij}(y) = \frac{y - \text{lowest value}}{\text{Highest value} - \text{Lowest value}} \quad (3)$$

where:

y = the measured quantity or assigned unit of the alternative for the attribute under consideration, which is also called the consequence.

$a_{ij}(y)$ = the utility score of the alternative for the attribute. The equation above represents the utility function for a benefit attribute, in which the benefit quantity increases as its utility score increases. For a cost attribute, the marginal utility function is presented in following equation, in which as the cost quantity increases, its utility score decreases.

$$a_{ij}(y) = \frac{\text{Highest value} - y}{\text{Highest value} - \text{Lowest value}} \quad (4)$$

The steps involved in SMART are as follows:

1. Identify the relevant criteria (attributes).
2. Assign numerical variables to each of the attributes and specify their restrictions (importance weights).
3. Construct utility functions and measure the utility values for the individual alternatives with respect to the attributes.
4. Evaluate the individual utility values and importance weights using the simple additive utility function shown in equations (3) and/or (4)
5. Aggregate the utilities and weights using equation (2)
6. Carry out sensitivity analysis to ensure the reliability and validity of the outcome of steps 1 - 5
7. Choose the alternative with the highest overall multi-attribute utility (ranking) value.
8. Report the whole analysis.

The popularity of MAUT can be ascribed to its feature of investigating the selection of optimum satisfactory solutions and best alternative solutions, which maximizes its utility for the decision maker's stated preference structure (Kahraman, 2008). MAUT methods consist of aggregating utility values of alternatives against the different criteria by creating a function that is optimized by allowing complete compensation between criteria, i.e. the gain on one criterion can compensate for the loss on another (Keeney *et al.*, 1976).

According to Hester *et al.* (2013), the significant advantage of MAUT compared to other methods is that it takes uncertainty into account and assigns a utility value which is a real number representing the preference of the considered action. Besides, MAUT may be used

in combination with other decision-making methods (Zabeo *et al.*, 2011); and it enables users to input data (Keeney *et al.* 1993) and incorporates the preferences of each consequence at every step of the method (Hester *et al.*, 2013).

However, Hester *et al.* (2013) also state that an enormous amount of input is necessary at every step of the procedure, making this method extremely data intensive. This level of input and this quantity of data may not be available for every decision-making problem. The preferences of the decision makers also need to be precise, giving specific weights to each of the consequences, which requires stronger assumptions at each level. Consequently, this method is not the best choice for research which seeks to develop frameworks as online tools or online assessment systems with the aim of increasing accessibility as well as ease of use. Therefore, this method was not chosen for calculating alternatives in the present study, whose aim is to help users to foresee the risks and rewards of BIM adoption. This is because the potential DSS of this present study needs to be designed as a simple tool whose aim is to enhance accessibility as well as helping SMEs to easily anticipate the risks and rewards they may face.

5.2.7.3. Adopting Voting Analytic Hierarchy Process to analyse data for validating the conceptual framework

The Voting Analytic Hierarchy Process (VAHP), proposed by Liu *et al.* (2005), is a new approach emerging from the Analytic Hierarchy Process (AHP) method. In this method, the weights of criteria are calculated through voting instead of using the paired comparisons of the AHP method. Data Envelopment Analysis (DEA) is used to aggregate the votes for each criterion received in different ranking positions into an overall score for each criterion (Hadi-Vencheh *et al.*, 2011). The overall scores are then normalized as the relative weights of the criteria. The procedure for this method, known as the LH-model, was developed by Liu *et al.* (2005), having been adapted from Noguchi's ordering (Noguchi *et al.*, 2002), and comprises the following six stages:

- Stage 1: Selection of the framework criteria, obtained from the review of literature or through other methodologies.
- Stage 2: Structuring of the hierarchy of criteria, using AHP to provide a theoretical multi-criterion methodology for evaluating alternatives.
- Stage 3: Voting on the main criteria and their sub-criteria.

- Stage 4: Calculation of the weight of criteria and sub-criteria by using the following formula:

$$\begin{aligned} d_{rr} &= \max \sum_{(s=1 \sim S)} u_{rs} x_{rs} \quad (5) \\ d_{rp} &= \sum_{(s=1 \sim S)} u_{rp} x_{rp} \leq 1, \quad p = 1, 2, \dots, r \\ u_{r1} &\geq 2u_{r2} \geq \dots \geq Su_{rs} \\ u_{rs} &\geq \alpha = \frac{1}{(1 + 2 + \dots + S) \times n} \\ &= \frac{2}{n \times S(S + 1)} \end{aligned}$$

where:

- x_{rs} = the total votes for the r th criteria for s th place by n voters. Thus, we obtain a figure x_{r1} for votes for first place, x_{r2} for second place, ..., x_{rs} for s th place
- $r = 1, 2, \dots, S$.
- α is the constraint which stands for the difference in weights between s th place and $(s+1)$ th place.

- Stage 5: Measurement of the performance of alternatives on the basis of the relative weight of each criterion.

- Stage 6: Identification of the priority of alternatives on the basis of the total weight obtained in Stage 5 through the summing of criterion weights.

As reported by Soltanifar *et al.* (2011), the advantages of the VAHP method are as follows:

- simple to understand.
- easy to use to obtain priority weights.
- allows criteria and performance to be ranked through voting instead of by paired comparisons, which helps to reduce the time necessary for the otherwise slow and laborious ranking process.

A comparison of the benefits of AHP and VAHP is presented in Table 20 below:

Table 20. Differences between AHP and VAHP

Step	VAHP	AHP
1	Selection of criteria for alternatives	Comparison of criteria and prioritisation of their order of importance
2	Structuring of criteria hierarchy	Calculation of criteria weights
3	Determination of comparison matrix by voting on criteria and sub-criteria	Eigen values normalized to 1
4	Calculation of weights (Eigen values)	Steps 1 to 3 repeated for comparison of alternatives
5	Measurement of alternative performance	Overall scores calculated for each alternative
6	Identification of alternative priority	Sensitivity analysis conducted and highest scoring alternative selected
7	Reporting of entire analysis	Reporting of entire analysis

In spite of its advantages, the LH-model still has limitations. Hadi-Vencheh *et al.* (2011) point out that the LH-model uses Formula (5) to bind u_{rs} , giving it a value greater than zero. Moreover, if the number of voters (n) cannot be given, this model cannot be applied. Besides, in order to obtain the weights of each criterion and its sub-criteria, we have to run the model $[R + P]$ times, where R is the number of criteria and P is the number of sub-criteria. Therefore, Hadi-Vencheh *et al.* (2011) propose an improvement to the LH-model, to counteract its limitations and thus maximise the strength of the VAHP method. In the improved model, the variable n is removed and formula (5) is replaced by formula (6) below:

$$(6) \quad w_1 \geq 2w_2 \geq \dots \geq Su_s \geq 0$$

$$\sum_{s=1}^S w_s = 1$$

$$(7) \quad \hat{d}_r = \sum_{s=1}^S x_{rs} w_s \quad r = 1, 2, \dots, R$$

where:

- x_{rs} = the total votes for the r th element for s th place.
- w_s is the constraint standing for the difference in weight between s th and $(s+1)$ th place.

After an in-depth review of existing MCA methods, the VAHP was chosen for analysing data collected from the survey, conducted to validate the conceptual framework of this research. This method allows compensation between criteria; i.e. the gain on one criterion can compensate for the loss on another (Fulop, 2005). The other strengths of VAHP that have influenced the decision to use it for this present study are outlined below:

- The VAHP method is easy to understand.
- It is simple to use to obtain priority weights.
- The time needed for the ranking progress is reduced by the use of voting.
- The weak points of VAHP have been improved upon in the new VAHP method detailed above (the Hadi-Vencheh variation of the LH model).
- It complies with the objectives of this present study, in as much as this model does not depend on the number of participants when it comes to its operation. In addition, the number of options for the answers can be equal to the number of the places (positions).

The next section deals with ethical issues that this research takes into consideration.

5.2.8. Ethical considerations

Before conducting the research to collect data, ethical considerations need to be reviewed. This procedure was taken into consideration to ensure the integrity and confidentiality of the research. An “Application Form for Ethical Review of Research Involving Human Participants” was sent to UWE’s Research Ethics Committees for approval, in accordance with UWE’s policy and procedure regarding research ethics. This application form serves to supply full information covering the following information:

- The aims and objectives of the research.
- The research methodologies that will be used.
- Participants from vulnerable groups.

- Determination of sample size, and identification and recruitment of participants.
- Informed consent and withdrawal.
- Confidentiality/anonymity.
- Data access, storage and security.
- Risk and risk management – risks faced by participants.
- Risk and risk management – potential risks to researchers.
- Publication and dissemination of research results.
- Other ethical issues.

Before the application form was submitted, it was signed, as required, by one of the research team supervisors. In addition, a copy of questionnaires together with invitation letter were sent along with ethical application form to UWE's Research Ethics Committees. Full ethic approval has been given before the survey began.

5.3. CONCLUSION

Research methodology comprises of a series of research method and technique that researchers use to conduct their studies. The success of any researches is significant influenced by the way research designed, methods as well as techniques adopted to collect data.

In this study, six-layer research design was adopted. As mentioned above, the primary research method in this study is the process known as framework validation which seeks to determine the level of robustness and usefulness of the criteria for SMEs to enable them to maximise their benefits and minimise their potential risks. Consequently, the positivism stance is the most suitable research philosophy for this study. Furthermore, deductive research approach was also adopted aiming to test the hypothesis identified from exiting literature.

Due to the nature of the current research as well as characteristics of data, the quantitative research method was selected together with cross-sectional time horizon. The technical method used to collect data was online survey. Typically, structured online questionnaire surveys were developed and deployed for the validation of the framework criteria as well as the DSS. The conceptual framework survey sought to examine the impact of each attribute within the framework on SME organisations, in terms of their potential risks and rewards. Whereas, the DSS validation survey was to measure the usefulness of the DSS in deciding whether or not adopting BIM to deliver construction projects.

In order to analyse data collected from surveys, VAHP and descriptive frequency methods were adopted. In addition, Chi-square test was also used to justify date validating the DSS.

The participants in the framework validation survey were limited to companies with BIM experience, working in the UK, and were largely selected from the main BIM groups on LinkedIn. Whereas, the DSS validation survey focussed on SMEs across the world.

Before the main surveys were conducted, pilot studies were carried out to ensure that the evaluation of questions were meaningful and easy to follow. Feedback led to adjustments were considered carefully. In addition, deciding sample size of surveys was calculated by formal formulas, ethical considerations were also reviewed. An “Application Form for Ethical Review of Research Involving Human Participants” was sent to UWE’s Research Ethics Committees for approval, in accordance with UWE’s policy and procedure regarding research ethics.

The findings of the framework validation process will be presented in the next chapter.

CHAPTER 6: FINDINGS AND DISCUSSION OF FRAMEWORK VALIDATION

6.1. INTRODUCTION

In the second part of this chapter, the reliability of the data collected from the online survey is indicated; while in Part 3 (6.3), the findings of the primary data are described. This section includes information regarding the response rate, and respondents' personal information including their roles within their organisations, their length of professional experience, their length of BIM experience, and the size of organisation that they are working for. Also in the third part, a statistical description of the findings is presented, on the basis of four key criteria: stage of involvement, project value, source of funding, and procurement route. Details of the risks and rewards associated with the criteria of the framework are also given in this part.

The fourth part of this chapter presents the outcomes of VAHP whereas a critical debate of the findings from the survey, based on the literature investigated in Chapters 2, 3 and 4 is shown in Part 5 (6.5). It then moves on to provide outcomes which indicate on what occasions and in what conditions SMEs can expect to achieve the highest levels of reward as well as deal with the highest levels of risk when they adopt BIM to deliver construction projects. The chapter concludes by summarising the key information provided within it (Section 6.6).

6.2. RELIABILITY OF DATA

As mentioned in Chapter 5 (Section 5.4.5), the questionnaires were sent to 960 BIM users across the UK through Qualtrics online survey platform. As a result of the invitation to be involved in the survey, 115 participants responded positively. However, only 93 participants completed all the questions in the survey, which constitutes to 96,8% of the target (96 responses).

According to Litwin (2003), the reliability is a statistical method used to measure data gathered by the survey instrument. It is usually measured in three forms: test-retest, alternate

form, and internal consistency. However, internal consistency reliability is the most commonly used to assess the survey instrument and scales. Similarly, to other survey researches, the data collected from the survey in this study were also analysed and measured carefully to ensure the reliability. The process of assessing the reliability of data in this research was conducted through adopting the quantitative approach based SPSS software. Its outcome is presented through Cronbach alpha coefficient (CA) which is ranged from 0 to 1 (Ware *et al.*, 1998). The different values of CA indicate different level of reliability of data collected from the survey. The range of reliability measurers are classified by Christmann *et al* (2004), Tan (2009), Hair *et al* (2010) and Cho *et al* (2014) as follow:

- $CA < 0.6$: Bad sample, data cannot be used.
- $0.6 < CA < 0.7$: Acceptable but not good enough for academic research.
- $0.7 < CA < 0.8$: Good, can be used for academic research.
- $0.8 < CA < 0.95$: Excellent, high reliability
- $CA > 0.95$: Fake sample or identical variables

The reliability test for 30 questions in the survey of this study has been conducted to assess the reliability level of variable. As can be seen from *Table 21*, there have been a strong internal consistency for the reliability measures based on the CA. The CA is recorded 0.868 which is considered an excellent reliability for an academic research. It also means that all questions in the survey are relevant to the research topic of the research (Field, 2013)

Table 21. The reliability of survey data

Reliability Statistics	
Cronbach's Alpha	N of Items
.868	30

The details of findings in this survey are presented in Sections below.

6.3. THE DESCRIPTIVE FINDINGS OF PRIMARY DATA

As mentioned in Section 5.4.4 and 5.4.5, the invitation letters with a link to the online survey included was sent to 960 personal emails of BIM users across the UK, selected carefully from the aforementioned BIM groups. The findings of the survey are presented in following sections:

6.3.1. The profession of participants

The participants were asked to provide personal information associated with their current occupation at their organisation. The findings of this question are presented in Char 1 and 2 below.

Chart 1 shows the number of participants in each professional category, and Chart 2 shows these figures as percentages of the total number of participants. Out of a total of 93 respondents, 18 reported their professional field as architecture (19% of the total), 6 were BIM consultant specialists (6%), 9 were BIM coordinators (10%), 15 were BIM managers (16%), 10 described themselves as BIM professionals (11%), 7 were BIM technicians (8%), 4 were civil engineers (4%), 1 was a construction designer (1%), 12 were quality surveyors (13%) and 4 were structural engineers (4%).

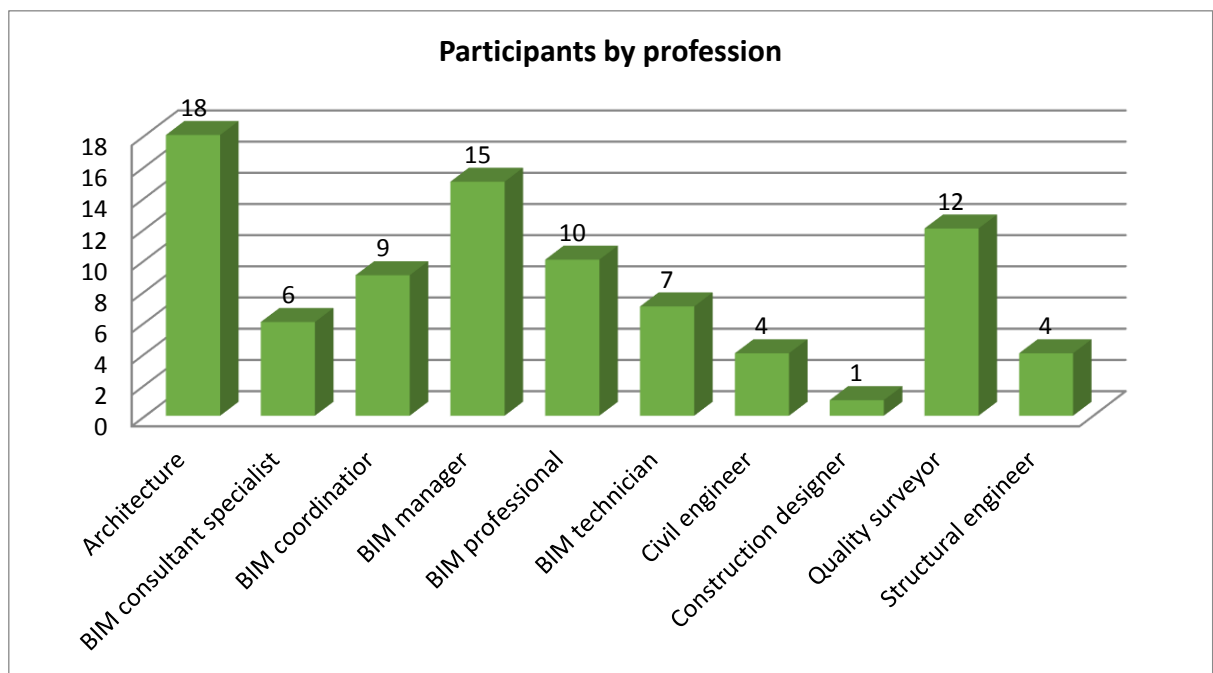


Chart 1. Participants by profession

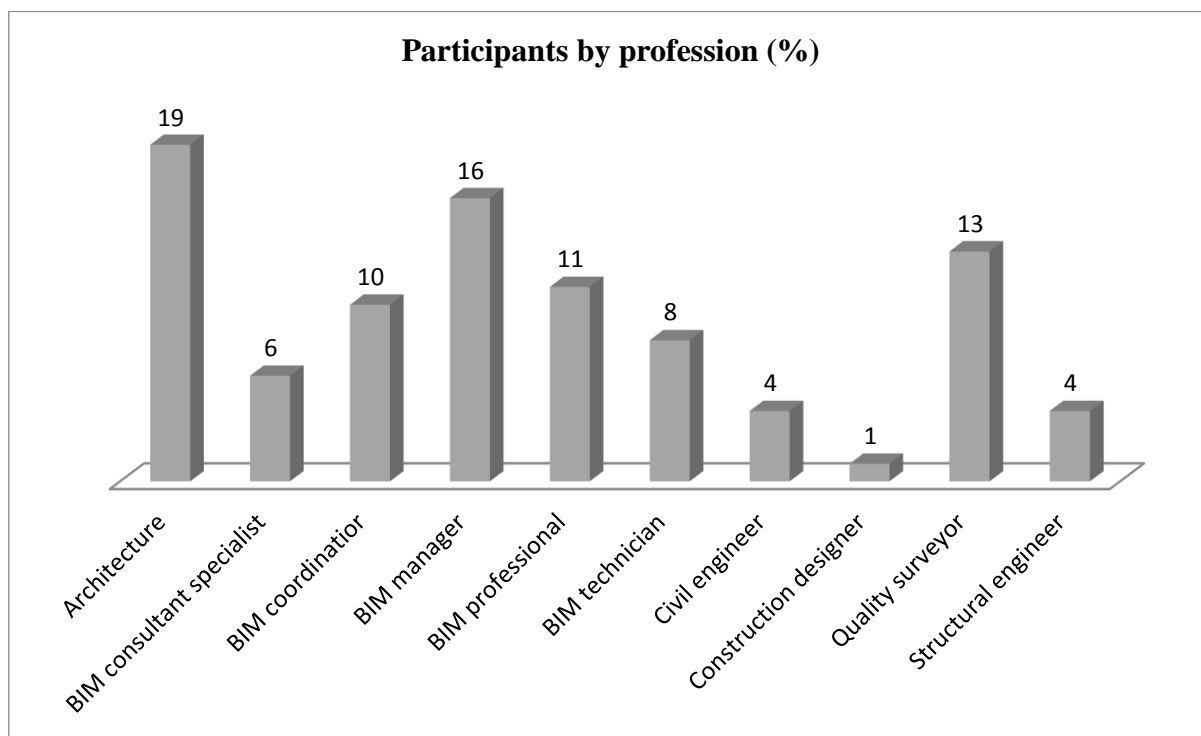


Chart 2. Participants by profession

6.3.2. Professional experience

The participants were asked to provide their professional experience associated with their career. The findings of this question are detailed in Char 3 and 4 below:

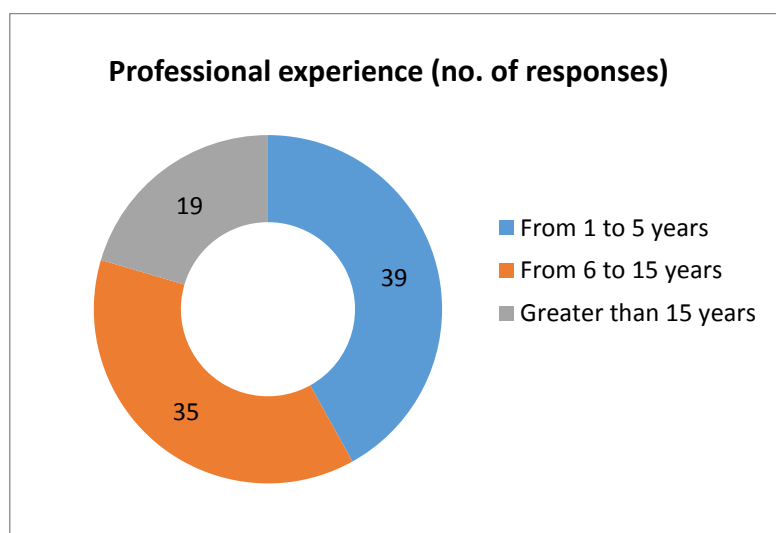


Chart 3. Professional experience (no. of responses)

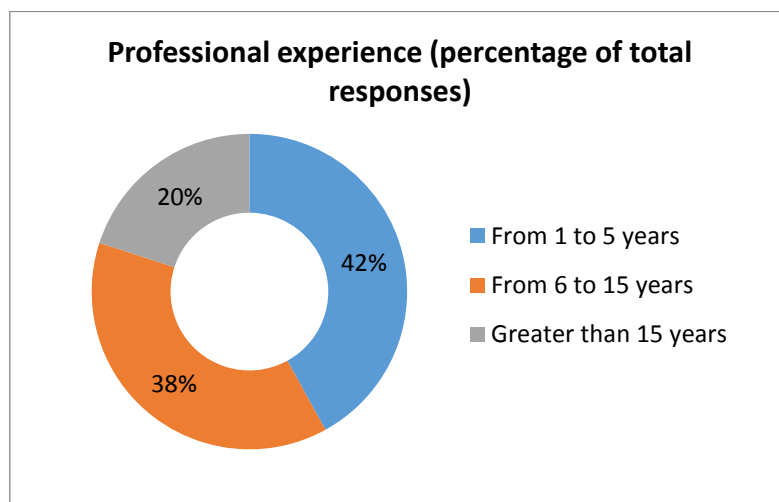


Chart 4. Professional experience (percentage of total responses)

Charts above show the length of BIM experience of participants, as either 1-5 years (blue), 6-15 years (red) or greater than 15 years (green). Chart 3 shows the number of participants in each category; while Chart 4 presents these three figures as percentages of the total number of participants. Of the 93 participants, 39 reported that they had 1-5 years' experience (42% of the total), while 35 reported that they had 6-15 years' experience (38% of the total) and 19 that they had more than 15 years' experience (20% of the total).

6.3.3. BIM experience

The participants were asked to provide their experience of working in BIM environment. The findings of this question are illustrated in Chart 5 and 6 below:

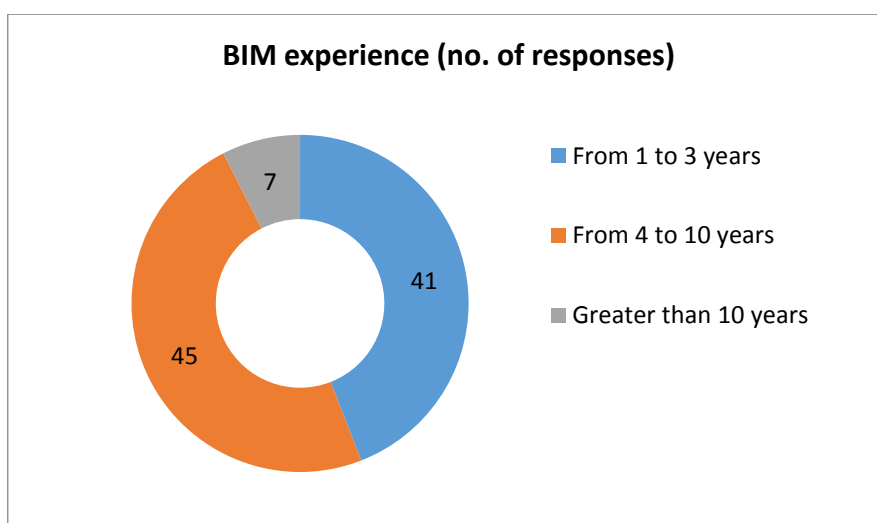


Chart 5. BIM experience (no. of responses)

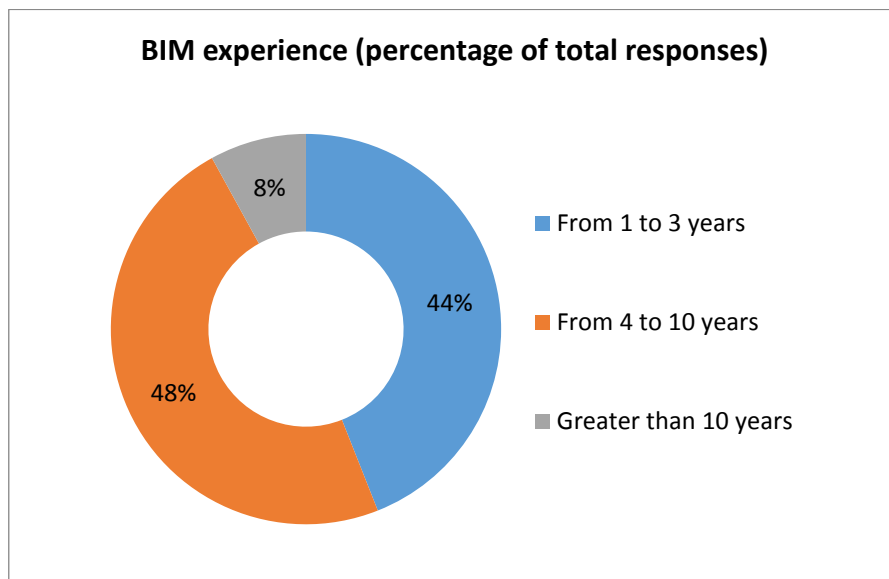


Chart 6. BIM experience (percentage of total responses)

The Chart of participants' experience of BIM is broken down into 3 categories: from 1 to 3 years (blue), from 4 to 10 years (red) and greater than 10 years (green). Chart 5 shows the number of participants in each category, while Chart 6 gives this information as percentages of the total no. of responses. Out of 93 responses, 41 claimed 1-3 years' experience (44% of total responses), 45 reported 4-10 years (48%), and 7 professed to more than 10 years' experience (8%).

6.3.4. Types of organisation that the participants are working for

The participants were asked to provide types of the organisation that they are working for. The outcomes of this question are detailed below:



Chart 7. Type of organisation

Chart 7 shows the types of organisation in which participants are employed, broken down into four categories: Professional consultancy, Construction, Legal and Other. Just under 60 respondents reported that they work as professional consultants, while just over 20 professed to work in construction, just under 5 in the legal sector, and just under 10 in other fields.

6.3.5. Size of organisation

The participants were asked to provide the size of the organisation that they are working for. Details of outcomes are presented in the Chart 8 below:

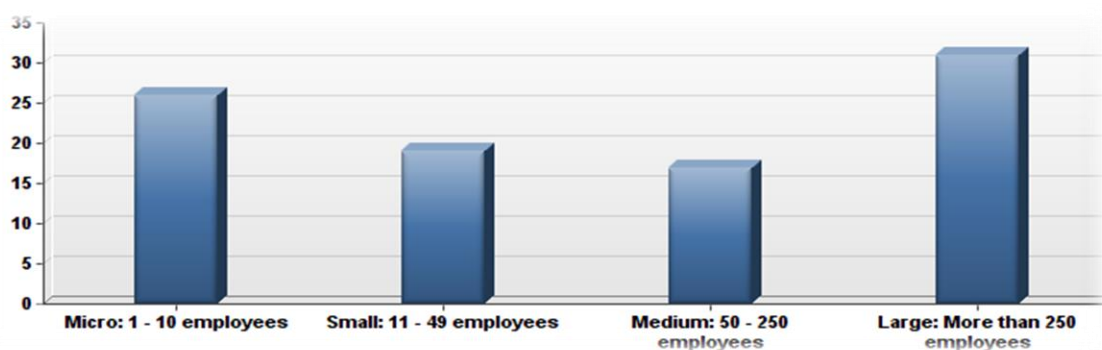


Chart 8. Size of organisation

Chart 7 breaks down respondents’ employing organisations into four categories: Micro (1-10 employees), Small (11-49 employees), Medium (50-250 employees) and Large (more than 250 employees). Of the 93 respondents, 26 reported that they work for Micro enterprises (28% of the total sample), 19 for Small enterprises (20%), 17 for Medium-size enterprises (18%) and 31 for Large enterprises (33%).

6.3.6. Potential rewards of BIM to SMEs in project delivery

The participants were asked to rank rewards provided which was developed from the literatures. The aim of this question is to find out which is the most the least rewards that SMEs may have when they adopt BIM to deliver construction projects. The outcomes of this question is presented in Chart 9 below:

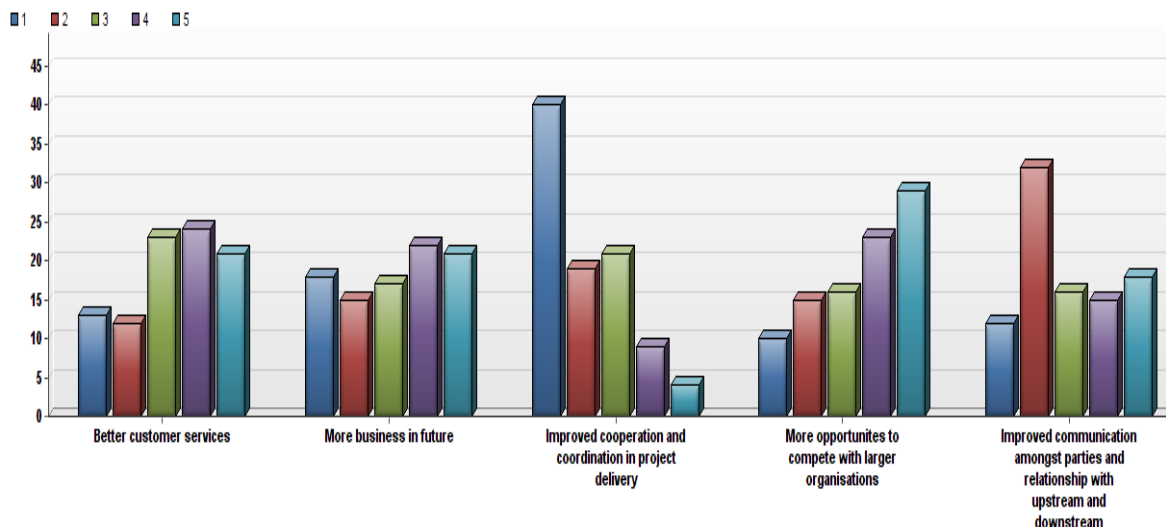


Chart 9. Potential rewards of BIM to SMEs in project delivery

Chart 9 ranks five rewards of BIM according to their perceived likelihood. As many as 40 participants felt the likeliest reward was “improved cooperation and coordination in project delivery”, whereas this was ranked second by 19 participants, and third by 21. “More future business” was ranked first by only 18 respondents, and fourth by 22. A majority of respondents (32) ranked “Improved communication between parties and relationships upstream and downstream” second; however, 18 participants ranked this fifth, with only 12 ranking it first. “Better customer services” was ranked fourth by 24 participants (the mode), third by 23, and fifth by 21. Only 10 respondents ranked “More opportunities...” first, while 23 ranked it fourth, and 29 ranked it fifth.

6.3.7. Potential risks of BIM to SMEs in project delivery

The participants were asked to rank risks that SMEs may face with in the event of not adopting BIM in their organisation. The outcomes of this question are detailed in Chart 10 below:

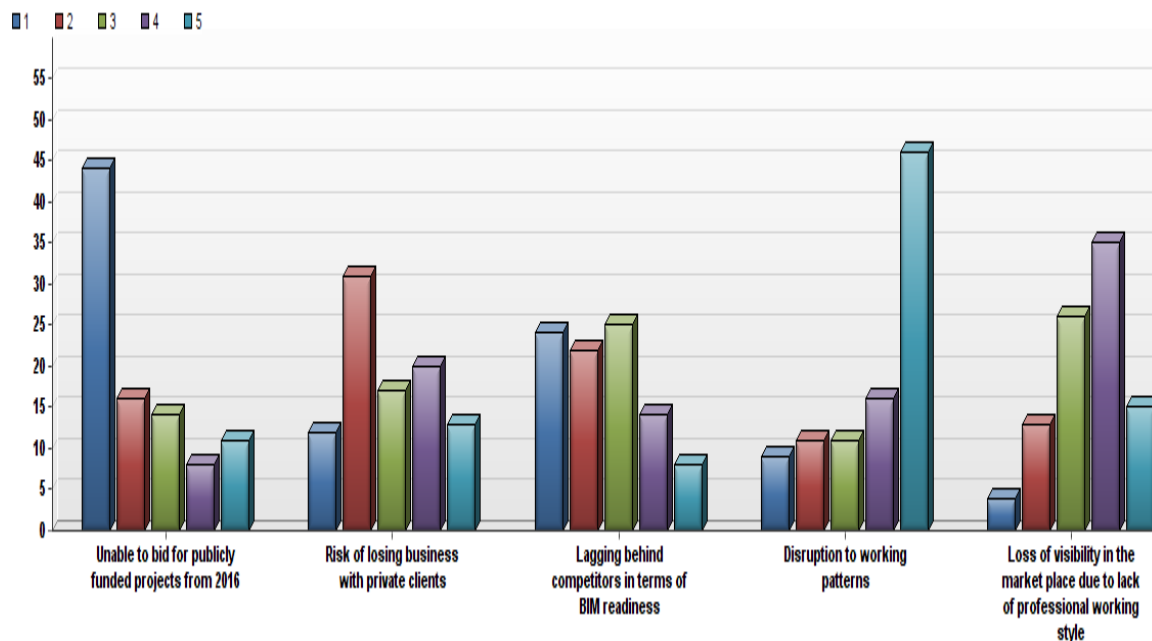


Chart 10. Potential rewards of BIM to SMEs in project delivery

Chart 10 ranks five risks of BIM according to their perceived likelihood. Forty-four participants felt the likeliest risk was “inability to bid for publicly funded projects from 2016”, whereas this was ranked second by 16 participants, and third by 14. “Risk of losing business with private clients” was ranked second by 31 participants, fourth by 20, and first by only 12. “Lagging behind competitors in terms of BIM readiness” was ranked third by 25 respondents. In contrast, for 35 respondents loss of marketplace visibility ranked fourth, with 26 ranking it third, and only 4 ranking it first. As for “Disruption to working patterns”, 46 participants ranked this fifth, while only 9 ranked it first.

6.3.8. Key criteria of the conceptual framework

The participants were asked to rank factors that allow an SME to maximise the benefits and minimise the risks when adopting BIM to delivery construction projects. The findings of this question are indicated in Chart 11 below:

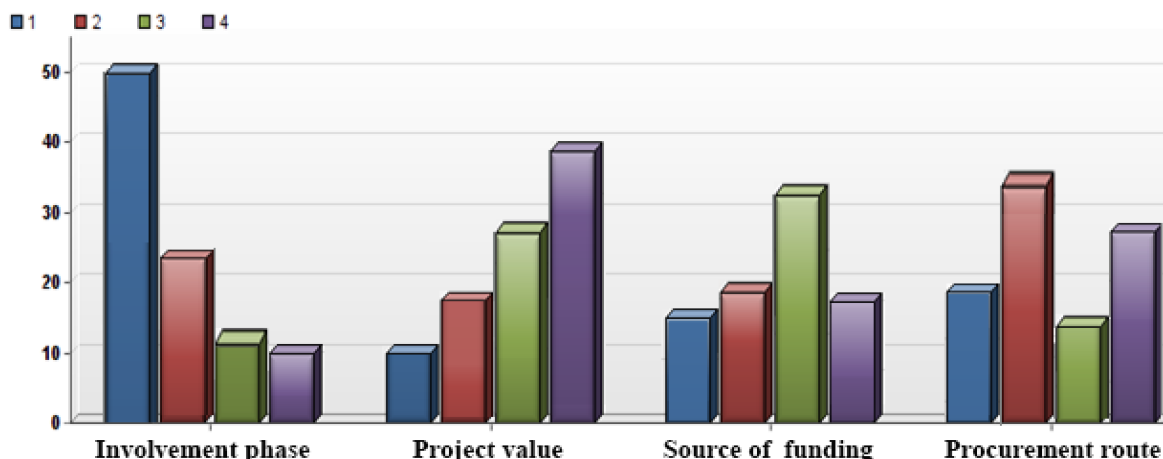


Chart 11. Factors allow an SME to maximise the benefits and minimise the risks when adopting BIM

Chart 11 ranks perceived likelihood and impact of four factors associated with adopting BIM to deliver construction projects. The involvement phase was ranked likeliest by 50 respondents (out of a total of 93), and ranked second by 22 respondents. Procurement route was ranked second by 35 respondents, first by 18, second by 21, and third by 13. Source of funding was ranked third by 42 participants, first by 15, second by 19, and fourth by 17. The project value was ranked fourth in likelihood by 39 respondents, and third by 27. In overall, the order of factors that allow an SME to maximise the benefits and minimise the risks begin with involvement phase, follow by procurement route and then source of funding. The project value was ranked last by 39 respondents (out of a total of 93).

6.3.9. Stage of project involvement

The participants were asked to rank stages of project involvement in order to identify the best/worst stages that allows SMEs to maximize the benefits and minimize the risks when adopting BIM to delivery construction projects. The findings of this question are indicated in Chart 12 below:

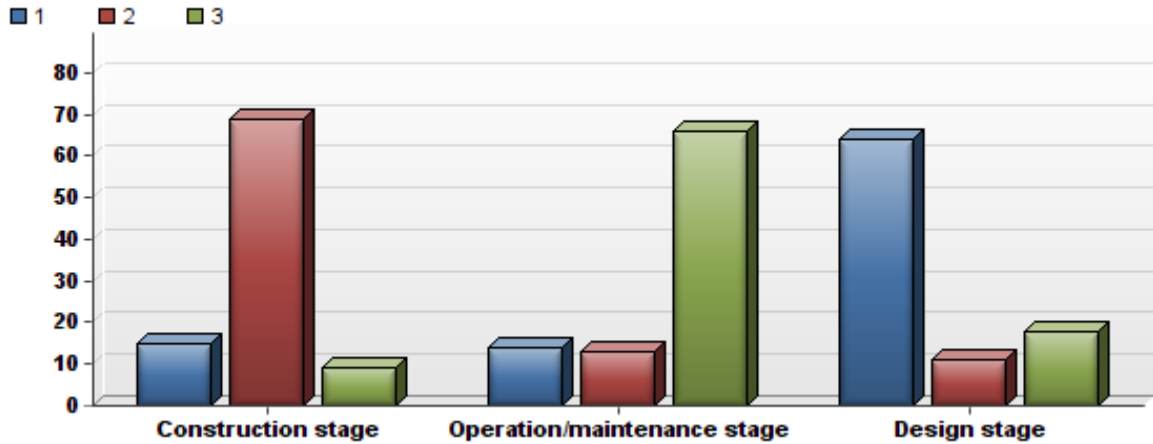


Chart 12. Stage of project involvement that allows SMEs to maximize the benefits and minimize the risks

Chart 12 ranks three stages of project delivery involvement according to their perceived likelihood of maximising BIM benefits and minimising its risks. Sixty-four participants considered the design stage the most likely; 69 ranked the construction stage the second most likely; and 66 considered the operation/maintenance stage the least likely. Only 15 participants ranked the construction stage as the most likely, with 9 ranking it third; only 14 ranked the operation/maintenance stage as the most likely, with 13 ranking it second; and only 11 ranked the design stage second, with 18 ranking it the least likely.

6.3.9.1. Potential rewards of BIM to SMEs at different stages of project involvement

The participants were asked to rank provided rewards developed from literatures in order to find out the most and the least ones that SMEs may face with when adopting BIM to deliver construction projects. The findings of these questions are presented in charts below:

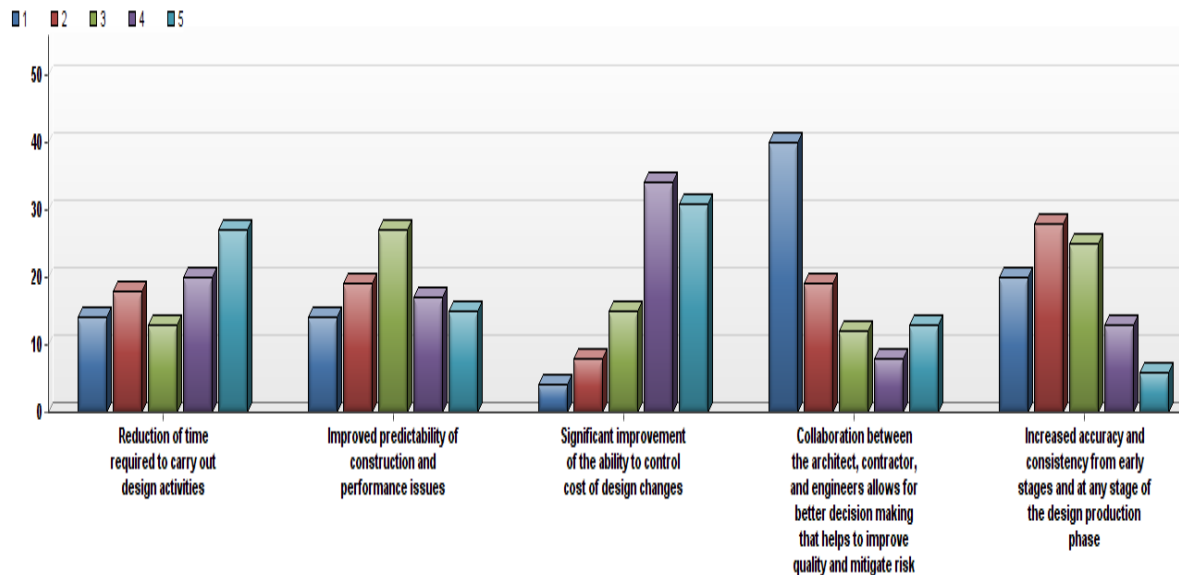


Chart 13. Rewards associated with the design stage in project delivery

Chart 13 ranks perceived likelihood and impact of five rewards associated with the design stage in project delivery. Forty participants considered “Collaboration between architect, contractor, and engineers, allowing for better decision making, which helps to improve quality and mitigate risk” the likeliest reward, while 19 participants ranked this second. Thirty-four participants ranked “significant improvement in [controlling] cost of design” only fourth, while 31 ranked this fifth, and only 4 first. As for “increased accuracy and consistency from the early stages and at any subsequent stage of the design production phase”, 20 participants ranked it first, 28 second, and only 6 fifth. “Reduction of time required to carry out design activities” was ranked first by 14 participants, fourth by 20, and fifth by 27. The mode for “improved predictability of construction and performance issues” was 27 (all ranking it fifth) with 14 participants ranking it first, and 20 fourth.

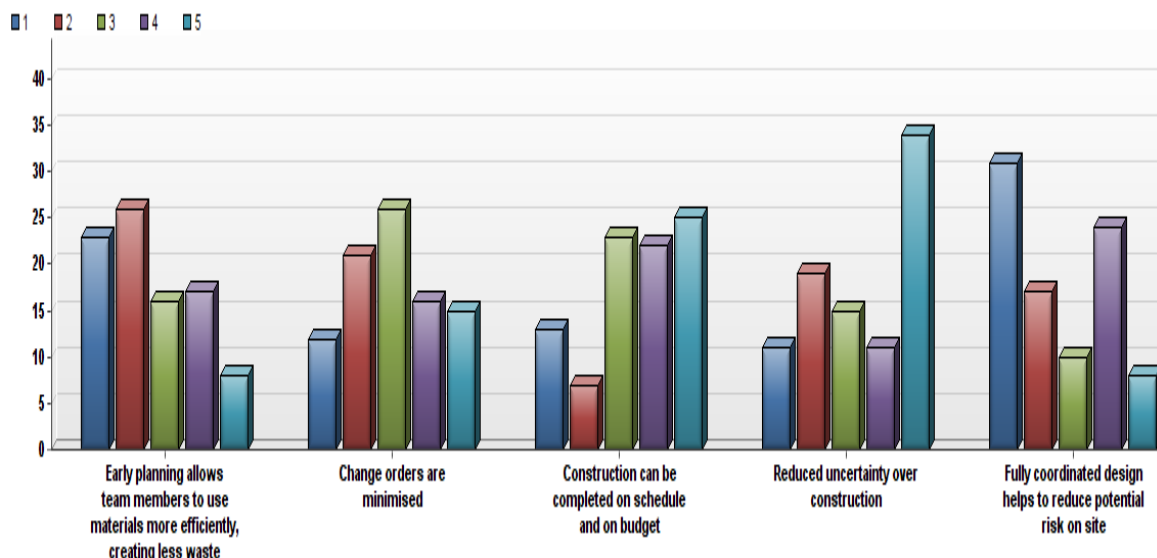


Chart 14. Rewards associated with the construction stage in project delivery

Chart 14 ranks perceived likelihood and impact of five rewards associated with the construction stage in project delivery. Thirty-one respondents considered “fully coordinated design helps to reduce potential risk on site” the likeliest reward, while 24 participants ranked this fourth. Minimisation of changes in orders” was ranked third by 26 participants, and second by 21. “Early planning allows team members to use materials more efficiently, creating less waste” was ranked first by 23 participants and second by 26. In contrast, timely completion within budget was ranked fifth by 25 participants, third by 23, and first by only 13; while reduced uncertainty ranked fifth for 34 participants, second for 19, and first and fourth for 11 each.

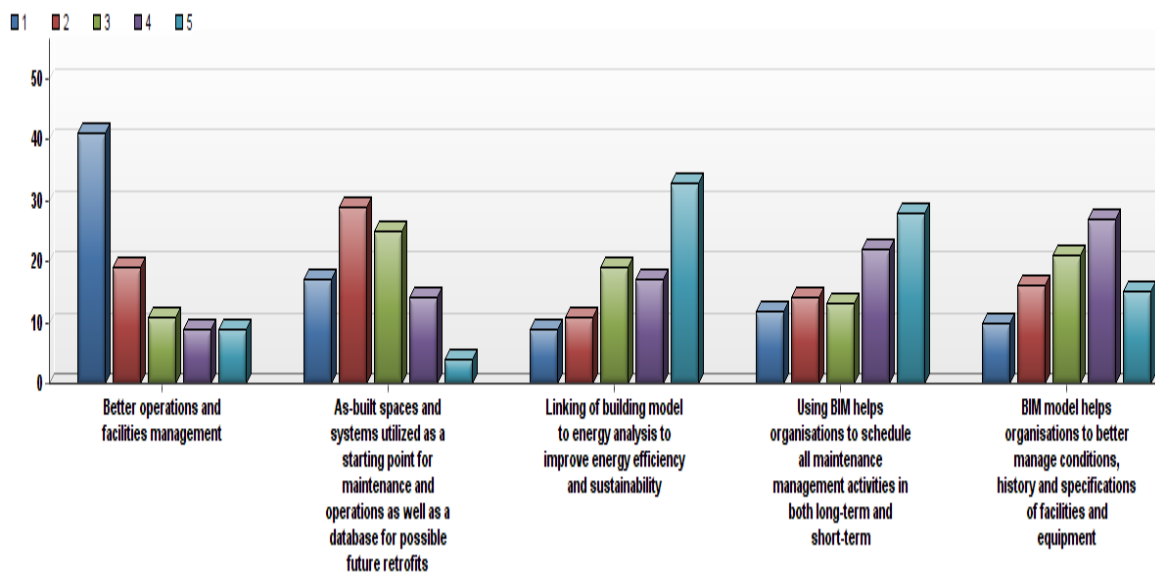


Chart 15. Rewards associated with the operation/maintenance stage in project delivery

Chart 15 ranks perceived likelihood and impact of five rewards associated with the operation/maintenance stage in project delivery. “Better operations and facilities management” was ranked likeliest by 41 out of 89 respondents, second by 19, and lower by only 11 or fewer. Utilisation of as-built spaces was ranked second by 29 respondents, third by 25, and first by 17. In contrast, “linking of building model to energy analysis model to energy analysis” was ranked only fifth by 33 participants, and first by only 9; maintenance scheduling ranked only fourth and fifth for 22 and 28 respondents respectively, while better management of equipment ranked fourth for 27 respondents, third for 21 and first for only 10.

6.3.9.2. Potential risks of BIM to SMEs at different stages of project involvement

The participants were asked to rank provided risks identified through reviewing relevant existing literatures in order to find out the most and the least ones that SMEs may face with when adopting BIM to deliver construction projects. The findings of these questions are presented in charts below:

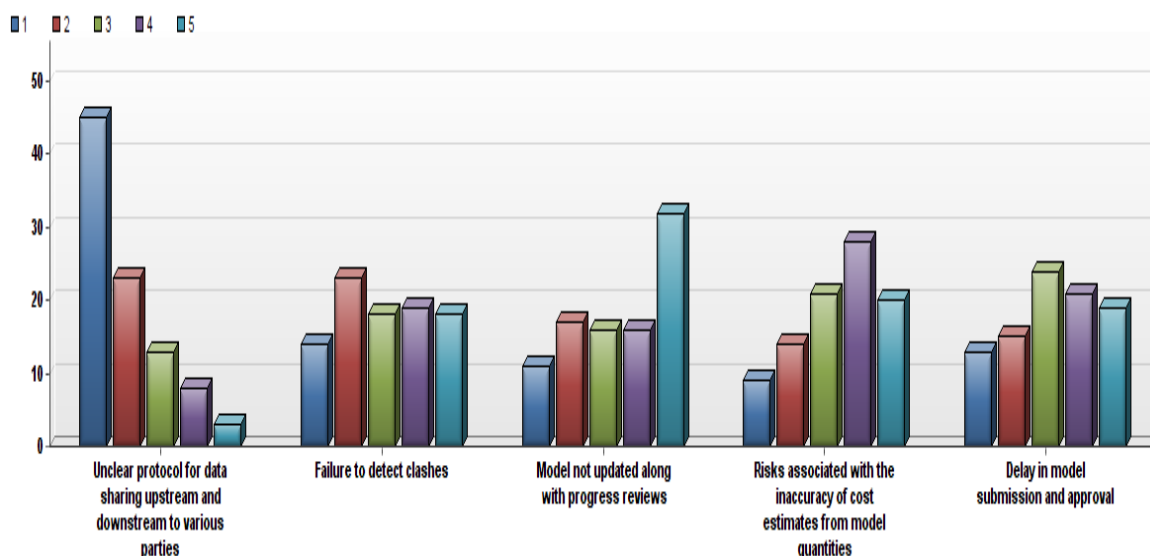


Chart 16. Risks associated with the design stage in project delivery

Chart 16 ranks perceived likelihood and impact of five risks associated with the design stage in project delivery. Forty respondents considered unclear data-sharing the likeliest risk, while 23 participants ranked this second. “Failure to detect clashes” was ranked second by 23 participants, and third by 18. “Model not updated along with progress reviews” was ranked only fifth by 32 participants, while 16 ranked this risk fourth. As for “inaccuracy of cost estimates from model quantities”, 20 participants ranked it first, and 28 second. Risks associated with cost estimate inaccuracy were ranked fourth by 28 participants, and first by only 9. As for “delay in model submission and approval”, 24 respondents ranked this risk third, and 13 first.

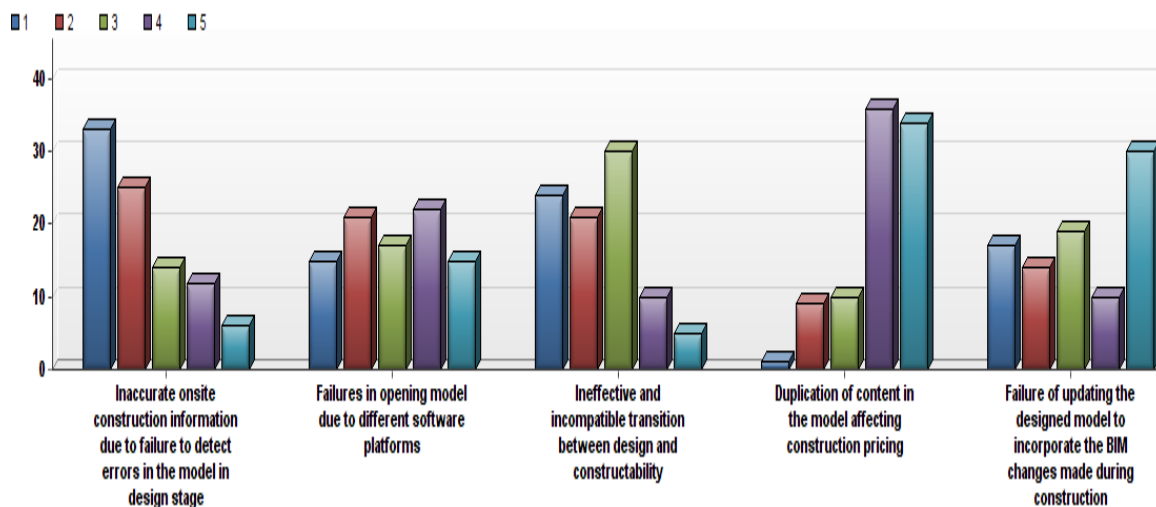


Chart 17. Risks associated with the construction stage in project delivery

Chart 17 ranks perceived likelihood and impact of five risks associated with the construction stage in project delivery. Inaccurate onsite construction information was ranked likeliest by 33 respondents (out of a total of 90), and ranked second by 25 respondents. Ineffective design-constructability transition was ranked third by 30 respondents, first by 24 and second by 21. Failures in opening the model were ranked fourth by 22 participants, and second by 21. In contrast, duplication of content was ranked only fourth in likelihood by 36 respondents, and fifth by 34; while failure to update was ranked fifth by 30 participants, and third by 19.

6.3.10. Project values that allow SMEs to maximize the benefits, minimize the risks in project delivery

The participants were asked to rank a set of project values identified through reviewing relevant existing literatures in order to find out the project values that allows SMEs to maximize the benefits and minimize the risk when adopting BIM to deliver construction projects. The findings of this question are presented in Chart 18 below:

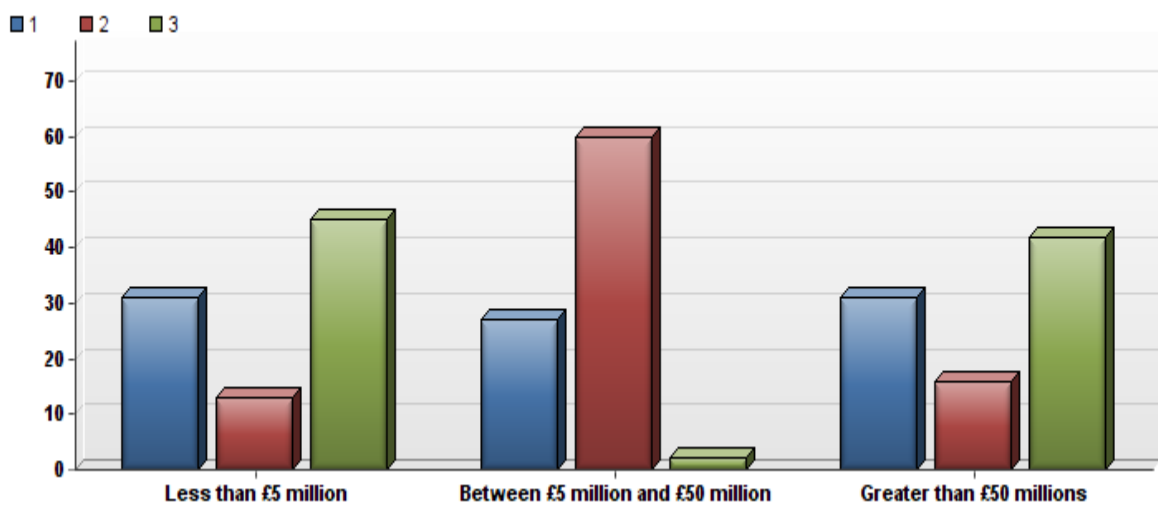


Chart 18. Project values that allow SMEs to maximize the benefits, minimize the risks in project delivery

Chart 18 ranks three project-sizes in terms of the likelihood that they would allow an SME to maximize benefits and minimize risks in adopting BIM. Thirty-one respondents felt that projects under £5 million would be most likely to allow this, while 45 respondents ranked such small projects as least likely in this respect. As for projects of between £5 million and £50 million, 27 participants ranked these first, 60 ranked them second and only 2 ranked them least likely. Projects greater than £50 million were ranked least likely by 42 participants, and most likely by 31 participants.

6.3.10.1. Potential rewards of BIM to SMEs associated with different types of project value

The participants were asked to rank a set of rewards associated with different types of projects value which were identified through reviewing relevant existing literatures. The findings of these questions are presented in charts below:

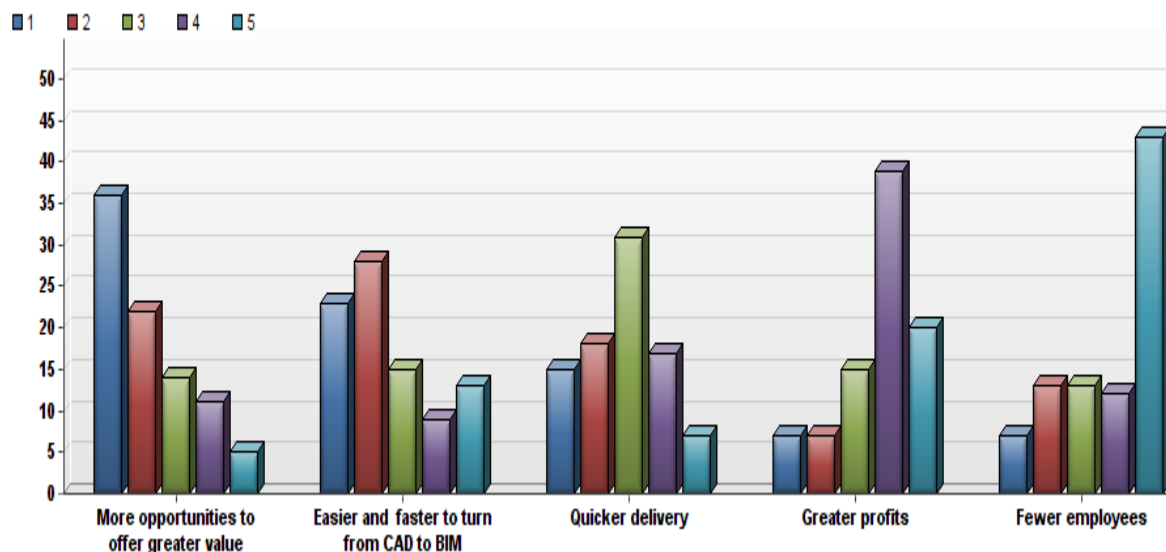


Chart 19. Rewards associated with projects of less than £5 million

Chart 19 ranks the perceived likelihood and impact of five rewards for projects below £5 million. Thirty-six respondents felt the likeliest reward was “greater opportunities to offer greater value”, while 22 ranked this second and 14 or fewer ranked it lower. Ease of CAD-BIM switching was ranked second by 28 participants, first by 23, and third or lower by 14 or fewer. Thirty-one respondents ranked quicker delivery third, 15 ranking it first. Greater profits were the most likely reward for only 7 participants, but this ranked fourth for 39 participants; while “fewer employees” was ranked fifth by 43 respondents.

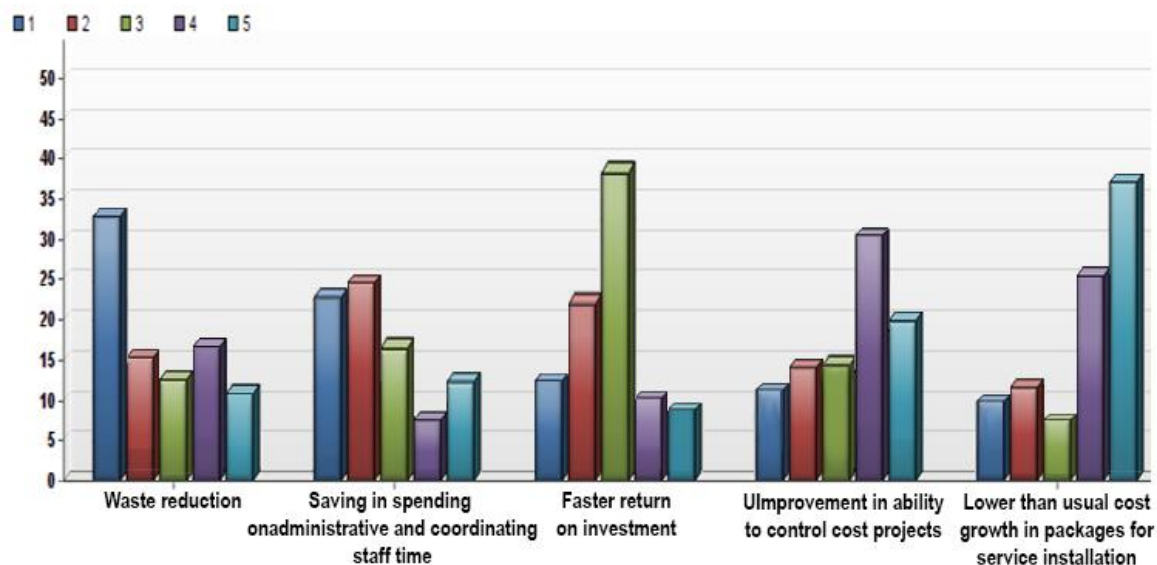


Chart 20. Rewards associated with projects between £5 million and £50 millions

Chart 20 ranks the perceived likelihood and impact of four rewards for projects between £5 million and £50 million. Thirty-three participants ranked waste reduction the likeliest reward, with 13 ranking it third, 15 second and 16 fourth. Lower cost growth of service installation packages ranked fifth for 36 participants, fourth for 25. Savings in spending on staff time were the second most likely reward for 28 respondents, ranked first by 23 respondents. Thirty-seven participants ranked higher ROI third for 37, and 37 ranked improve in ability to control cost of control fourth.

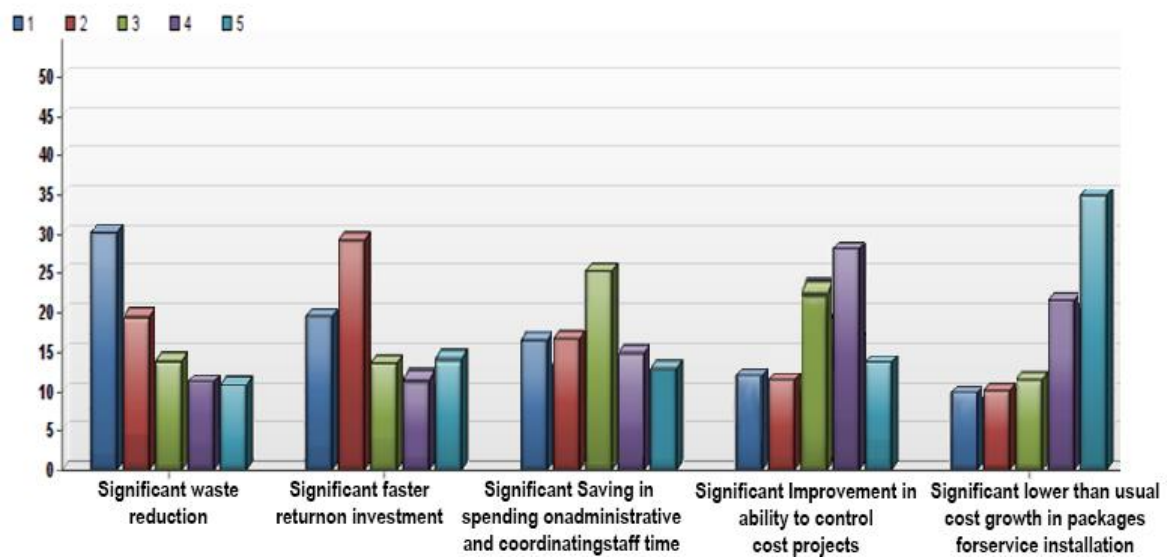


Chart 21. Rewards associated with projects greater than £50 millions

Chart 21 ranks the perceived likelihood and impact of four rewards for projects greater than £50 million. Out of 85 participants, thirty ranked significant waste reduction the likeliest reward, with 19 ranking it second, and 14 or fewer ranking it third. Significantly lower cost growth in service installation packages ranked least likely by 34 participants, fourth for 21. Significant savings in spending on staff time were ranked third by 21 respondents, second likeliest reward ranked by 29 participants is significant faster ROI whereas significant improvement in ability to control cost of projects ranked fourth by 27 respondents.

6.3.10.2. Potential risks of BIM to SMEs at different types of project value

The participants were asked to rank a set of risks associated with different types of projects value which were identified through reviewing relevant existing literatures. The findings of these questions are presented in charts below:

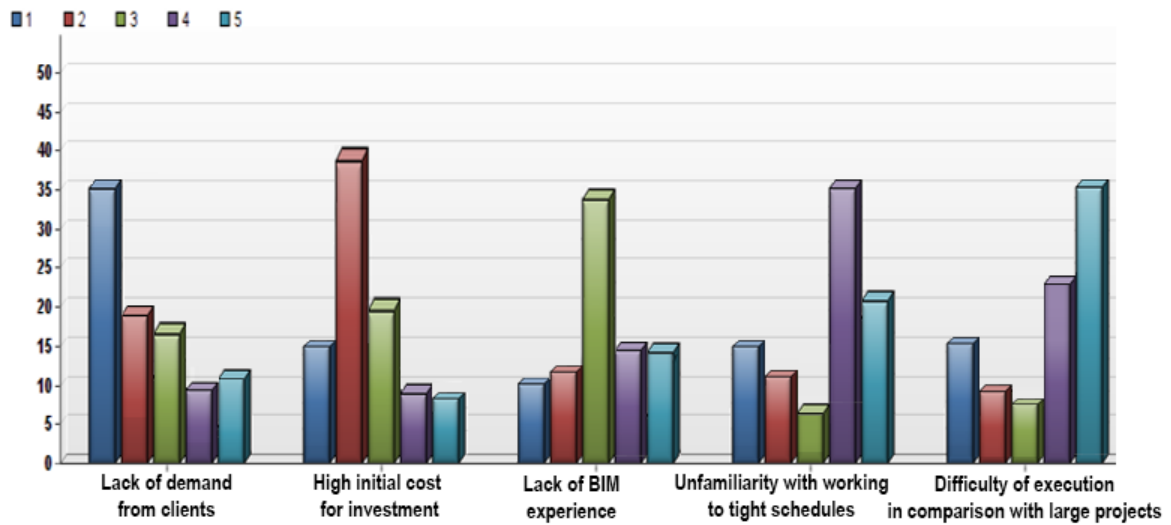


Chart 22. Risks associated with projects of less than £5 million

Chart 22 ranks the perceived likelihood and impact of four risks for projects below £5 million. Lack of demand from clients was ranked likeliest by 35 respondents, with 18 ranking it second and 8 or fewer ranking it otherwise. Risk of high initial cost for investment was ranked second for 39 participants and third for 20. Lack of BIM experience ranked third for 38 participants, unfamiliarity with tight schedules ranked fourth for 35 participants; while 35 respondents ranked difficulty of execution fifth.

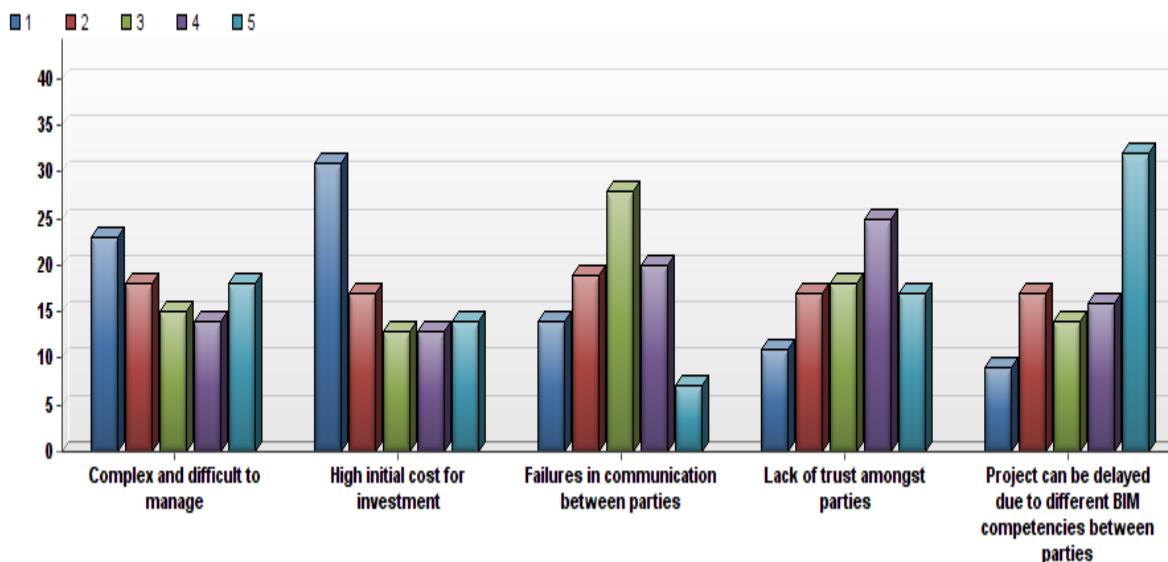


Chart 23. Risks associated with projects between £5 million and £50 millions

Chart 23 ranks the perceived likelihood and impact of four risks for projects between £5 million and £50 million. Twenty-three participants felt complexity of management was likeliest, with 18 or fewer ranking it otherwise. High initial cost was ranked likeliest by 31 respondents, with 17 or fewer ranking it otherwise. Communication failures were ranked third by 28 participants and fourth by 20. Lack of trust was ranked fourth by 25 participants, and first by 11. Only 9 participants ranked potential project delay the likeliest risk, while 32 ranked it fifth, and 17 or fewer ranked it otherwise.

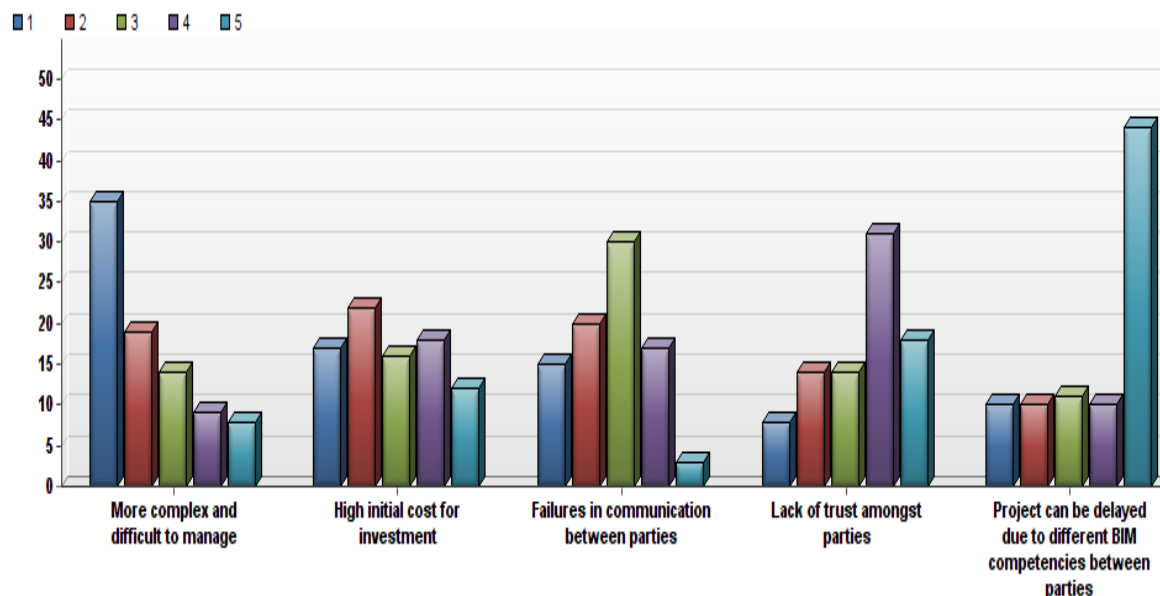


Chart 24. Risks associated with projects greater than £50 millions

Chart 24 ranks the perceived likelihood and impact of four risks for projects greater than £50 million. Of 85 participants, 35 felt complexity of management was likeliest, with 19 or fewer ranking it otherwise. Lack of trust was ranked fourth by 31 participants, fifth by 18, and first by only 8. High initial cost was ranked second by 22 respondents, with 18 or fewer ranking it otherwise. Communication failures were ranked third by 30 participants, second by 20, fourth by 17, and likeliest by 15. Only 10 participants ranked potential project delay the likeliest risk, while 44 ranked it fifth.

6.3.11. Sources of funding that allow SMEs to maximize the benefits and minimize the risks

The participants were asked to rank sources of funding for project delivery from the most to the least likely to allow an SME to maximise the benefits and minimise the risks when adopting BIM. The findings of this question are presented in Chart 25 below:

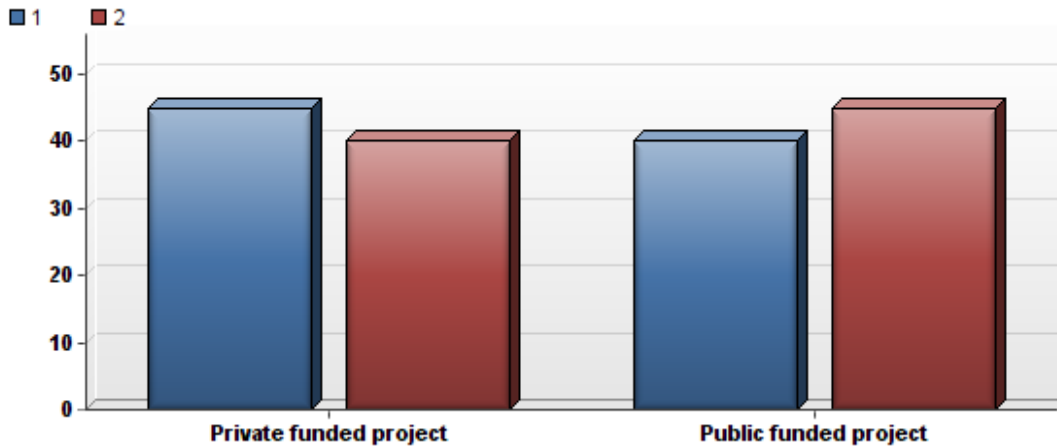


Chart 25. Sources of funding that allow SMEs to maximize the benefits and minimize the risks

Chart 25 ranks two project delivery funding sources (public and private) in terms of the perceived likelihood that they will allow maximization of benefits and minimization of risks when adopting BIM. Out of 85 respondents, 45 ranked private funding as the more likely, while 40 ranked it the less likely. As for public funding, 45 ranked it the less likely, while 40 ranked it the more likely.

6.3.11.1. Potential rewards of BIM to SMEs associated with project funded by public and private sectors

The participants were asked to rank a set of rewards associated with projects funded by public and private sectors which were identified through reviewing relevant existing literatures. The findings of these questions are presented in chart below:

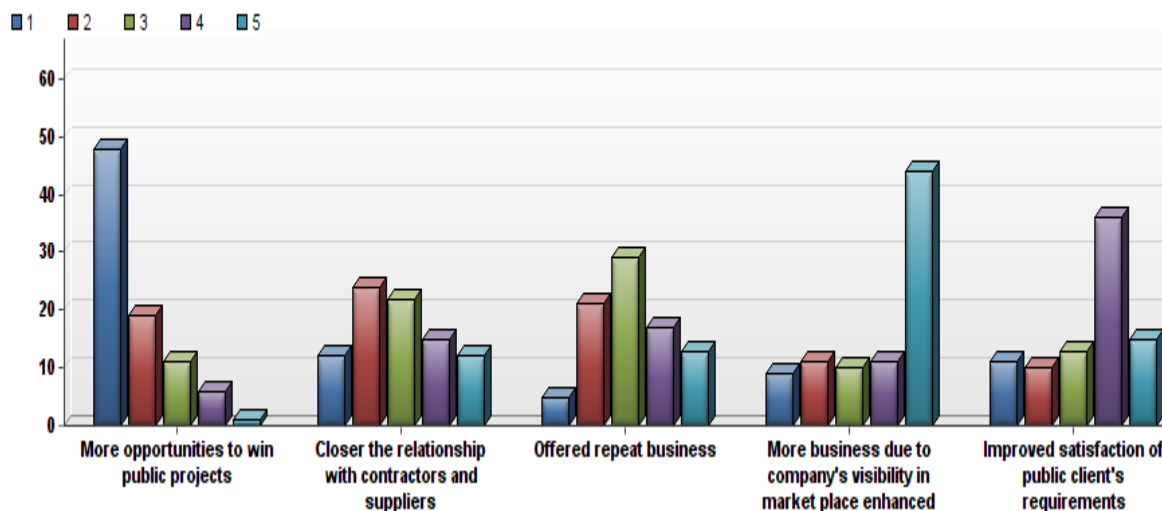


Chart 26. Rewards associated with projects funded by the public sector

Chart 26 ranks the perceived likelihood and impact of five rewards for publicly funded projects. Forty-eight participants felt greater opportunities to win public projects was likeliest, with 19 or fewer ranking it otherwise. Closer relationships with contractors and suppliers was ranked second by 24 participants, third by 22, and otherwise by 15 or fewer. Repeat business was ranked third by 29 respondents, second by 21, and otherwise by 17 or fewer. Increased business was ranked fifth by 44 participants, and otherwise by 11 or fewer. Improved satisfaction of requirements was ranked fourth by 36 participants, and otherwise by 15 or fewer.

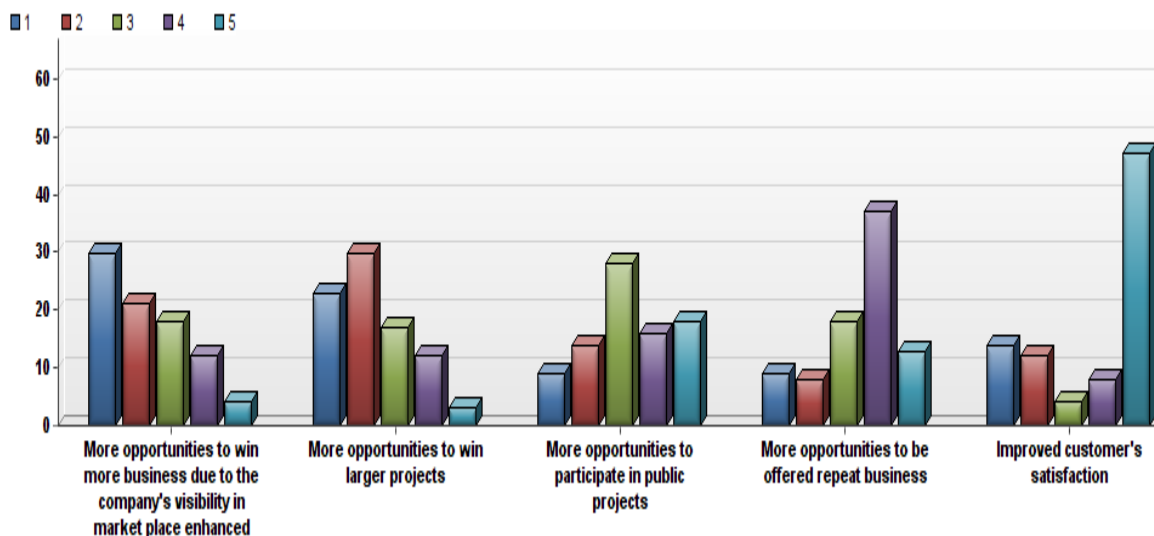


Chart 27. Rewards associated with projects funded by the private sector

Chart 27 ranks perceived likelihood and impact of five rewards for privately funded projects. Thirty participants ranked enhanced company visibility as likeliest, with 21 ranking this second, and 18 or fewer ranking it lower. Winning larger projects was ranked second by 30 participants, first by 23, and otherwise by 17 or fewer. Participation in public projects was ranked third by 28 respondents, and otherwise by 18 or fewer. Repeat business was ranked fourth by 37 participants, and otherwise by 18 or fewer. Improved customer satisfaction was ranked fifth by 47 participants, and otherwise by 14 or fewer.

6.3.11.2. Potential risks of BIM to SMEs associated with different sources of funding in project delivery

The participants were asked to rank a set of risks associated with projects funded by public and private sectors which were identified through reviewing relevant existing literatures. The findings of these questions are presented in chart below:

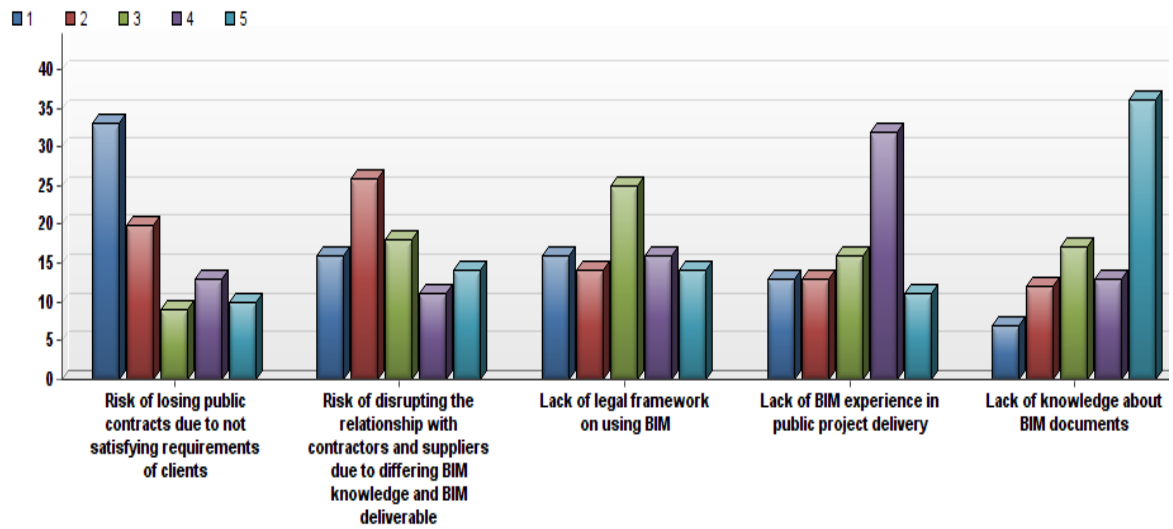


Chart 28. Risks associated with projects funded by the public sector

Chart 28 ranks the perceived likelihood and impact of five risks for publicly funded projects. Thirty-three participants ranked loss of public contracts the likeliest risk, with 20 ranking this second, and 13 or fewer ranking it otherwise. Disruption of relationships was ranked second by 26 participants, and otherwise by 18 or fewer. Lack of legal framework was ranked third by 25 respondents, and otherwise by 16 or fewer. Lack of BIM experience was ranked fourth by 32 participants, and otherwise by 16 or fewer. Lack of knowledge regarding documentation was ranked fifth by 36 participants, and otherwise by 17 or fewer.

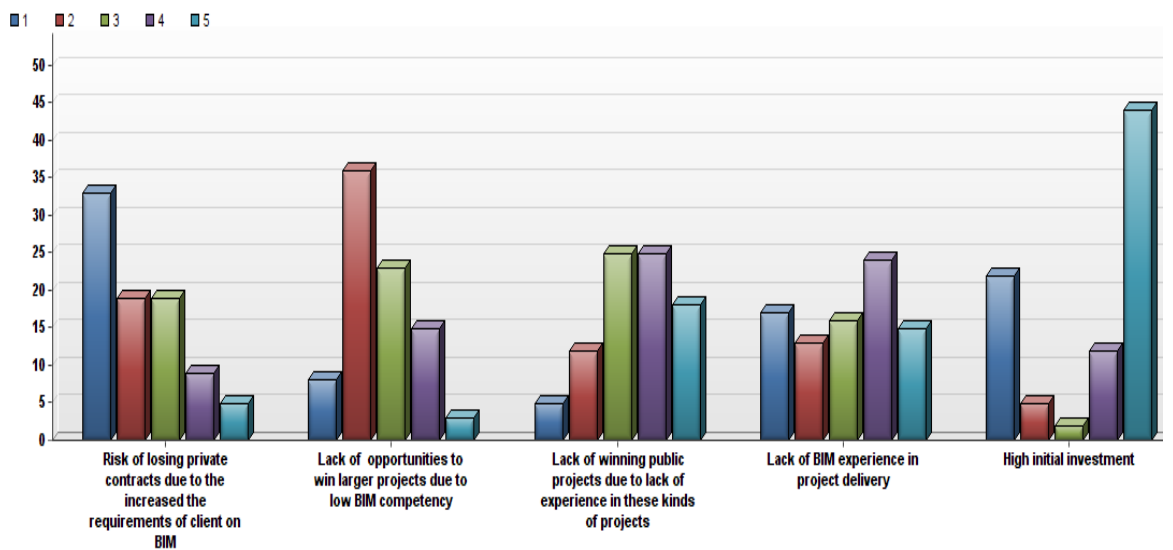


Chart 29. Risks associated with projects funded by the private sector

Chart 29 ranks perceived likelihood and impact of five risks for privately funded projects. Thirty-three participants ranked loss of private contracts as likeliest, with 19 or fewer ranking this lower. Lack of opportunities to win larger projects was ranked second by 36 participants, third by 23, and otherwise by 15 or fewer. Failure to win public projects was ranked third and fourth by 25 respondents each, and otherwise by 18 or fewer. Lack of BIM project delivery experience was ranked fourth by 24 participants, and otherwise by 16 or fewer. High initial investment was ranked fifth by 44 participants, first by 22, and otherwise by 12 or fewer.

6.3.12. Procurement routes that allow SMEs to maximise the benefits and minimise the risks

The participants were asked to rank from the most to the least likely a set of procurement routes in terms of their likelihood of occurrence and level of impact to allow SMEs to maximise the benefits and minimise the risks when adopting BIM to deliver construction projects. The findings of this question are presented in Chart 30 below:

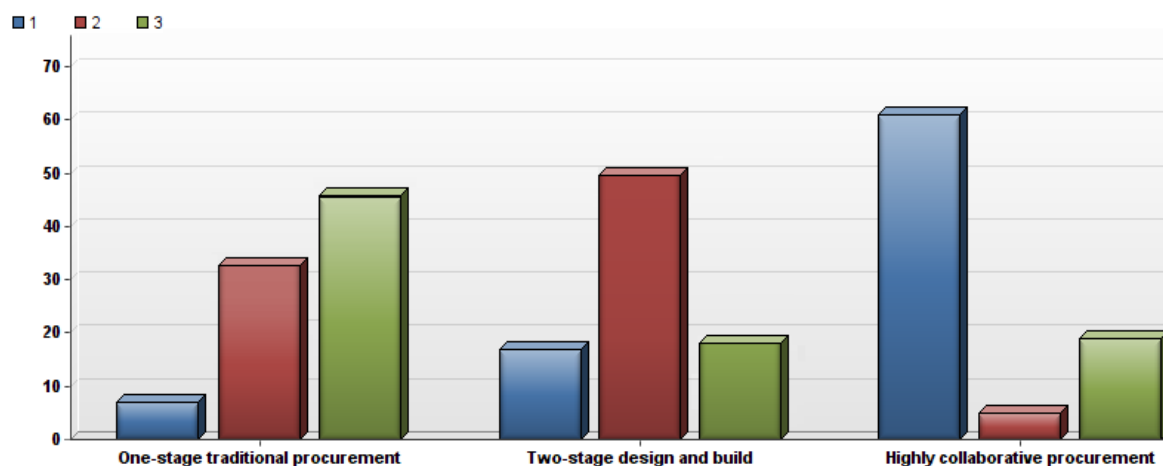


Chart 30. Procurement routes that allow SMEs to maximise the benefits and minimise the risks

Chart 30 ranks three procurement routes in terms of their perceived likelihood of allowing maximisation of BIM benefits and minimisation of its risks. Highly collaborative procurement was ranked likeliest by 61 participants, with only 5 ranking it second, and 19 ranking it least likely. Two-stage design and build was ranked second by 50 respondents,

likeliest by 17, and least likely by 18. Forty-seven respondents ranked one-stage traditional procurement as least likely, with 31 ranking this second and only 7 ranking it first.

6.3.12.1. Potential rewards of BIM to SMEs associated with different types of procurement route

The participants were asked to rank a set of rewards associated with projects adopting types of procurement to deliver BIM projects. The findings of these questions are presented in charts below:

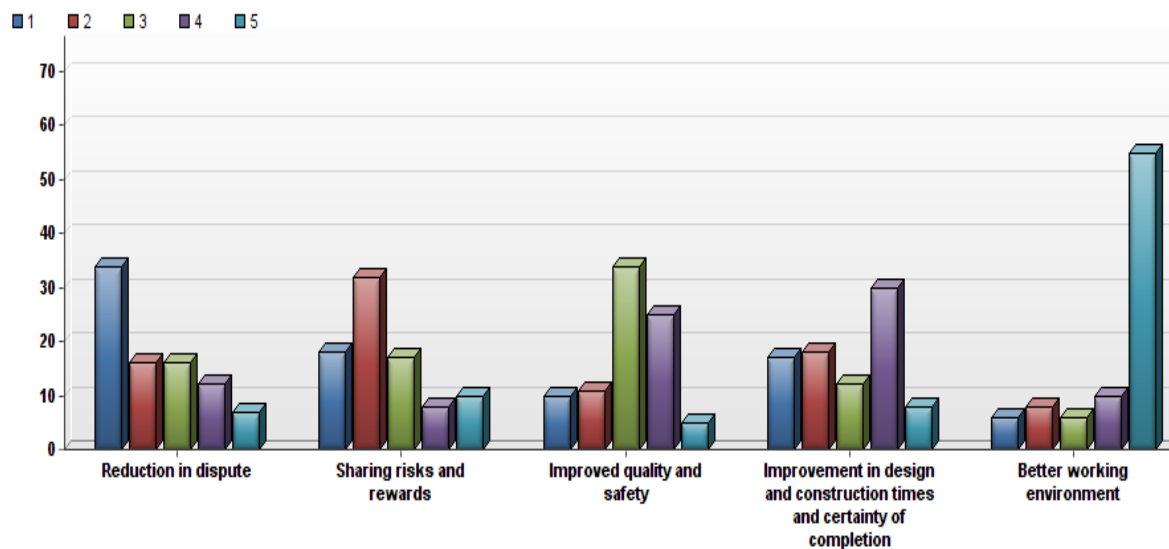


Chart 31. Rewards associated with projects adopting high collaborative procurement routes to deliver BIM projects

Chart 31 ranks perceived likelihood and impact of five rewards for projects adopting highly collaborative procurement routes. Thirty-four respondents ranked reduction in disputation the likeliest reward, with 16 or fewer ranking it lower. Sharing of risks and rewards was ranked second by 32 participants, and otherwise by 18 or fewer. Improved quality and safety was rated third likeliest by 34 participants, fourth by 25, and otherwise by 11 or fewer. Improved design and construction times was ranked fourth by 30 participants, and otherwise by 18 or fewer. Better working environment was ranked fifth by 55 participants, and otherwise by 10 or fewer.

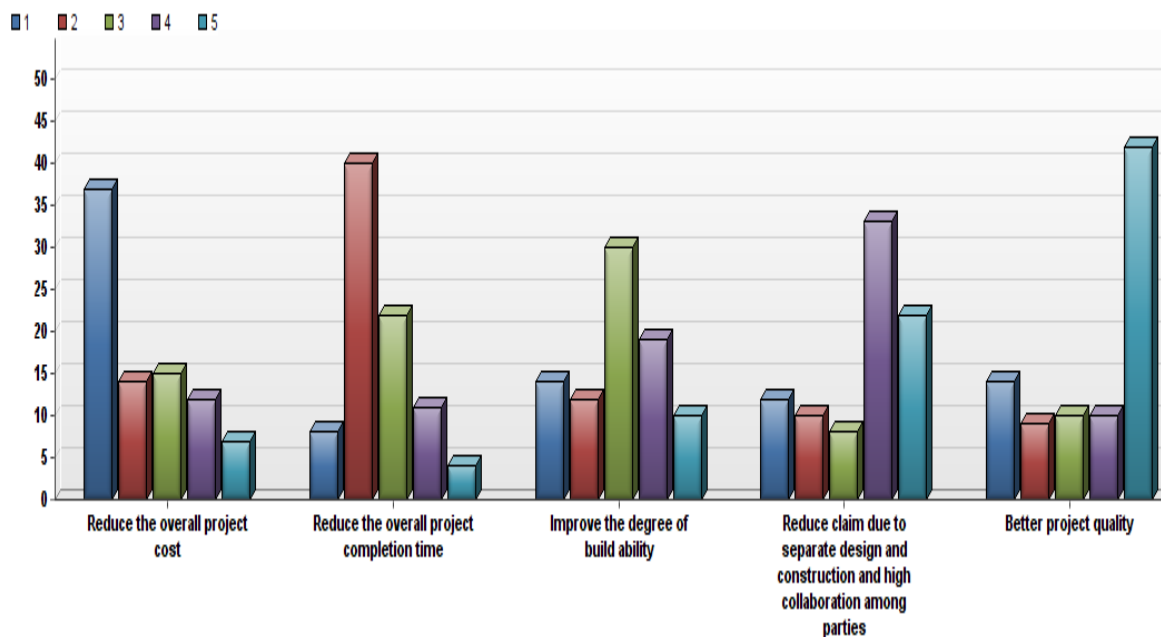


Chart 32. Rewards associated with projects adopting two-stage design and build procurement method to deliver BIM projects

Chart 32 ranks perceived likelihood and impact of five rewards for projects adopting two-stage design and build procurement routes. Reduction in project costs was ranked likeliest by 37 participants, and otherwise by 15 or fewer. Reduction in completion time was ranked second by 40 respondents, third by 22 and otherwise by 11 or fewer. Improvement in build ability was ranked third by 30 participants, and otherwise by 19 or fewer. Reduction in claims was ranked fourth by 33 respondents, fifth by 22, and otherwise by 12 or fewer. Better project quality was rated least likely by 42 participants, and otherwise by 14 or fewer.

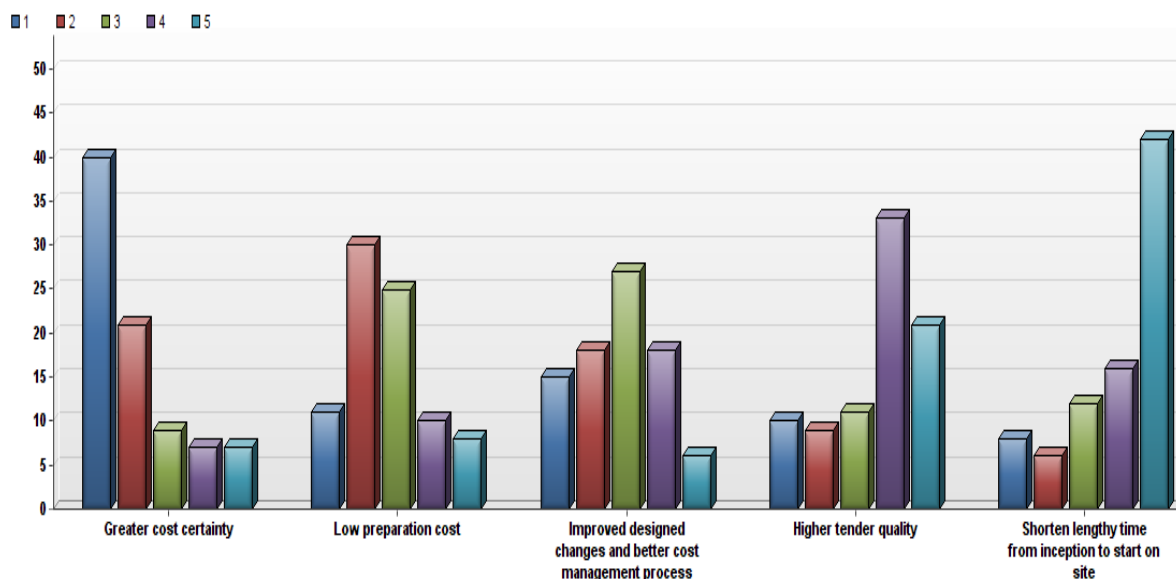


Chart 33. Rewards associated with projects adopting traditional procurement method to deliver BIM projects

Chart 33 ranks perceived likelihood and impact of five rewards for projects adopting one-stage traditional procurement routes. Greater cost certainty was ranked likeliest by 40 participants, second likeliest by 21, and otherwise by 9 or fewer. Low preparation cost was ranked second by 30 respondents, third by 25 and otherwise by 11 or fewer. Improved design changes was ranked third by 27 participants, and otherwise by 18 or fewer. Higher tender quality was ranked fourth by 33 respondents, fifth by 21, and otherwise by 11 or fewer. Shortened timespan was rated least likely by 42 participants, and otherwise by 16 or fewer.

6.3.12.2. Potential risks of BIM to SMEs associated with different types of procurement route

The participants were asked to rank a set of risks associated with projects adopting types of procurement to deliver BIM projects. The findings of these questions are presented in charts below:

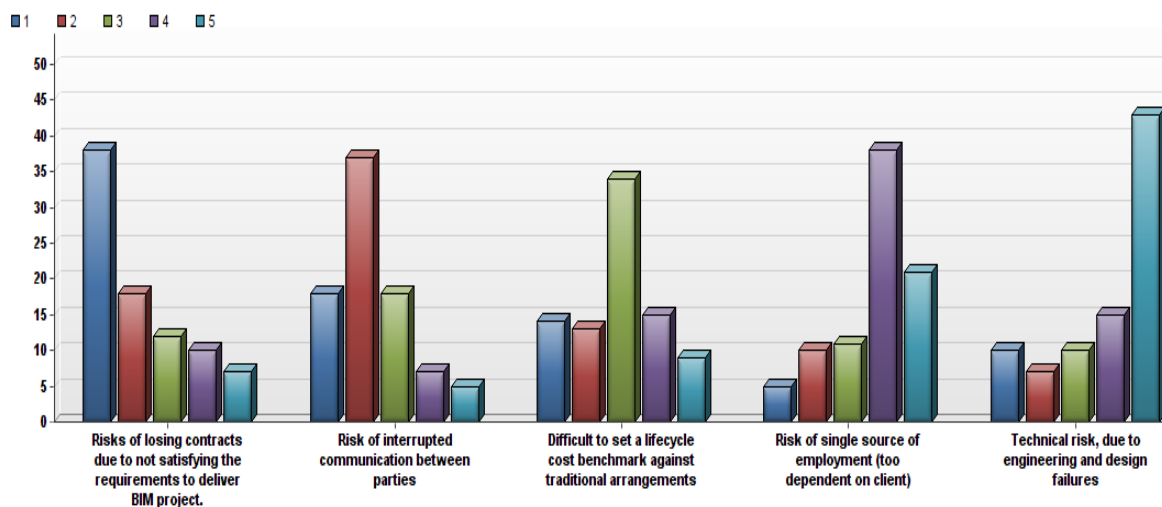


Chart 34. Risks associated with projects adopting high collaborative procurement routes to deliver BIM projects

Chart 34 ranks perceived likelihood and impact of five risks for projects adopting highly collaborative procurement routes. “Loss of contracts... failure to satisfy requirements” was ranked likeliest by 38 participants, and otherwise by 18 or fewer. Interrupted inter-party communication was ranked second by 37 respondents, and otherwise by 18 or fewer. “Difficulty of setting cost benchmark” was ranked third by 34 participants, and otherwise by 15 or fewer. Lack of BIM experience in project delivery was ranked fourth by 38 respondents, fifth by 21, and otherwise by 11 or fewer. Different BIM competencies between parties was rated least likely by 43 participants, and otherwise by 15 or fewer.

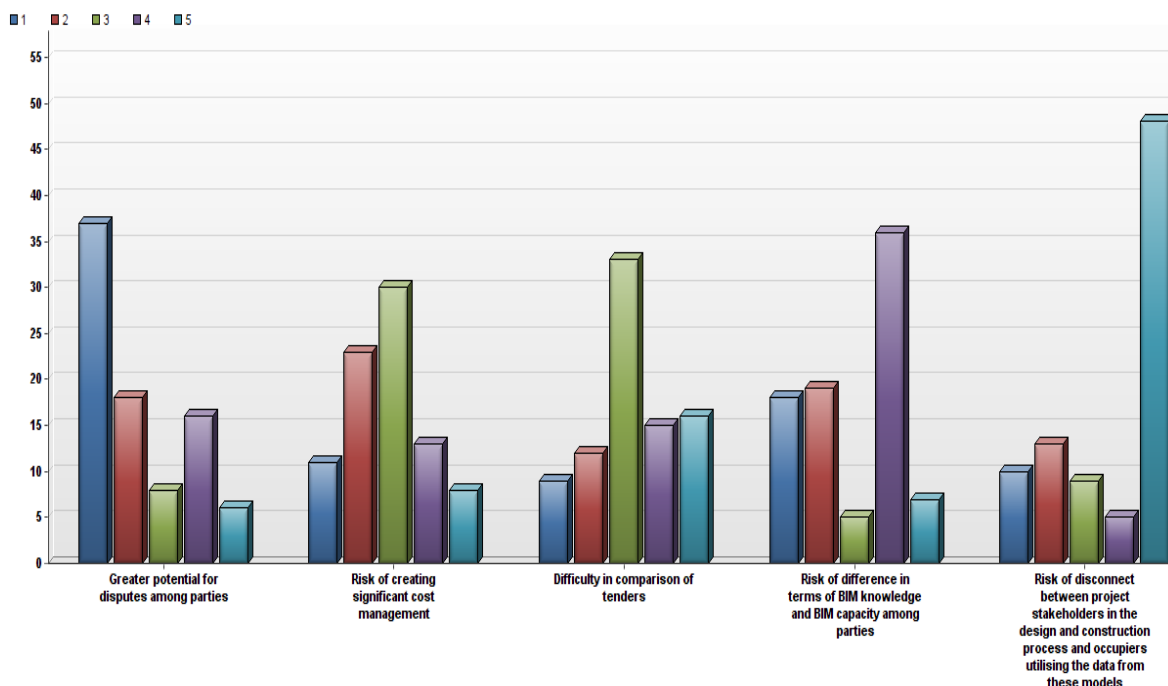


Chart 35. Risks associated with projects adopting two-stage design and build procurement method to deliver BIM projects

Chart 35 ranks perceived likelihood and impact of five risks for projects adopting two-stage design and build procurement routes. Greater dispute potential was ranked likeliest by 37 participants, and otherwise by 18 or fewer. Cost management issues was ranked third by 30 respondents, second by 23 and otherwise by 13 or fewer. Difficulty in tender comparison was also ranked third, by 33 participants, and otherwise by 16 or fewer. Differences in degree of BIM knowledge was ranked fourth by 36 respondents, and otherwise by 19 or fewer. Disconnect between stakeholders was rated least likely by 48 participants, and otherwise by 13 or fewer.

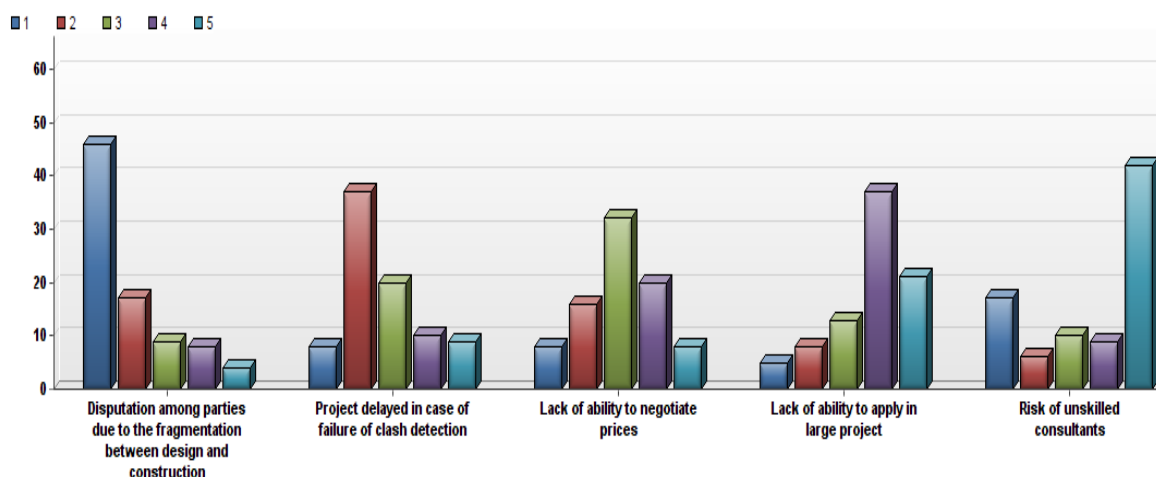


Chart 36. Risks associated with projects adopting traditional procurement method to deliver BIM projects

Chart 36 ranks perceived likelihood and impact of five risks for projects adopting one-stage traditional procurement routes. Inter-party disputation was ranked likeliest by 46 participants, and otherwise by 17 or fewer. Project delays was ranked second by 37 respondents, third by 20 and otherwise by 10 or fewer. Lack of price negotiating ability was ranked third by 32 participants, fourth by 20, and otherwise by 16 or fewer. Lack of ability to apply BIM in large projects was ranked fourth by 37 respondents, fifth by 21, and otherwise by 13 or fewer. Unskilled consultants were rated the least likely risk by 42 participants, and otherwise by 17 or fewer.

6.4. THE VOTING ANALYTICAL HIERARCHY PROCESS RESULTS

In order to validate the conceptual framework and identify the performance of alternatives, the weight of criteria and sub-criteria were calculated based on data collected from the survey. The following successive steps using formula (6) and (7) (Section 4.6.2) of VAHP model are presented as follows:

Step 1: Calculate the constraint (w_s) which stand for the difference weights between the place s th and $(s+1)$ th. In this step, depending on the difference in the number of answers (options/places) of each questions associated with criteria or sub-criteria of the conceptual framework, the coefficient w_s are different and assessed based on formula (6) detailed in Table 22 below:

Table 22. The coefficient w_s according to different places/options

Formula	Number of options (places)	Coefficient w_s
$w_1 \geq 2w_2 \geq 3w_3 \geq 0$ $\sum_{s=1}^s w_s = 1$	2	- $w_1 = 0.666666$ - $w_2 = 0.333333$
	3	- $w_1 = 0.545455$ - $w_2 = 0.272727$ - $w_3 = 0.181818$
	4	- $w_1 = 0.48$ - $w_2 = 0.24$ - $w_3 = 0.16$ - $w_4 = 0.12$
	5	- $w_1 = 0.437956$ - $w_2 = 0.218978$ - $w_3 = 0.145985$ - $w_4 = 0.109489$ - $w_5 = 0.087591$

Step 2 – calculate weights and rank criteria by using the VAHP formula: $\hat{o}_{\pi} = \max \sum_{s=1}^S x_{rs} w_s$.

For example, the involvement phase in the framework of this study consists of three sub-criteria: Design stage, Construction stage and Operation stage. Therefore, by using the formula (6), the value of w_s will be: $w_1 = 0.545455$, $w_2 = 0.272727$, and $w_3 = 0.181818$. Base on the number of votes obtained from the survey, the total weight of each /criteria/answer/option as below:

- Design stage: $64 \times 0.545455 + 11 \times 0.272727 + 18 \times 0.181818 = 41.182$
- Construction stage: $15 \times 0.545455 + 69 \times 0.272727 + 9 \times 0.181818 = 28.636$
- Operation stage: $14 \times 0.545455 + 13 \times 0.272727 + 66 \times 0.181818 = 23.182$

Consequently, based on the scale of ranking, the VAHP method has helped to determine the weight for each criterion. The weights were subsequently normalised and then ranked. Similarly, this process of calculation is applied to all the other criteria of the framework, which are presented in tables below:

Table 23. Factors that allow an SME to maximise the benefits and minimise the risks

Criteria	1st	2nd	3rd	4 th	Weight	Normal	Rank
Involvement phase	50	22	11	10	34.667	0.347	1
Procurement route	18	35	13	27	24.043	0.240	2
Source of funding	15	19	42	17	22.065	0.221	3
Project value	10	17	27	37	19.226	0.192	4
Total	93	93	93		93	1	

Table 24. Stages of involvement that allow an SME to maximise rewards and minimise risks

Criteria	1st	2nd	3rd	Weight	Normal	Rank
Design	64	11	18	41.182	0.443	1
Construction	15	69	9	28.636	0.308	2
Operation	14	13	66	23.182	0.249	3

Total	93	93	93	93	1
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Table 25. Value of project that allows an SME to maximise rewards and minimise risks

Criteria	1st	2nd	3rd	Weight	Normal	Rank
Between £5million and £50million	27	60	2	31.455	0.353	1
Greater than £50million	31	16	42	28.909	0.325	2
Less than £5million	31	13	45	28.636	0.322	3
Total	89	89	89	89	1	

Table 26. Sources of funding that allow an SME to maximise rewards and minimise risks

Criteria	1st	2nd	Weight	Normal	Rank
Private funded projects	45	40	43.329	0.51	1
Public funded projects	40	45	41.671	0.49	2
Total	85	85	85	1	

Table 27. Procurement routes that allow an SME to maximise benefits and minimise risks when adopting BIM

Criteria	1st	2nd	3rd	Weight	Normal	Rank
Integrated project delivery	61	5	19	38.091	0.448	1
Two-stage design and build	17	50	18	26.182	0.308	2
Traditional	7	31	47	20.818	0.245	3
Total	85	85	85	85	1	

6.5. DISCUSSION OF FRAMEWORK VALIDATION

A total of 93 participants responded to the survey, which amounts to 96.8% of the target (96 responses). Participants of the survey are working for different types of organisation ranging from micro (less than 10 staff) to large (greater than 250 staff). This sample selection was expected to achieve a full range of views on BIM in terms of risks and rewards, when adopting it to deliver construction projects. The sample breakdown is shown in Table 28 and the size of organisation is defined by the European Union criteria (European Commission, 2015).

As expected, the survey revealed that the majority of the organisations that have adopted BIM in project delivery are large organisations (33.33%). It can be inferred that these types of organisations are more likely to be getting ready to achieve BIM adoption at level 2 by 2016. Furthermore, a large number of participants, accounting for the second highest responses (27.96%) in the survey, are working for micro organisations, across the UK.

Table 28. Organisation size from sample

Organisation size	Number	Percentage of respondents	Cumulative %
1–10 (micro)	26	27.96%	27.83%
11–50 (small)	19	20.43%	48.39%
51–250 (medium)	17	18.28%	66.67%
>250 (large)	31	33.33%	
Total	93	100	100

A large number of participants, accounting for the second highest responses (27.96%) in the survey, are working for micro organisations, across the UK. Despite the larger participation amongst SMEs, the results revealed that the majority of the organisations that have adopted BIM in project delivery are large companies (33.33%). This is in agreement with previous studies revealed that these types of organisations are more likely to be getting ready to adopt BIM (SmartMarket Report, 2012; NBS, 2015). Indeed, large gaps amongst organisations in terms of BIM adoption was found, and the large one is still dominant (Electrical Contractor Association, 2015).

The respondents represented many professions within the construction industry, as indicated in Table 29. They were asked to list the professional duties that they are carrying out for their company. The professional experience and BIM experience of participants was highly relevant, as detailed in Table 24. The experience of the respondents is to ensure knowledge and experience of participants within the issues under investigation and the validity of collected data. The results showed that more than 70% of participants had more than four years of experience in the construction industry, and about 55% had more than four years of working with BIM in project delivery (Table 30). It seems that there is an increasing trend for professionals to have BIM experience in accordance with the growth in BIM adoption. This finding concurs with the SmartMarket Report (2014), which revealed that the number of organisations with five and more years' experience in BIM use doubled between 2009 and 2012: from 6% to 13% for those with five years' experience, and from 18% to 36% for those with more than 5 years' experience. Indeed, an investment in upskilling staff in BIM is increasingly seen as critical as it enables organisation to have more competencies to compete with other rivals (Fewings, 2013).

Table 29. Sample breakdown by professional duties

Professional duties	Frequency	Percentage of respondents
Architecture	18	19.35%
BIM manager	15	16.13%
Quality surveyor	12	12.9%
BIM professional	10	10.75%
BIM coordinator	9	9.68%
BIM technician	7	7.53%
BIM consultant specialist	6	6.45%
Civil engineer	4	4.3%
Structural engineer	4	4.3%
Construction designer	1	1.08%

Table 30. Experience of participants

Years of experience	Professional experience		BIM experience	
	Number	% of respondents	Number	% of respondents
1–3 years	27	29.03%	41	44.09%
4–10 years	31	33.33%	45	48.39%
>10 years	35	37.63%	7	7.53%

6.5.1. Key criteria of the conceptual framework

As the target of the validation is to identify the most and the least likelihood of occurrence of criteria/factors within the conceptual that allow SMEs to maximise the benefits and minimise the risks, the participants were asked to rank key criteria including Involvement phase, Project value, Source of funding, and Procurement route. As the results indicated in Table 23, the Involvement phase was ranked first among criteria being investigated with the weight of 0.347. This is followed by Procurement route which accounts for the weight of 0.240. Source of funding and Project value were ranked third and fourth with the weight of 0.221 and 0.192 respectively.

The findings indicate that the involvement phase plays the most important role in helping SMEs to maximise benefits and minimise risks when adopting BIM to deliver construction projects. This criterion refers to the timing of the engagement in project delivery that strongly impacts not only on SMEs but also all project participants (Al-Hammad *et al.*, 1997; Negendahl, 2015; Succar, 2012). This finding is in an agreement with MacLeamy (2004) which indicates that a high collaborative amongst participants in the early stages of BIM projects can impact on the overall functionality, costs, time, and benefits of building projects. Consequently, all parties including SMEs can participate and derive benefit form BIM. For example, cost consultants can use BIM to take off quantities and get prices; Fabricators can make a significant contribution to the project while gaining benefit themselves; Manufacturers can earn benefits through supplying their data in interoperable forms for use in design, construction and management systems. Electronic product data, which held in catalogues that designers and specifiers can access seamlessly, offers great promise (British

Standards Institution - BSI, 2010). As a result of new collaborative working process, the procurement route which is known as a process that clients make decision about how they will build (Hogg *et al.*, 2007) and how success of any building projects (Squires *et al.*, 2011), was also examined as a significant factor in BIM projects by survey participants. This factor was ranked second after the Involvement phase. The recent evidence indicates that traditional procurement methods does not fit well to BIM. Researchers and industry practitioners recommend that BIM needs new processes in order to maximise the benefits of BIM in project delivery (Lu *et al.*, 2015). Therefore, adopting the most appropriated procurement method in order to deliver BIM project is essential.

Project funding is sourced from either the public or private sector (Jaafar *et al.*, 2012). The public sector client, primarily the government, is observed to be the initiator of major developments in social amenity projects. This sector is considered the main driver of the BIM agenda which is no any public projects conducted without BIM level 2 (British Standard Institute, 2013). Private clients are characterised by being increasingly better informed, more aware and more knowledgeable about how to get into the building process. There is evidence to suggest that the demands on BIM in this sector are also increasing (SmartMarket Report, 2014). However, compared to others, this factor is not seeming to cause high impacts on SMEs when they adopt BIM to deliver construction projects. Therefore, it was ranked third by survey participants, before the Project value which was ranked last among four key factors being investigated.

As mentioned in Table 12 (Section 4.3), each key criterion within the conceptual framework consists of sub-criteria associated with issues that attract the attention of SMEs when they consider to adopt BIM in their organisation. Sections below will discuss in details findings achieved from the framework validation. It includes indicating sub-criteria that allow SMEs to maximise the benefits and minimise the risks when adopting BIM to delivery construction projects. Furthermore, the most/least likelihood of occurrence of rewards risks associated with criteria are also provided.

6.5.2. Stages of involvement

Respondents were asked to rank the stage of involvement in projects from the most to the least likelihood of occurrence. The results in Table 24 indicate that the design stage is ranked as the best stage with the weight of 0.443. This is followed by the construction stage and the operation stage, occupying the weight of 0.308 and 0.249 respectively. The findings show that the SMEs who usually participate in the early stage of project involvement are likely to get more opportunities to maximise rewards and minimise risks. This trend is downward, reaching the lowest point in terms of benefits and the highest level of risks in the events of organisations participating in projects tardily.

This can be explained by the phenomenon that critical decisions have been taken in the early stages of the project. Lahdenperä, (2012) and Light (2011) found that the later decisions are made, the more expensive the design changes are. The findings of this study confirm previous research that by starting in very early stages of the project, stakeholders are more likely to see the benefits of BIM such as enhancing coordination, productivity, and business operations (Zuppa et al., 2009). Indeed, early involvement means higher chance to minimize waste and increase value through visualising model, which can help to avoid errors and omissions (Azhar et al., 2012). By doing so, any errors, omissions, risks can be identified and mitigated early. This can help parties obtain significant waste reduction across the whole project (Azhar et al., 2011). In addition, high collaborative working in the early stages of the project can lead to more time for managing and predicting implications on construction, maintenance and operations, and as a result, project performance can be improved dramatically (MacLeamy, 2004).

6.5.3. Project values

In terms of project value, the participants were asked to rank types of project value from most to least in terms of enabling for SMEs to maximise rewards and minimise risks when using BIM to deliver BIM projects. The survey shows that the best project value for BIM is between £5million and £50million, closely followed by projects greater than £50million and less than £5million (Table 25). The difference in terms of weight between elements is 0.028, when comparing the first ranked element to the second one, and 0.003 for the difference between the second ranked item and the lowest ranked one.

The result of this study demonstrated that whatever the project value is, BIM is potentially beneficial. It suggests that BIM could be relevant to various project values, including humbler projects-less than £5m in value. This finding challenges the prevailing assumption that we should not bother with BIM for small-scale projects (i.e. NBS, 2015; Bryde et al., 2013). Indeed, research found that BIM is applicable to projects of all scales, and it is useful in assisting organisations to build small as well as high-risk projects successfully (Furneaux et al., 2008). However, industry currently perceives the prime added value of BIM is in managing large and complex projects, where failures in communication are more likely. Therefore, BIM is seen as essential in addressing the various challenges, such as clash detection, schedules and communication (Azhar et al., 2011). This attitude often resulted in ignoring BIM adoption in the context of a lower project value. Levy (2012) argued that smaller projects are also vulnerable to erroneous quantitative analysis, and therefore BIM is more critical as these types of buildings “tend to have smaller budget margins, and even a small error may lead to project damaging cost overruns.”

6.5.4. Source of funding

Essentially, public and private clients are the main sources of funding for construction projects. For this question, participants were asked to rank whether public or private sector is the potential sector that allow them to maximize the benefits and minimize the risks in adopting BIM. Results presented in Table 26 show that both private and public source of funding are significant, as they are respectively closely related (0.51 and 0.49). This result concurs with recent findings, which indicates that around two thirds of both public sector (65%) and private sector (70%) UK clients require now BIM on new projects they will be starting (SmartMarket Report, 2014).

The current trend of adopting BIM for project delivery is not only affecting public clients (British Standard Institute, 2013), but they are also required by the private sector. This finding is fundamental in encouraging SMEs to invest BIM in their organisations to be able to win public projects, as they are currently relying heavily on private projects where a BIM mandate has not been applied yet. Blackwell (2012) warns SMEs against slow uptake of BIM, leading to a loss of contracts in both the domestic and international markets. Above all, this trend may worsen their rate of success in winning bids for public sector contracts (Federation of Master Builders, 2013). Furthermore, the findings of this study is urging for

new strategies by SMEs to adopt BIM technology and collaborative practices to be able to win both public and private projects in an increasingly competitive market.

6.5.5. Procurement routes

In the construction industry, procurement routes are considered as the backbone in terms of the process of project delivery. A selection of an appropriate procurement route could reduce project cost dramatically and enhance the probability of project success (Gordon, 1994; Luu et al., 2005). Consequently, when making decisions about whether to adopt BIM in project delivery or not, a consideration of procurement routes cannot be ignored. In this survey, participants were asked to rank three kinds of procurement routes, presented in Table 27. The question required respondents to rank the potential that organisations can see in terms of maximising the rewards and minimising the risks when adopting BIM to deliver construction project, according to the different types of procurement route.

The findings indicated in Table 27 show that the integrated project delivery procurement route is the best method to conduct BIM projects (0.448), followed by two-stage design and build, and traditional procurement with the weight of 0.308 and 0.245 respectively. This finding supports the assumption that BIM together with the integrated project delivery procurement method can help organisations to improve communication, eliminate waste, reduce costs, address expectations and generate value for all parties involved in projects (Hardin, 2009; Asmar et al., 2013). There is currently a large gap between the highest and the lowest element of investigation with the weight of 0.203. Moreover, traditional procurement is considered as the most popular method and widely used by SMEs to deliver projects (The Chartered Institution of Building, 2010). As such, this result provides a useful reminder to SMEs when they make decisions about adopting BIM to implement construction projects. The risks and rewards associated with procurement methods may vary greatly and SMEs need to consider this carefully.

6.6. CONCLUSION

This chapter has presented the findings of the primary data collected from the framework validation process. This conceptual model was validated by 93 participants from UK companies using BIM.

While it is true that the number of completed questionnaires does not quite reach the target response rate (96 responses), nevertheless an acceptable rate of 96% of the target has been achieved. Besides, the reliability of the data may also be considered excellent, with a CA of 0.868, highly acceptable for academic research.

The validation of the framework reveals the four most significant factors that are able to help SMEs to maximise the benefits and minimise the risks in adopting BIM to deliver construction projects. Firstly, for SMEs the most significant phase in which to participate in BIM projects is the design phase. This stage is identified as the essential stage in which all the key decisions are taken. Early involvement in BIM projects is critical to maximisation of rewards and minimisation of risks.

Secondly, regardless of project value, BIM is seen as beneficial in all cases. Although projects valued between £5 million and £50 million seem the best choice for optimum BIM benefits, the gaps between this size of project and other project sizes are very small, different by only 0.028 and 0.003, in terms of weight, from the second-ranked and lowest-ranked project size respectively. This finding is meaningful insofar as it should encourage organisations working on different types of projects to invest in BIM in their organisations.

Thirdly, private clients remain the principal sector to which SMEs need to pay attention when conducting BIM projects. The traditional close relationship between SMEs and private clients is changing. This is mainly because demand from private clients in terms of BIM implementation has increased in recent years, whereas SMEs remain slow to invest in BIM.

Fourthly, SMEs need to pay particular attention where traditional procurement is used as the most popular method of deploying BIM projects. This present study shows that this kind of procurement method is the least beneficial for BIM compared to its counterparts, accounting for a weight of 0.245. The highest ranked method is the integrated project delivery procurement route, which has a weight of 0.448. Therefore, the risks and rewards of using BIM to conduct construction projects with traditional procurement methods may render it of

questionable value. SMEs need to carefully consider alternative procurement routes before investing in BIM for their organisations.

The risks and rewards associated with the criteria of the conceptual framework have also been laid out in this chapter. These risks and rewards will be used in the DSS to provide instructive information to SMEs when they use the DSS to anticipate risks and rewards. The outcomes obtained from the framework validation including criteria, risks and rewards will be used to develop the DSS which is detailed in next chapter.

CHAPTER 7: DECISION SUPPORT SYSTEM DESIGN AND VALIDATION

7.1. INTRODUCTION

In the first section of this chapter (7.2), the concept of a decision support system is explained aiming to provide knowledge of how the DSS should be, and the DSS for this study is introduced. The second section deals with the software platforms used to design the DSS for this study (7.2). The third section explains the adoption of MySQL database management in developing the DSS (7.3). Section 7.4 presents the alternatives in the conceptual framework of this study, generated through framework validation using the VAHP model, demonstrated by the DSS and made available online in order to enhance the accessibility of the DSS. A demonstration of the operation of the DSS is presented in Section 7.5, in which screenshots are used to illustrate the functions of the DSS. In order to validate these functions as well as the information that the tool provides, a validation process needs then to be conducted, which is presented in Section 7.6. In this section, the validation methodology and the outcomes of this process are also presented. Section 7.7 concludes the chapter.

The next section of this chapter will present the software platforms and the database management system used to design the DSS for this study.

7.2. SOFTWARE PLATFORMS ADOPTION

As mentioned in the previous section, the DSS for this study was developed as a web-based tool, to enhance its accessibility and enable it to be disseminated to end users quickly. Currently, there are many popular software platforms that could have been adopted to design the DSS for this study, such as the Linux operating system, the Apache network server, the MySQL Database, and the PHP programming language (PHP standing for Hypertext Pre-processor). The last of these, PhP and MySQL, are noted for their use by IT professionals, and were used to design the DSS for this study because they are both free, open source platforms (Chen *et al.*, 2012). This meant that the present author did not need to buy any software platforms or pay for any copyrights either during the process of designing the DSS or after the DSS came into operation.

According to Tatroe *et al.*, (2013), PHP is a simple, powerful language designed for creating HTML (Hyper Text Markup Language), the fundamental foundation of web pages. A simply structured webpage may thus be represented in HTML code as follows:

```
<!DOCTYPE html>
<html>
<head>
<title>Page Title</title>
</head>
<body>

<h1>My First Heading</h1>
<p>My first paragraph.</p>

</body>
</html>
```

Figure 22. A Simple HTML Document (Created by the author)

Web browsers such as Chrome, IE, Firefox, or Safari read HTML documents and display them as in *Figure 23* below:

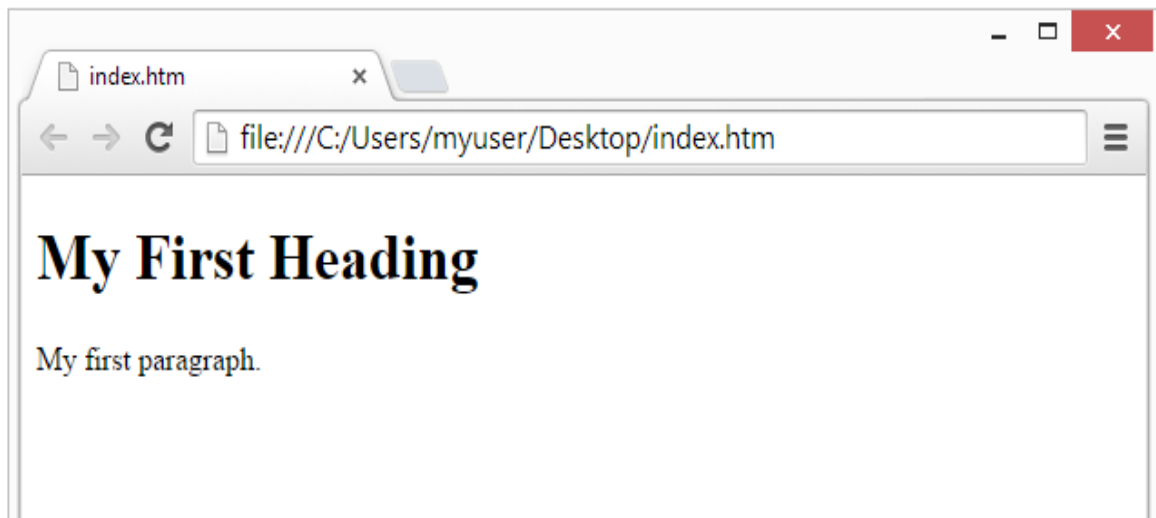


Figure 23. The product of a simple HTML document (created by the author)

Basically, PHP can be used in three main ways (Tatroe *et al.*, 2013):

- Server-side scripting: PhP used in this way generates dynamic web content (HTML), and has also become popular for generating XML documents, graphics, flash animations, PDF files, and other formats.
- Command-line scripting: PHP can run from command line prompts, in a similar way to Perl, Awk, and the Unix shell. This type of scripting is usually used for system administration tasks.
- Client-side GUI applications: PHP can be used through Graphical User Interface applications.

A simple example of PHP code can be seen in *Figure 24* below:

```
<!DOCTYPE html>
<html>
<body>

<?php
echo "My first PHP script!";
?>

</body>
</html>
```

Figure 24. A simple example of PHP code (created by the author)

Given the context and aim of this present study, to develop the DSS, server-side scripting was adopted, to develop dynamic web content in combination with another platform, CSS (Cascading Style Sheets).

Cascading Style Sheets (CSS) is the name given to a style sheet language used for describing the presentation of a document written in HTML (McFarland, 2009). CSS works with HTML, but they differ from each other. While HTML helps to structure webpages by organising information into separate parts such as title, heading, and paragraph, is responsible for dressing up the text – the product of HTML – to ensure that the user interface is eye-catching. This point is of considerable importance and worthy of careful attention when designing a web-based DSS (Pomerol *et al.*, 2000; Sauter, 1997). A simple example of CSS code is presented in *Figure 25* below:

```
body {  
    background-color: lightblue;  
}  
  
h1 {  
    color: white;  
    text-align: center;  
}  
  
p {  
    font-family: verdana;  
    font-size: 20px;  
}
```

Figure 25. An example of CSS code (created by the author)

The most significant benefits of CSS mentioned by McFarland (2009) for designing web pages in general, and DSSs in particular, are that:

- CSS offers great capabilities for formatting the content of webpages;
- CSS is able to create events better and faster than HTML;
- CSS helps to update websites more easily and more quickly;

Aside from PHP, HTML, and CSS platforms, Pomerol *et al.* (2000) and Sauter (1997) state that a DSS must include database management, which will give multi-criteria DSSs the potential to store, retrieve and update information easily. With this in mind, the DSS for this study used the MySQL database management system to store and manage information associated with the weight of criteria and their related risks and rewards. Details of this choice of database management system are presented in the next section.

7.3. THE ADOPTION OF MySQL DATABASE MANAGEMENT

As mentioned in the previous section, the adoption of a database management system in developing a DSS is essential. After careful consideration, the MySQL database management system was adopted for this study.

According to Butcher (2003), MySQL is the most popular open source relational data management system in the world, with around 27,000 downloads per day from the MySQL site. Because of its high speed and high degree of reliability, most of the world's best-known companies and organisations have chosen this data management system, for instance Yahoo!, Motorola, NASA, Silicon Graphics, Hewlett Packard, Xerox, and Cisco.

In MySQL, all domain and application data is managed and organised through a central database. The advantages of using a database to manage data are in a variety of areas, as highlighted by Suehring (2002):

- Speed: data can be retrieved and stored quickly through synchronisation of the reading and writing processes.
- Reporting: information can be selected, quantified, and customised flexibly.
- Accuracy: given careful data input, databases provide accurate and consistent results based on their data.
- Thoroughness: databases can store and report results as complete and detailed as their entire contents.

In each database, data is classified into tables according to the attributes of the domain that that database is designed to manage. In this research, the database was also designed to manage data from the DSS and was divided into seven Tables, used to accommodate information on the different criteria and sub-criteria as detailed in *Figure 26* below:

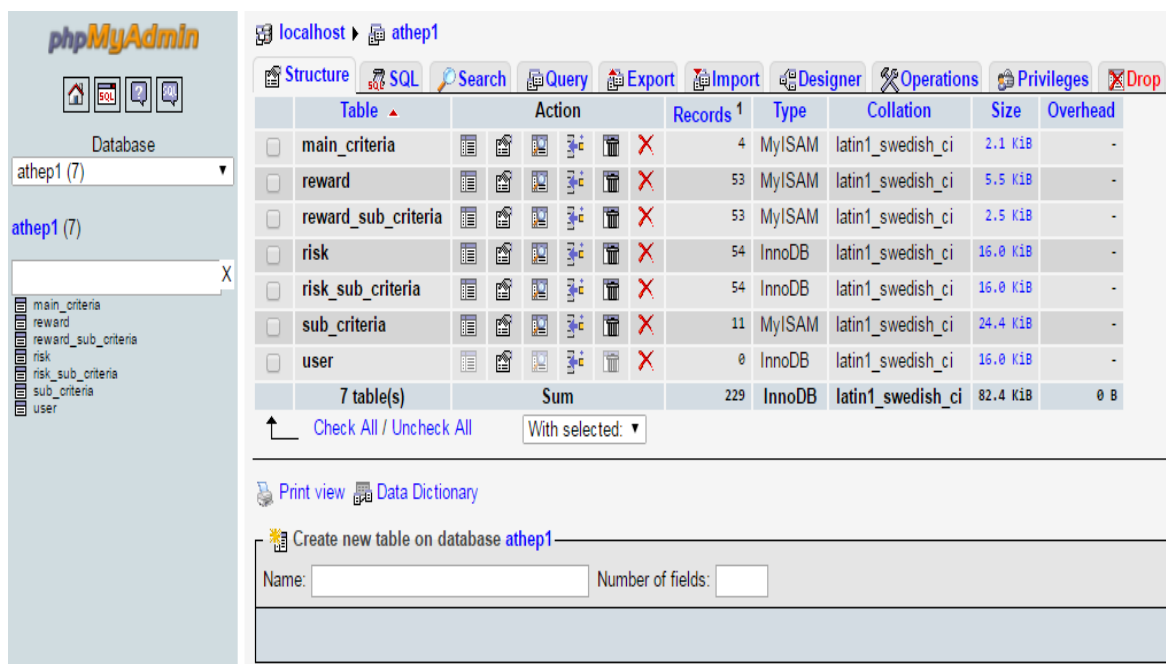


Figure 26. DSS Database (created by the author)

Details of a Table storing information relating to the key criteria of the DSS framework are shown below:

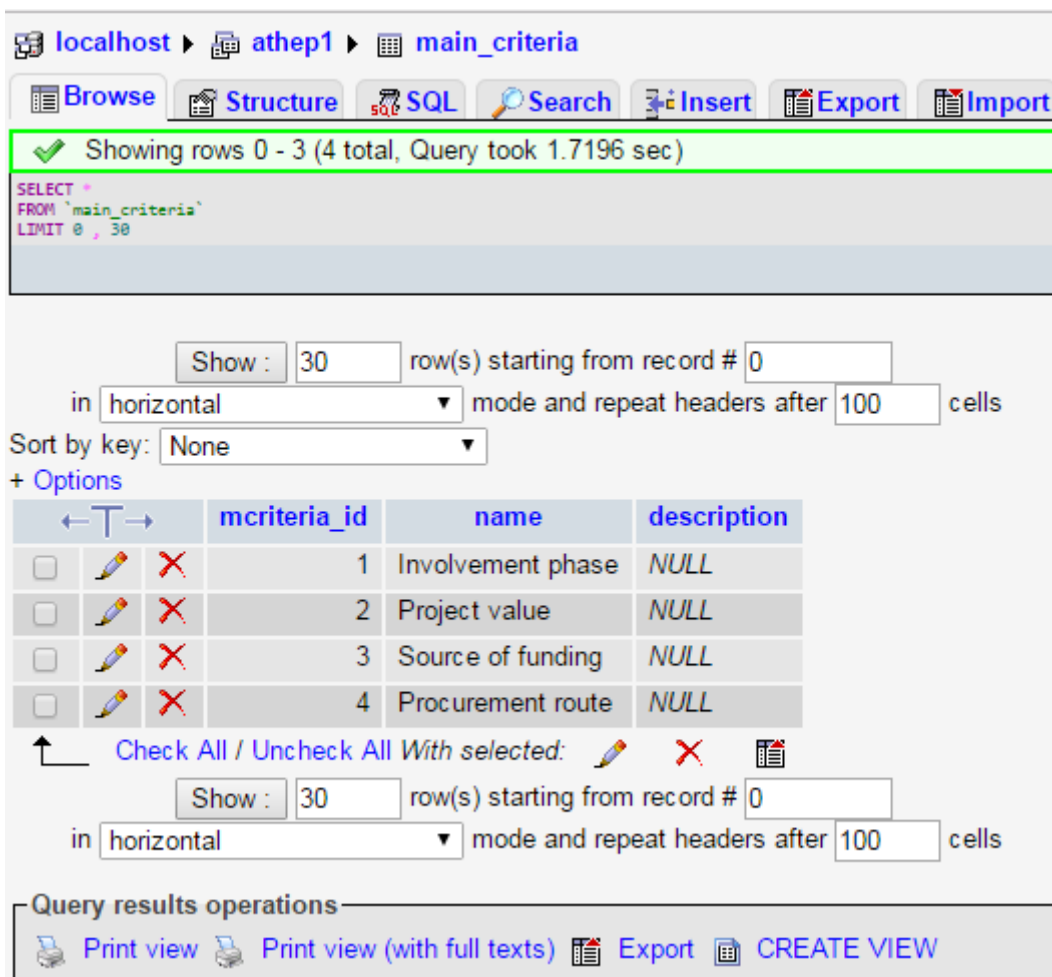


Figure 27. An example of Table accommodating the key criteria of the framework

Databases always consist of different tables which are linked together in a relationship with strict constraints. The relationship between the tables in the DSS database is shown in Figure 28 below, which includes six tables as detailed below:

- *main_criteria*: stores records of information associated with the main criteria of the DSS, including attributes:
 - *mcriteria_id*: the indices of the main criteria
 - *name*: the names of the main criteria
 - *description*: the descriptions of the main criteria.
- *sub_criteria*: stores records of information associated with the sub-criteria of the DSS, including attributes:
 - *scriteria_id*: the indices of the sub-criteria.
 - *name*: the names of the sub-criteria.

- *mcriteria_id*: the attributes used to identify the names of the main criteria that the sub-criteria belong to.
 - *weight*: the weights of the sub-criteria as calculated by the VAHP model.
 - *Description*: the descriptions of the sub-criteria.
 - *Assumption*: the assumptions developed from the literature in combination with the outcomes of the framework validation.
- *risk*: stores records of the risks (the risk profile) of the DSS, including attributes:
- *risk_id*: the indices of the risks.
 - *name*: the names of the risks.
 - *weight*: the weights of the risks as calculated by the VAHP model
- *reward*: stores records of the rewards (the reward profile) of the DSS, including attributes:
- *risk_id*: the indices of the rewards.
 - *name*: the names of the rewards.
 - *weight*: the weights of the rewards as calculated by the VAHP model
- *risk_sub_criteria*: this table was generated as a result of the normalisation of the relationship between the *risk* and *sub_criteria* tables.
- *rewad_sub_criteria*: this table was generated as a result of the normalisation of the relationship between the *reward* and *sub_criteria* tables.
- *user*: this table, used for administration purposes only, was additionally created to store user information entered by individuals registering to use the DSS.

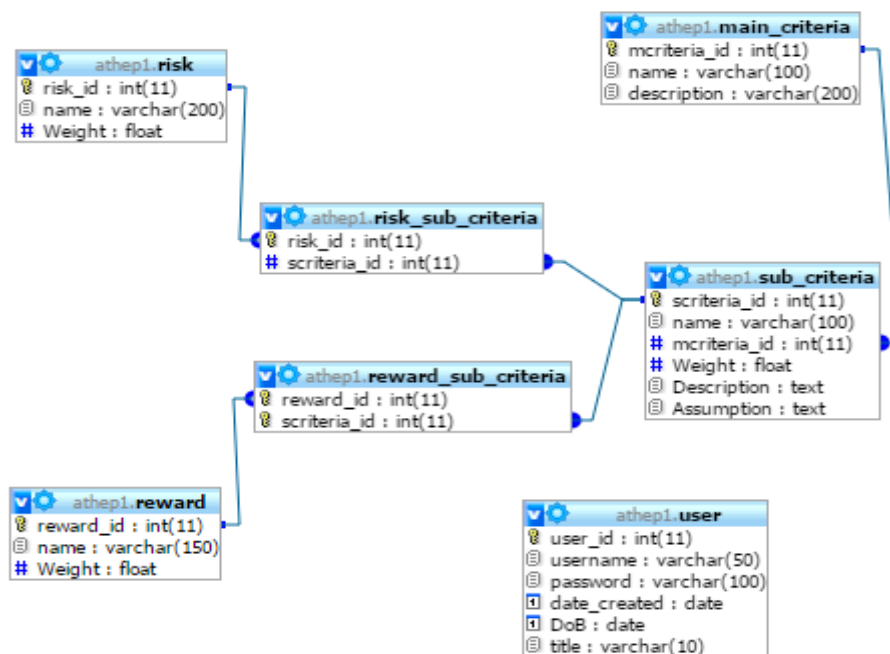


Figure 28. The relationship between tables in the DSS database

All data obtained from the framework validation are stored in a central database, the “backbone” of the DSS. Consequently, when users access the DSS from web browsers to anticipate risks and rewards, web servers are required to link the relevant tables together according to the type of data and the information that the web browsers are seeking to obtain, and provide the required results in response.

An example PHP and MySQL script used to extract data from the DSS database is shown in *Figure 29* below:

```
public function GetColumnCount($table = "") {
    $this->ResetError();
    if (empty($table)) {
        $result = mysqli_field_count($this->mysql_link);
        if (! $result) $this->SetError();
    } else {
        $records = mysqli_query($this->mysql_link, "SELECT * FROM " . $table . " LIMIT 1");
        if (! $records) {
            $this->SetError();
            $result = false;
        } else {
            $result = mysqli_field_count($this->mysql_link);
            $success = @mysqli_free_result($records);
            if (! $success) {
                $this->SetError();
                $result = false;
            }
        }
    }
    return $result;
}
```

Figure 29. An example of data extraction using PHP and MySQL

Based on the data stored in the DSS database, all alternatives of the DSS risk-reward anticipation process are presented in the next section.

7.4. ALTERNATIVES OF THE DECISION SUPPORT SYSTEM

In this section, all alternatives of the multi-criteria decision process are described.

On the basis of the primary data collected from the framework validation process in combination with the VAHP model, all key criteria and sub-criteria of the conceptual framework were assigned a weight to distinguish them one from another. The weights of criteria obtained from the framework validation represent the likelihood of occurrence and level of impact of situations that will allow SMEs to maximise the benefits and minimise the risks when adopting BIM to deliver construction projects. Therefore, the alternative that carries the highest overall weight will be the best choice for SMEs to refer to in order to make decisions as to whether or not to invest in BIM in their organisations. Depending on the criteria that SMEs use to generate alternatives, they will also be able to foresee the greatest risks and the greatest rewards that their organisation will encounter in the event that they adopt BIM to deliver construction projects. This feature of the DSS provides instructive information associated with the risks and rewards of BIM adoption for SMEs, in order to help them plan well for their businesses in the future. Also, this feature helps SMEs to optimise their solutions as regards whether to accept, mitigate, or avoid risks in the event that their organisation does not score the highest weight.

There are four main criteria and eleven sub-criteria within the DSS, such that there will be fifty-four alternatives generated (Table 33). With these alternatives, SMEs can alter the criteria so as to be able to choose the scenario closest to the context of their organisation for consideration before making a final decision.

As can be seen from Table 31, the best alternative allowing SMEs to maximise the benefits and minimise the risks when adopting BIM to deliver construction projects is ranked 1. This alternative also accounts for the highest overall weight (44.168) of the fifty-four alternatives generated. This means that if organisations participate at the design stage in private sector funded BIM projects valued at between £5 million and £50 million and using a highly collaborative procurement route (IPD), they will be able to enjoy the highest level of benefits while facing the lowest level of risks. In contrast, at the other extreme, those organisations that participate at the operation/maintenance stage in public sector funded BIM projects

valued at less than £5 million and using traditional procurement methods will only be able to enjoy the lowest level of benefits, while facing the highest level of risks.

Details as to assumptions regarding the benefits and risks associated with the criteria of the DSS are presented in Appendix III. These assumptions have been compiled on the basis of the existing literature relating to the criteria and the outcomes of the framework validation process; and they offer, it is hoped, valuable advice on the adoption of BIM to deliver construction projects, advice which comes from participants who have worked with BIM across the UK.

The next section will demonstrate how the DSS can help SMEs to anticipate the risks and rewards of adopting BIM to deliver construction projects.

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Table 31. Summary of alternatives for the risk-reward anticipation process

Involvement phase	Weight	Project value	Weight	Source of funding	Weight	Procurement route	Weight	Total weight	Rank of alternative
Design	15.357	≥ £5 m, ≤ £50m	6.787	Private	11.253	Highly collaborative	10.771	44.168	1
						Two-stage design and build	7.405	40.802	7
						Traditional procurement	5.886	39.283	14
				Public	10.812	Highly collaborative	10.771	43.727	2
						Two-stage design and build	7.405	40.361	8
						Traditional procurement	5.886	38.842	18
		≥ £50m	6.248	Private	11.253	Highly collaborative	10.771	43.629	3
						Two-stage design and build	7.405	40.263	9
						Traditional procurement	5.886	38.744	19
				Public	10.812	Highly collaborative	10.771	43.188	5
						Two-stage design and build	7.405	39.822	11
						Traditional procurement	5.886	38.303	23

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	<£5m	6.191	Private	11.253	Highly collaborative	10.771	43.572	4
					Two-stage design and build	7.405	40.206	10
					Traditional procurement	5.886	38.687	20
			Public	10.812	Highly collaborative	10.771	43.131	6
					Two-stage design and build	7.405	39.765	12
					Traditional procurement	5.886	38.246	24
Construction	≥ £5 m, ≤ £50m	6.787	Private	11.253	Highly collaborative	10.771	39.488	13
					Two-stage design and build	7.405	36.122	31
					Traditional procurement	5.886	34.603	37
			Public	10.812	Highly collaborative	10.771	39.047	15
					Two-stage design and build	7.405	35.681	32
					Traditional procurement	5.886	34.162	38
10.677	≥ £50m	6.248	Private	11.253	Highly collaborative	10.771	38.949	16
					Two-stage design and build	7.405	35.583	33
					Traditional procurement	5.886	34.064	40

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		Public	10.812	Highly collaborative	10.771	38.508	21		
				Two-stage design and build	7.405	35.142	35		
				Traditional procurement	5.886	33.623	43		
		<£5m	6.191	Private	11.253	Highly collaborative	10.771	38.892	17
						Two-stage design and build	7.405	35.526	34
						Traditional procurement	5.886	34.007	41
				Public	10.812	Highly collaborative	10.771	38.451	22
						Two-stage design and build	7.405	35.085	36
						Traditional procurement	5.886	33.566	44
Operation/ maintenance	8.632	Private	11.253	Highly collaborative	10.771	37.443	25		
				Two-stage design and build	7.405	34.077	39		
				Traditional procurement	5.886	32.558	49		
		Public	10.812	Highly collaborative	10.771	37.002	26		
				Two-stage design and build	7.405	33.636	42		
				Traditional procurement	5.886	32.117	50		

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	≥ £50m	6.248	Private	11.253	Highly collaborative	10.771	36.904	27
					Two-stage design and build	7.405	33.538	45
					Traditional procurement	5.886	32.019	51
		Public	10.812	Highly collaborative	10.771	36.463	29	
				Two-stage design and build	7.405	33.097	47	
				Traditional procurement	5.886	31.578	53	
	<£5m	6.191	Private	11.253	Highly collaborative	10.771	36.847	28
					Two-stage design and build	7.405	33.481	46
					Traditional procurement	5.886	31.962	52
		Public	10.812	Highly collaborative	10.771	36.406	30	
				Two-stage design and build	7.405	33.04	48	
				Traditional procurement	5.886	31.521	54	

7.5. DEMONSTRATION OF THE DSS

As mentioned in Section 7.4, all alternatives of the multi-criteria decision process are structured and stored in the DSS database. Through the DSS, SMEs can select the criteria most suitable to their organisation for the anticipation of risks and rewards. Depending on users' selections, different alternatives are generated, providing an informed basis for decision-making regarding the best course of action for BIM adoption. Potential risks and rewards are assessed in terms of their likelihood of occurrence and level of impact on an SME, and provided together with the outcomes of alternatives. The DSS can be accessed online via:

- **Bimbroker.com**
- **User name: admin**
- **Password: 123**

A simple rich picture of the DSS of this study is presented in *Figure 30* below. The typical steps in the process of anticipating risks and rewards in the DSS are illustrated by screenshots.

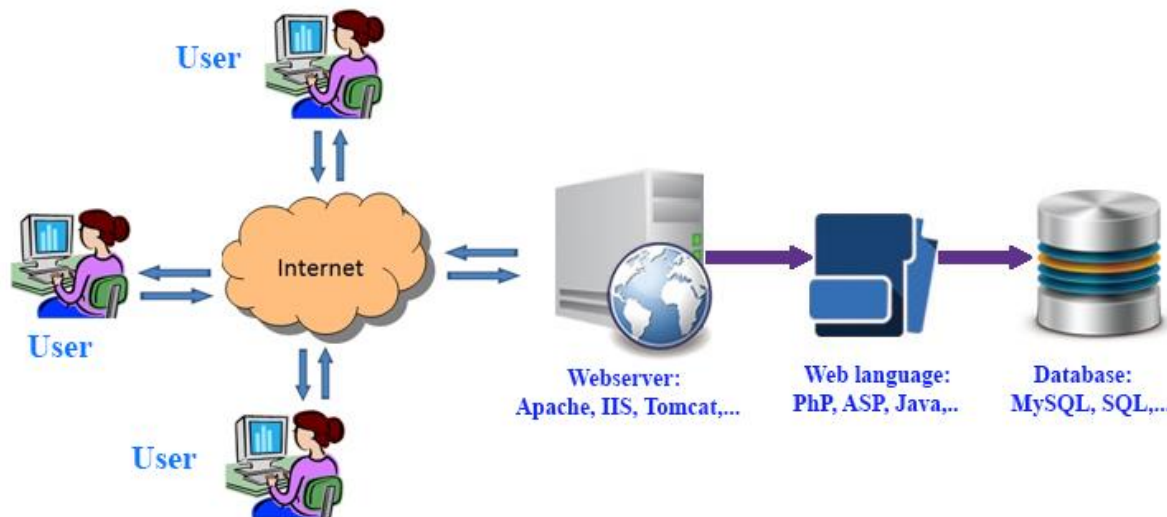


Figure 30. A rich picture of the DSS

Step 1: Go to the main page of the DSS (Figure 31). In this is to be found:

- A1: The main DSS menu:
 - About BIM: a brief introduction to BIM.

- SMEs: a brief introduction to SMEs.
- About the research: a brief introduction to the research.
- Brokering risks & rewards: the function of anticipating risks and rewards.
- Feedback: comments from users after using the DSS.

A1 About BIM | SMEs | About the research | Broker Risk & Reward | Feedback

A2 Home | Involvement phase | Project value | Source of funding | Procurement route Search

A3 **Building Information Modelling (BIM) Risk or Reward?**
 The aim of this tool is to help Small and Medium sized Enterprises (SMEs) to foresee the risks and the rewards of adopting BIM to deliver construction projects.
 When you start the assessment, you will be required to provide background information on your organisation and the projects that you intend to participate in. BIM Broker will use these details and show you the results your exposure to risks and the likely benefits to be attained.
 Please click on the button below to start using the tool

A4 Start Assessment

A5 BIM Standard | BIM document | Technology support | Available framework | Useful links

In recent years, building information modelling (BIM) has made great strides forward in the construction industry. Governments across the world are encouraging use of BIM for delivering construction projects. However, whether the extent to which BIM brings risks and/or benefits to SMEs is still not clear.

The potential risks and rewards of adopting BIM for project delivery are presented in the charts below. Risks and rewards are ranked from highest to lowest in term of likelihood of occurrence and level of impact on an SME. The percentage shown on the charts represents the weighted importance of each risk and reward calculated in relation to organisation/project scenario.

A6 **Potential rewards of BIM to SMEs**

Reward	Percentage
Improved cooperation and coordination i...	28%
More business in future	16.2%
Improved communication amongst part...	17.4%
Better customer services	19.2%
More	19.2%

A7 **Potential risks of BIM to SMEs**

Risk	Percentage
Unable to bid for public funded projects from...	28.7%
Lagging behind competitors in terms of BIM...	22.8%
Risk of losing business with private client	19.2%
disruption to working patterns	14.8%
Loss of	14.6%

Figure 31. The main page of the DSS

- A2: the second level of the main menu:
 - Home: go to the home page.
 - Involvement phase: one of the four main criteria of the framework, consisting of three sub-criteria: Design stage, Construction stage, and Operation/maintenance stage.
 - Project value: one of the four main criteria of the framework, consisting of three sub-criteria: Less than £5 million, Between £5 million and £50 million, and Greater than £50 million.
 - Source of funding: one of the four main criteria of the framework, consisting of two sub-criteria: Public sector and Private sector.
 - Procurement route: the last of the four main criteria of the framework, consisting of three sub-criteria: Traditional, Two-stage Design-and-Build, and IPD.
- A3: presentation of the aim of the tool
- A4: the main function of the tool: SMEs click on this button to start anticipating risks and rewards
- A5: an additional menu used to provide additional information relating to BIM. This function will be developed in future work.
- A6: potential rewards of BIM that SMEs may garner.
- A7: potential risks that SMEs may face in BIM environments.

Step 2: Selection of button A4 activates the main page for selecting criteria for the anticipation of risks and rewards (*Figure 32*). In this is to be found:

- B1: instruction to select criteria.
- B2: list of 11 sub-criteria grouped and colour-coded by their main criteria.
- B3: selection of a specific criterion.
- B4: description of the criterion currently selected.
- B5: presentation of final criteria that users have selected.
- B6&B7: list of rewards/risks associated with the particular criterion that users have selected. The percentages indicated in the charts represent the weights of rewards/risks.

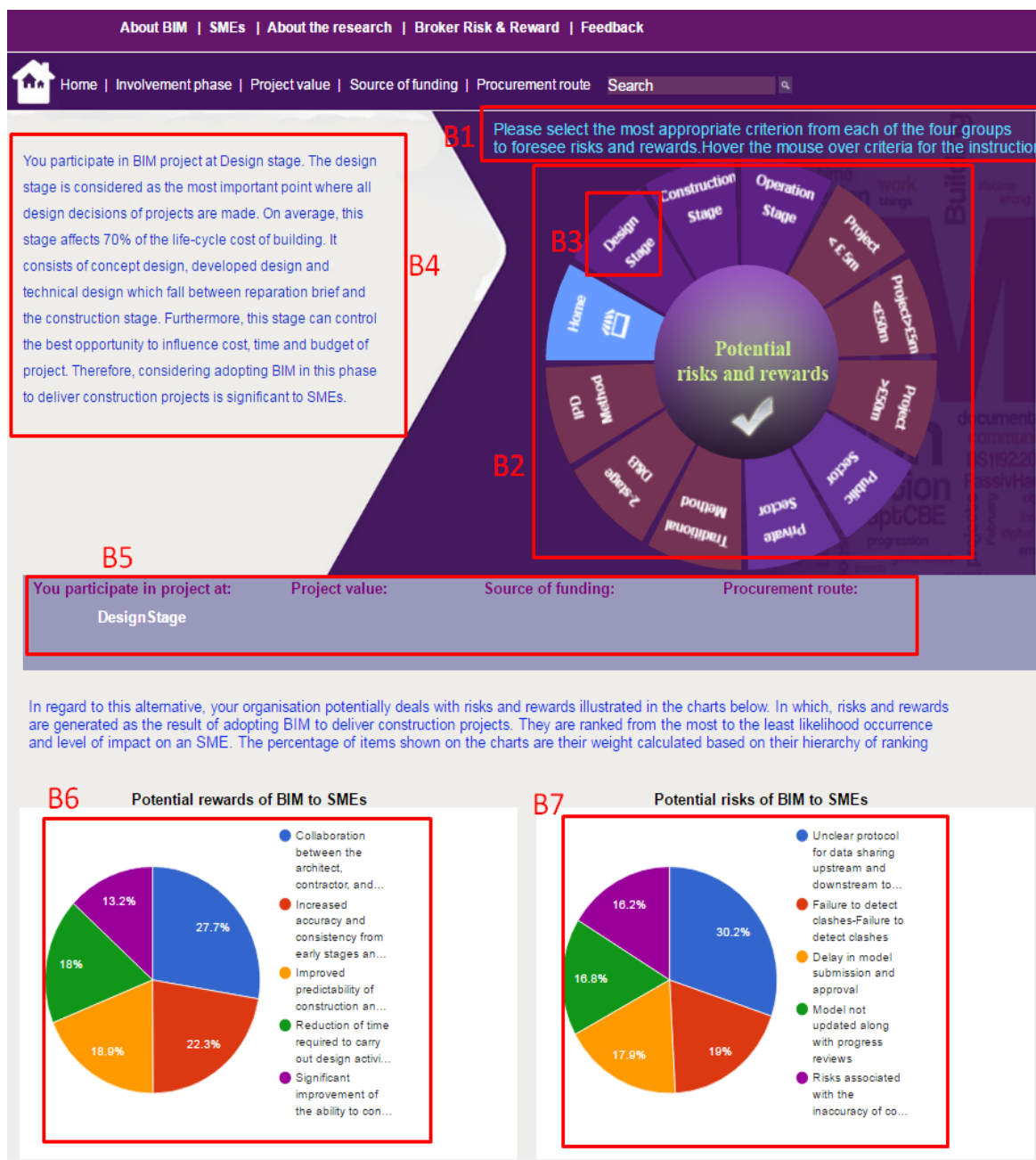


Figure 32. The main page for anticipating risks and rewards

Step 3: Selection of the function “Potential risks and rewards” shows the outcomes of the anticipation of risks and rewards, as illustrated in Figure 33

- C1: summary of criteria selected by users.
- C2: assumptions of the selected criterion. These provide users with helpful advice relating to the criterion that they have selected, including an indication

of the risks and rewards that they may face when adopting BIM to deliver construction projects.

- C3: potential risks and rewards associated with option selected in C4.
- C4: here users can change their choices in order to see not only the rank of criteria in a given group but also the relevant risks and rewards.

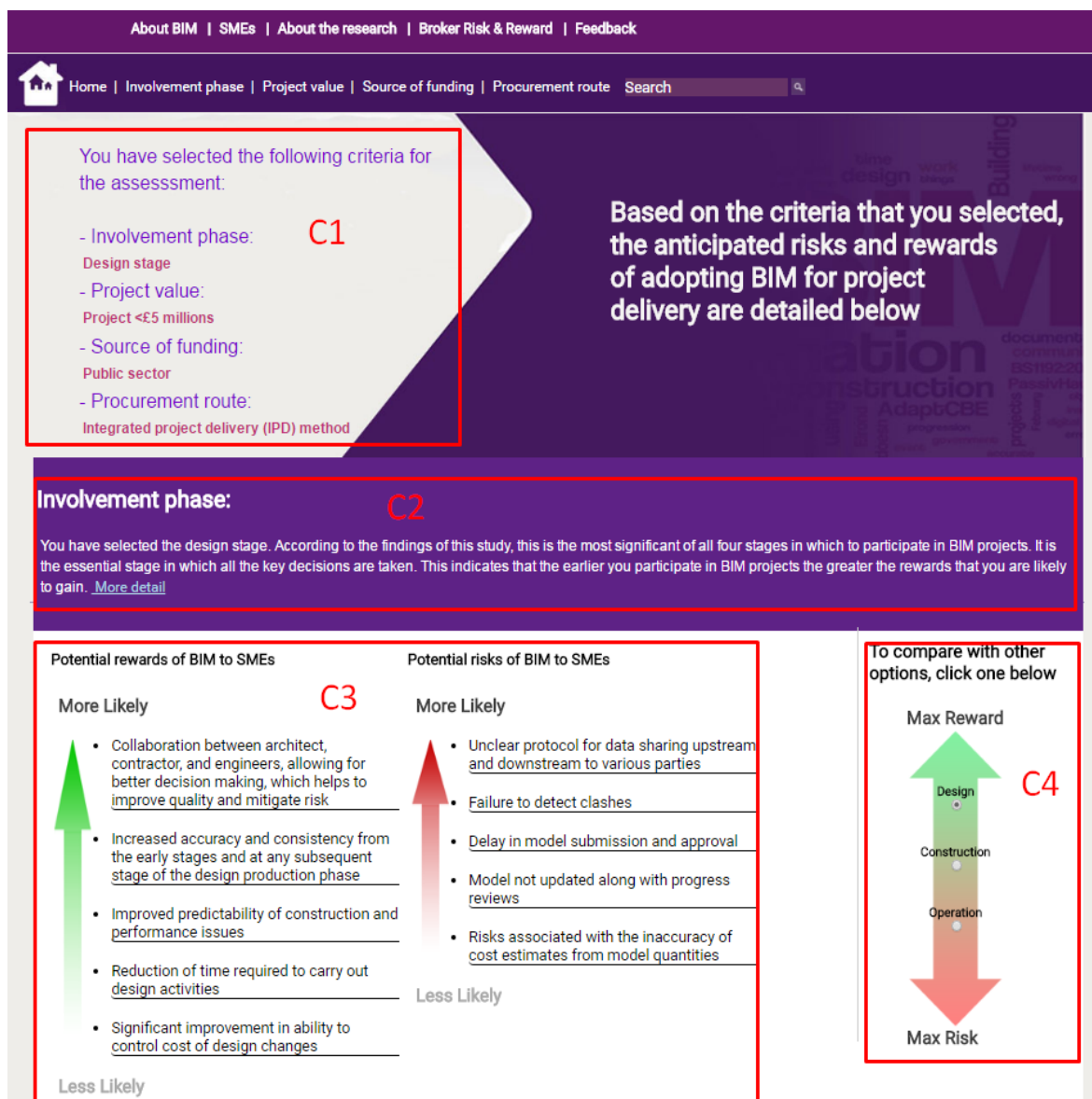


Figure 33. The outcomes of the risk-reward anticipation process

The assumptions associated with the main criteria of Project value, Source of funding, and Procurement route are formatted with the same structure as C1, C2, C3 and C4, and all presented on the outcomes page.

Aside from anticipating risks and rewards as indicated in Step 3. SMEs can select separate criteria from the sub-menu illustrated in *Figure 34* to foresee the risks, rewards and assumptions associated with the criterion selected. The outcomes of this selection are demonstrated *Figure 35* and known as the interim report, as mentioned in the framework workflow diagram (Chapter 4, Section 4.5).



Figure 34. Sub-menu

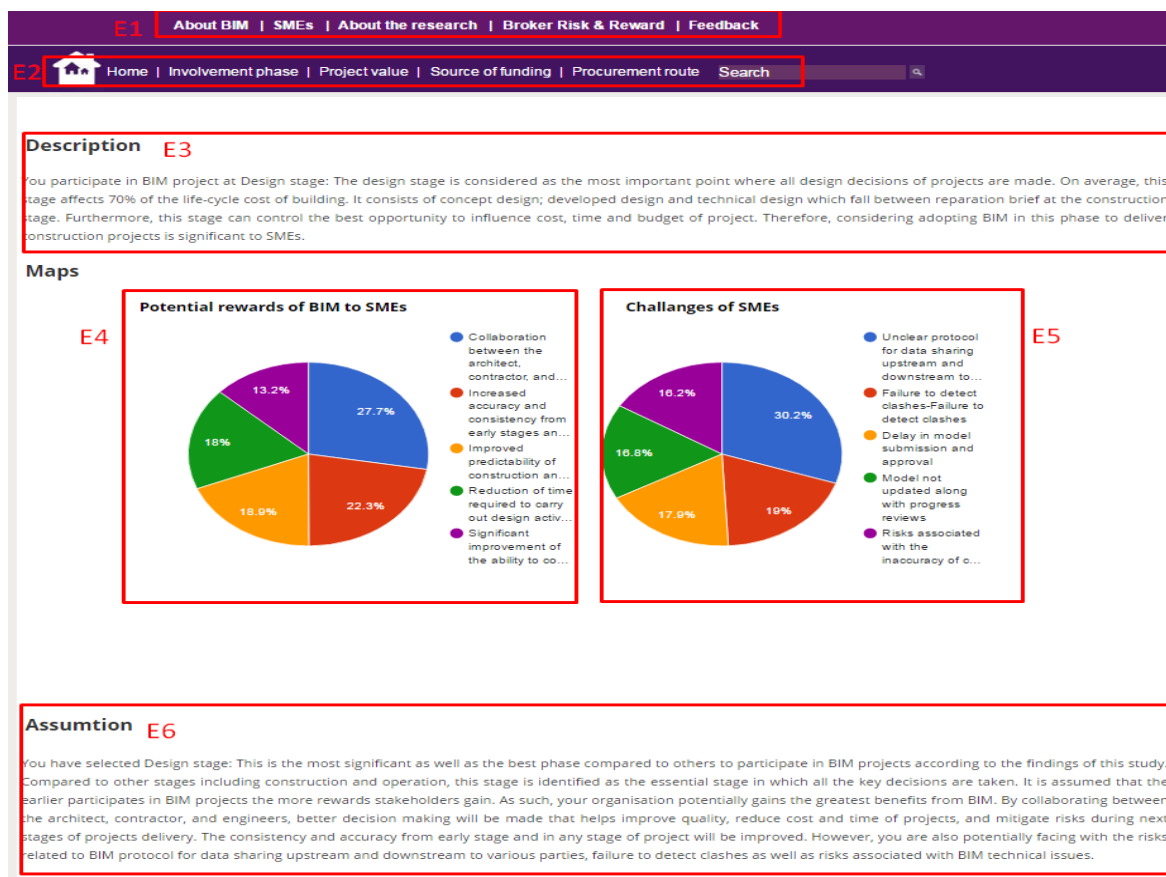


Figure 35. Interim report

7.6. VALIDATION OF THE DECISION SUPPORT SYSTEM

Tool validation is a process usually carried out at the final stage of tool development. Its aim is to determine whether a tool has met with user expectations and requirements (Thomas-Alvarez *et al.*, 2013). Thus, the Tool of this research was validated on completion of the development process. This validation will help to assess the value of the Tool as well as the extent to which it meets the target of the study.

7.6.1. Questionnaire design and survey implementation for DSS validation

When the design of the DSS was complete, it was uploaded to the internet and assigned a domain name, *bimbroker.com*. A one-year Hosting contract was also purchased by the researcher, to ensure availability and accessibility of the Tool throughout the validation process, as well as to collect feedback from users within a twelve-month period.

A further benefit of using the internet as a means of conducting the validation process is that it facilitates enhanced interaction between the Tool and its users, as well as increasing its accessibility. A structured questionnaire survey, detailed in Appendix II, was attached with a view to garnering comments and measuring how well the Tool was seen to meet the intended target of the research. All constructive comments received will be used to improve the Tool in future work.

In this survey, a five-point Linkert scale was adopted in order to determine the likelihood that the Tool will be of assistance to SMEs in deciding whether or not to adopt BIM in project delivery. The reason for adopting the Linkert scale is that it is a popular method for survey collection (Asun *et al.*, 2016), easy to understand (de Winter, 2010), and the most appropriate ordinal psychometric method (Hartley, 2014) to measure the attitudes, opinions of validators by indicating the degree of agreement or disagreement in a multiple-choice type format.

The structure of survey was divided into following sections:

- Section 1: included questions designed to elicit information about the participants themselves.
- Section 2: comprised questions seeking to measure the reaction of validators to the graphical user interface (GUI) of the DSS. The GUI is considered as a one of the most important factor that contributes to the success of any system (Kung *et al.*, (2008). It was decided how the system looks like and the main communication

environments between users and the Tool (Hu, *et al.*, 1999). Therefore, this factor cannot be ignored when validating the usefulness of the DSS of this study.

- Section 3: questioned evaluators about the ease of use of the DSS. The questions in this section sought to determine to what extent the DSS is easy to use, in terms of selecting criteria, as well as overall process of assessing risks and rewards. Similar to the GUI, the ease of use of any systems are highlighted by researchers as it may cause the system to be neglected by users (Thomas-Alvarez *et al.*, 2013).
- Section 4: dealt with investigating the quality of information presented in the DSS. Basically, the quality of information provided by systems is one of the main concern for users. As such, the good quality of information can help to boost up the number of system accessibility, as well as enhance its popularity in industry (Edwards *et al.*, 2014; Grudzień *et al.*, 2016).
- Section 5: examined the level of information presented in the DSS. The level of information represents “how much” information is presented in systems (Thomas-Alvarez *et al.*, 2013). In addition, it is illustrated by the way information is organised and formatted (Telang *et al.*, 2005). Likewise, an effective balance between having the right amount of information is critical, as too much and too little information is detrimental in any systems (Telang *et al.*, 2005)
- Section 6: included questions seeking to determine the extent to which the DSS is useful in assisting SMEs to make an informed decision about adopting BIM in project delivery.
- Section 7: is the final section that asked validator to provide constructive feedback in order to help the author to improve future versions of the.

Before the DSS was sent out for validation, two pilots had been conducted. Firstly, the Tool was sent to three IT experts to be tested for technical and functional errors in relation of the objectives of the study, to ensure that the Tool would be error-free when it becomes operational. The Tool was then sent to five general users to test its functionalities, including the questions in the attached survey, to ensure that these were both understandable – bearing in mind that participants would be required to review the Tool, before answering the survey questions.

To conduct the validation, an online structured survey, which included the link for the Tool with the questionnaires, was sent to members of CNBR and LinkedIn groups, including members working in the construction industry across the world. The purpose of this was to collect useful feedback from SMEs, especially in the UK; and thus, as well as enabling the researcher to measure the validity of the Tool, to garner a range of comments which it is hoped may inform not only improvements to the Tool but also future research.

The next section proposes the method used to analyse data collected for validating the DSS.

7.6.2. Data analysis methods used to analyse data for validating the DSS

As indicated in previous section, five-point Likert scales were adopted to design the questionnaire for the DSS validation survey. For example, in evaluating the ease of use of the tool, the five-point scale used was: In this survey, (1) represents “Extremely difficult”, (2) represents “Somewhat difficult”, (3) represents “Neither easy nor difficult”, (4) represents “Somewhat easy”, and (5) represents “Extremely easy”.

Descriptive statistics method was used to describe and present the data collected from the survey. It includes outlining the frequencies of respondents, which were represented by simple graphics analysis. Denscombe (2010) and Naoum (2007) state that descriptive statistics is most appropriated method and usually used to ascertain the distribution of data. Consequently, this method has been employed by many researchers especially in their PhD theses. For instance, “An investigation into the accident causal influence of construction project features” (Manu, 2012), “Organisational readiness to implement building information modeling: a framework for design consultants in Malaysia” (Haron, 2013), “Development of a comprehensive systematic quantification of the costs and benefits (CB) of property level flood risk adaptation measures in England. (Rotimi, 2014), and “Development of a decision support framework to aid selection of construction supply chain organisations for BIM-enabled projects” (Mahamadu, 2017).

In the context of this research, the distribution of respondents helps to establish the validity of the findings, which indicate the extent of the effectiveness of the DSS in assisting SMEs to anticipate risks and rewards of adopting BIM to deliver constructions projects.

In answer to the invitation to be involved in the survey, fifty-five responses to this survey were received. However, only 50 respondents completed all the questions. It is therefore on these 50 responses that the data analysis for the survey is based.

7.6.2.1. Reliability of data

Similar to data collected from the survey conducted for framework validation. The reliability of data collected in this survey was also considered carefully based on the CA. The CA (0.875) and the CA if item deleted, collected in this survey is recorded an excellent reliability for an academic research (Table 32). It also means that all questions in the survey are relevant to the research topic of the research (Field, 2013)

Table 32. The reliability of survey data

Reliability Statistics	
Cronbach's Alpha	N of Items
.875	9

Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q5	30.42	23.228	.590	.864
Q6	30.20	23.837	.529	.868
Q7	30.16	22.341	.661	.857
Q4	30.16	22.423	.623	.861
Q8	30.14	22.898	.502	.872
Q9	29.94	23.200	.617	.862
Q10	30.00	22.082	.691	.855
Q11	30.12	21.210	.670	.856
Q12	30.22	20.665	.678	.856

The details of findings and discussion in this survey are presented in Sections below

7.6.2.2. General information of participants

The main purpose of Tool validation was to collect feedback on the DSS’s performance from practitioners in the construction industry. Comments from participants would indicate the degree of success of the DSS in both functionality (graphical user interface, ease of use) and validity (level of information, quality of information, knowledge contribution). Of the evaluators completing the survey, architects accounted for 30% of responses, while 14% of

respondents stated that they were consultant. Thirty-four percent of respondents described themselves as Engineers: 22% Civil or Structural Engineers, and a further 12% Mechanical or Electrical Engineers. Project Managers accounted for 8% of responses. At the other end of the scale, 2% of respondents described their profession as QS, and a further 8% as “Engineer (other)”. Four percent of respondents stated that they belonged to other areas of engineering, and are listed as “Others” (Chart 37).

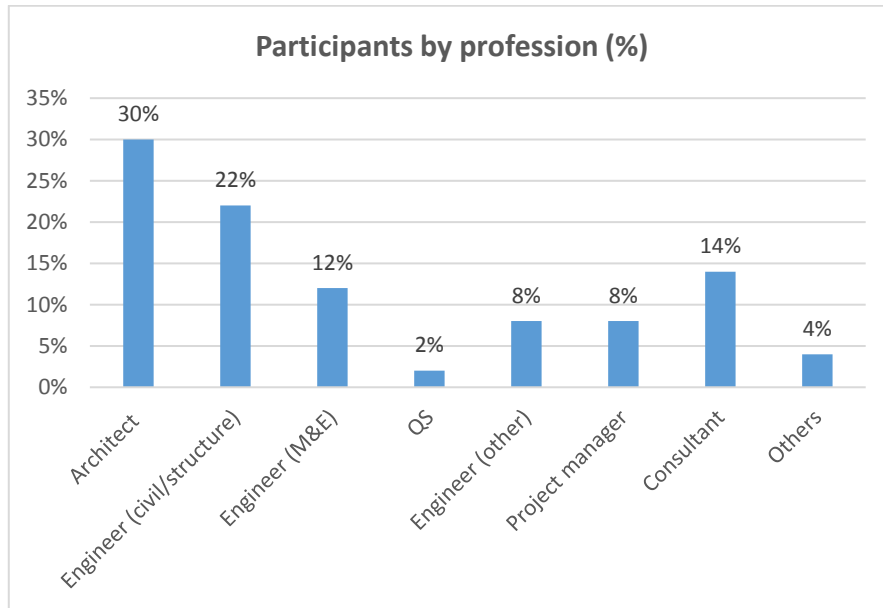


Chart 37. Participants by profession

Regarding the type of organisation for which evaluators currently work, as many as twenty-four percent categorised their area of business as MEP. Architecture accounted for 20% of responses, Consultancy for 18%, and Construction for 16%. Lower numbers of respondents stated their areas to be Infrastructure (at 6%), while the lowest number described themselves as Main Contractors (at 4%) and as working in Maintenance (also at 4%). Eight percent of respondents stated that they belonged to other areas, and are listed as “Other” (Chart 38).

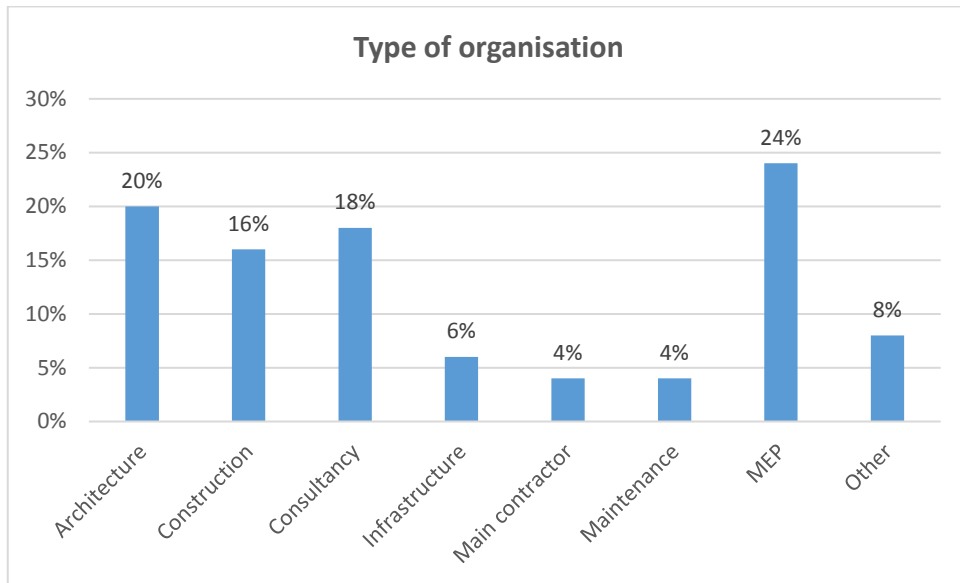


Chart 38. Type of organisation

In terms of organisation’s size, evaluators’ organisations were principally categorised into three primary groups: those with less than 10 employees, those with 11 to 50 employees, and those with 51 to 250 employees. The largest number of respondents (42%) stated that their organisations consisted of between 11 and 50 employees. The remaining respondents stated that they worked in smaller organisations: 30% in those with less than 10 employees, and 28% in workplaces of between 51 and 250 employees (Chart 39).

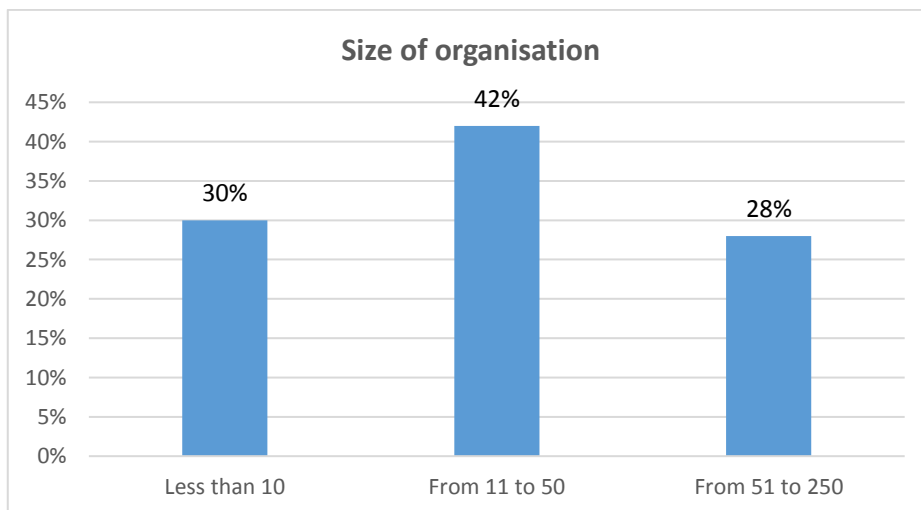


Chart 39. Size of organisation

Overall, general participant information helps the researcher to track and identify anonymous responses as well as decide the validity of collected data. Respondent

information resulting from the survey indicated that all validators are currently working in the construction industry in clearly defined professions and types of organisation, and that the business areas in which their organisations are engaged are similarly clearly defined. These findings met with the aim of the survey inasmuch as it sought feedback on the DSS's performance from professionals working in construction industry.

7.6.2.3. Graphical user interface (GUI)

In any web-based technology, the GUI plays a significant role in contributing to the success of a system as well as enhancing the interaction between a system and its users. Kung *et al.* (2008) state that the GUI usually decides “how a system is”, including its appearance, the impression it creates, its input/output data, and how it formats data to render it more understandable. Hu *et al.* (1999) also support the view that the efficiencies and benefits of an information retrieval system essentially depend on its GUI, the point not only where communications between users and systems take place but also where knowledge and information representation are visualised.

Thus, in order to validate the GUI of the DSS, validators were asked to give their first impressions of the Tool. The findings presented in Chart 40 show that the majority, at 46%, rated it as “Good”, while 18% thought it “Excellent”, 30% considered it “Average”, and 6% judged it “Poor”. No respondents rated it “Terrible”.

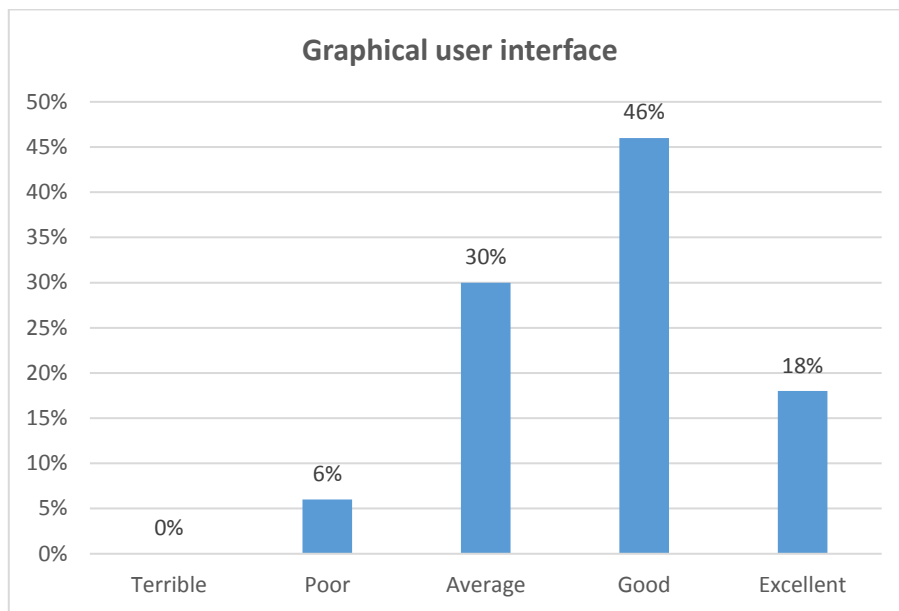


Chart 40. Graphical user interface

	Frequency	Percent	Valid Percent	Cumulative Percent
Poor	3	6.0	6.0	6.0
Average	15	30.0	30.0	36.0
Valid Good	23	46.0	46.0	82.0
Excellent	9	18.0	18.0	100.0
Total	50	100.0	100.0	

Moreover, respondents were also asked to assess how easy the Tool was to understand, in other words how straightforward they felt it to be. The majority (46%) stated that they felt it to be “Somewhat easy” to use, with a further 40% judging it “Neither easy nor difficult” to use. Eight percent of respondents found it “Somewhat difficult” to use, while in contrast 6% found it “Extremely easy” to use. No respondents assessed it as “extremely difficult” to use (Chart 41).

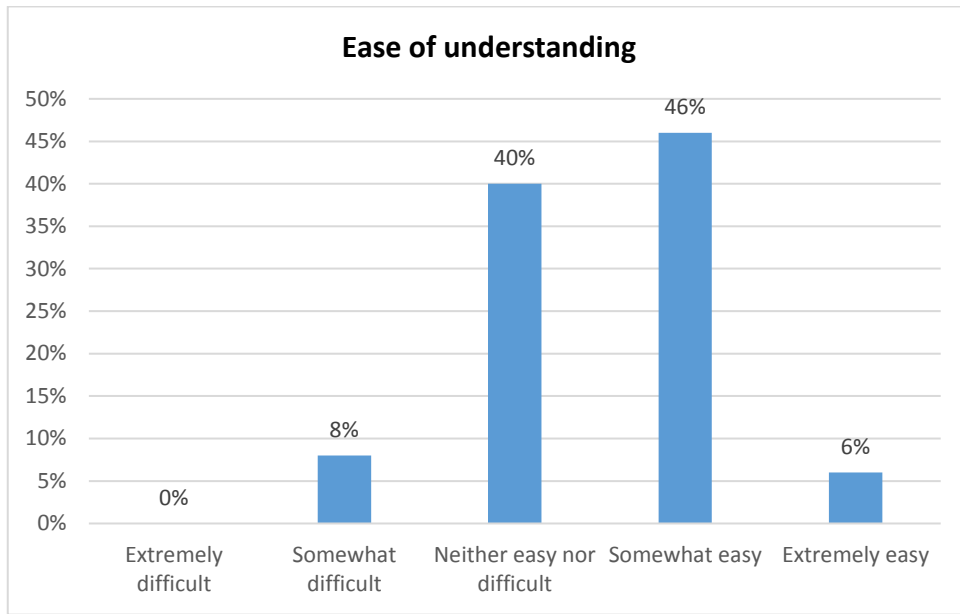


Chart 41. Ease of understanding

	Frequency	Percent	Valid Percent	Cumulative Percent
Somewhat difficult	4	8.0	8.0	8.0
Neither easy nor difficult	20	40.0	40.0	48.0
Valid Somewhat easy	23	46.0	46.0	94.0
Extremely easy	3	6.0	6.0	100.0
Total	50	100.0	100.0	

In conclusion, the findings of the validation survey reveal that the GUI of the DSS is closely in line with the desirable general characteristics of a web-based technical system (Kung *et al.*, 2008; Hu *et al.*, 1999), with a large number of validators rating it as giving a “Good” impression at first sight, and considering it “somewhat easy” to understand. These results suggest that the DSS when it comes into operation might be able to generate a user-friendly interface capable of attracting the attention of potential users, as well as improving communication and interaction between the DSS and its existing users (Ramakrisnan *et al.*, 2012).

7.6.2.4. Ease of use

Along with a good GUI, ease of use is also highlighted as an important feature by designers when developing prototypes, applications or software in general (Thomas-Alvarez *et al.*, 2013). The DSS in this study is no exception in this regard. Once the DSS design was fully complete, its ease of use feature was also validated both in terms of its specific steps and in

terms of the entire overall process of anticipating risks and rewards. In the first place, respondents were asked whether they found it easy to select criteria within the Tool. In response, at the top end of the scale, 56% found it “Somewhat easy”, and 30% “Neither easy nor difficult”. However, here more respondents found it “Extremely easy” (10%) than “Somewhat difficult” (4%). Once again, no respondents found it “Extremely difficult” (Chart 42).

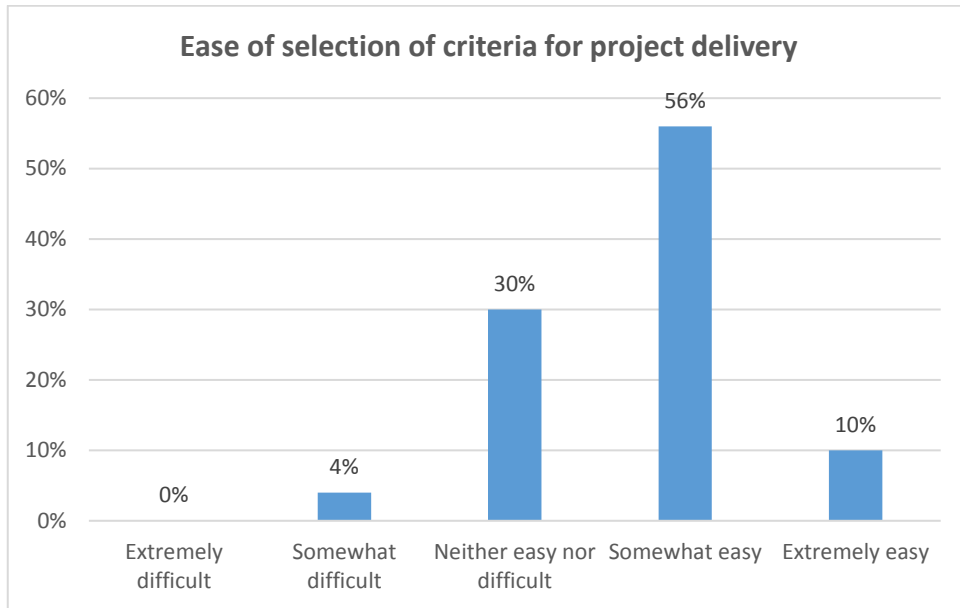


Chart 42. Ease of selection of criteria for project delivery

	Frequency	Percent	Valid Percent	Cumulative Percent
Somewhat difficult	2	4.0	4.0	4.0
Neither easy nor difficult	15	30.0	30.0	34.0
Valid Somewhat easy	28	56.0	56.0	90.0
Extremely easy	5	10.0	10.0	100.0
Total	50	100.0	100.0	

When respondents were asked to assess the relative ease of the entire process of using the Tool, results were parallel to those for the previous question (as indicated in Chart 43). The majority of respondents (50%) found the entire process “Somewhat easy”, with 28% finding it “Neither easy nor difficult”, 16% finding it “Extremely easy”, and 6% finding it “Somewhat difficult”. Once again, no respondents found it “Extremely difficult” to use.

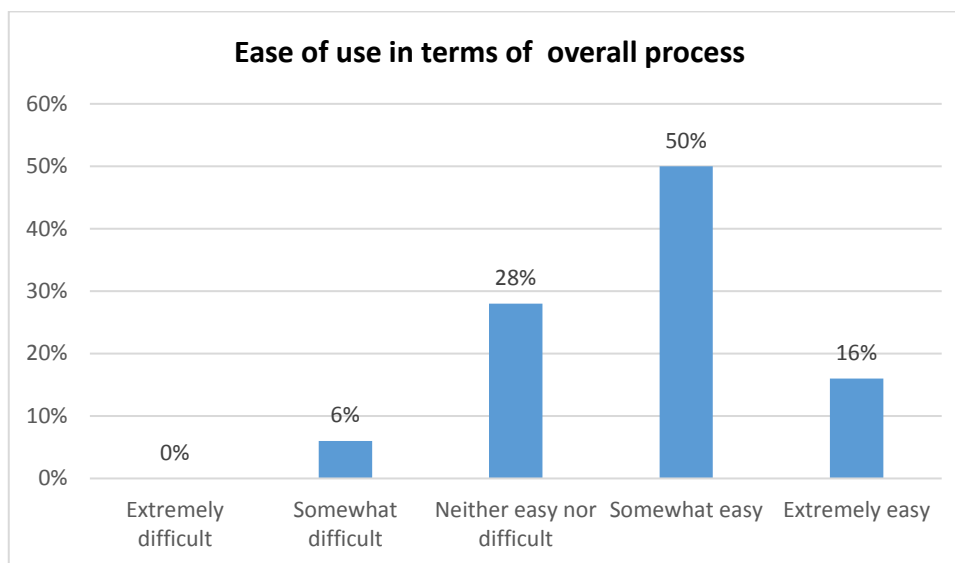


Chart 43. Ease of use in terms of overall process

	Frequency	Percent	Valid Percent	Cumulative Percent
Somewhat difficult	3	6.0	6.0	6.0
Neither easy nor difficult	14	28.0	28.0	34.0
Valid Somewhat easy	25	50.0	50.0	84.0
Extremely easy	8	16.0	16.0	100.0
Total	50	100.0	100.0	

All in all, use of the DSS to anticipate risks and rewards, in terms of both specific steps and overall process, was generally found to be easy. Ease of use, like the GUI, is another critical factor that might cause a system such as a DSS to be neglected by users (Thomas-Alvarez *et al.*, 2013); but as a consequence of a high number of evaluators commenting positively on the DSS in this research, it seems reasonable to expect that the DSS has the potential to be disseminated to the wider SME community, and perhaps even to become one of the most popular BIM tools in the construction industry.

7.6.2.5. Quality of information

To validate the quality of information provided by the DSS, respondents were asked to answer the question “How would you rate the quality of information presented?”. The results presented in Chart J show that most answers (48%) rated it “Very useful”, with 22% rating it “Moderately useful”, 20% “Extremely useful”, and 10% “Slightly useful”. All respondents found it to some degree useful: none considered it “Not at all useful” (Chart 44).

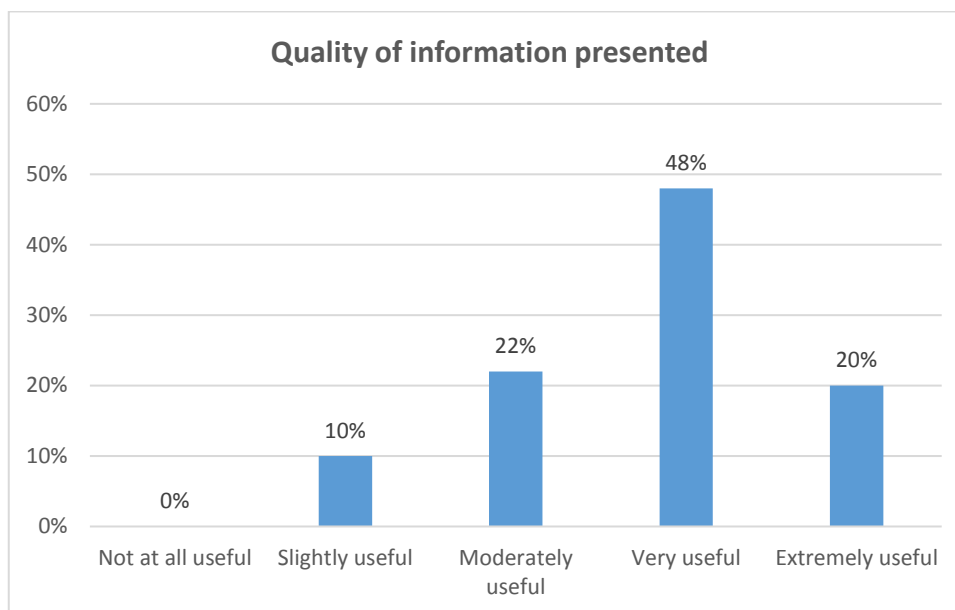


Chart 44. Quality of information presented

	Frequency	Percent	Valid Percent	Cumulative Percent
Slightly useful	5	10.0	10.0	10.0
Moderately useful	11	22.0	22.0	32.0
Valid Very useful	24	48.0	48.0	80.0
Extremely useful	10	20.0	20.0	100.0
Total	50	100.0	100.0	

Clearly, quality of information is always a significant target that enquirers usually expect to be met, depending on the topics that they are pursuing. Quality of information generally depends on the sources of providers, and on whether or not the information has been validated (Grudzień *et al.*, 2016). In the context of designing software or applications, quality of information defines how useful a product is (Edwards *et al.*, 2014).

The information presented in the DSS consists of data collected through a framework validation process conducted during the previous research stage. This data has been validated by 93 validators and analysed carefully by means of the academic methodology VAHP. Once again, the quality of information provided by the DSS has been confirmed as generally positive, based on the outcomes of this validation survey. Thus, the DSS is expected to be able to provide SMEs with useful information and knowledge relating to BIM in construction project delivery.

7.6.2.6. Level of information presented in the Tool.

Aside from the quality of information provided by the DSS, consideration of its level of information is also essential. “Level of information” here refers to how much information is presented in the DSS, and how it is organised. To measure this, respondents were asked to what extent the Tool provided them with an appropriate level of information to enable them to assess the risks and rewards associated with BIM adoption. A clear majority of respondents (78%) rated the level of information provided either “Extremely good” (22%) or “Somewhat good” (56%). Twenty percent of respondents, however, found it “Neither good nor poor”, with only 2% finding it “Somewhat poor“. No respondents found it “Extremely poor” (Chart 45).

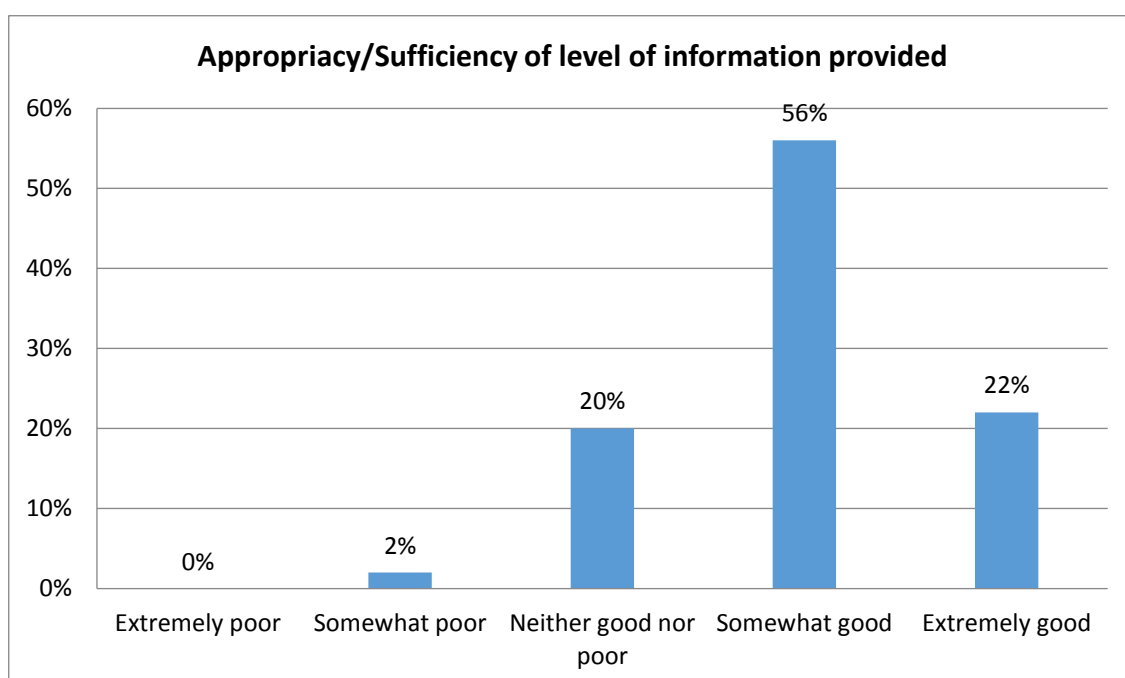


Chart 45. Appropriacy/Sufficiency of level of information provided

	Frequency	Percent	Valid Percent	Cumulative Percent
Somewhat poor	1	2.0	2.0	2.0
Neither good nor poor	10	20.0	20.0	22.0
Valid Somewhat good	28	56.0	56.0	78.0
Extremely good	11	22.0	22.0	100.0
Total	50	100.0	100.0	

The findings on this question suggest that the level of information presented in the DSS is highly acceptable, with respondents' attitudes leaning towards the positive. This result bodes well for the potential performance of the DSS, inasmuch as appropriacy of level of information can contribute to a successful system (as noted by Thomas-Alvarez *et al.*, 2013). Furthermore, as Telang *et al.* (2005) stress, a good tool needs to provide just the right amount of information, striking an effective balance between too much and too little. Typically, the provision of too much information can distract users, while a tool that provides insufficient enough information may turn out to be useless. In view of this, the responses summarised in Chart K (with 20% of respondents choosing "Neither good nor poor", 56% "Somewhat good", and 22% "Extremely good") offer a realistic hope that the DSS will be able to satisfy SME users accessing it to anticipate risks and rewards of BIM adoption in construction project delivery.

7.6.2.7. Effect on the decision of adopting BIM in project delivery

As the aim of this research is to develop the DSS in order to help SMEs in deciding whether or not to use BIM to deliver construction projects, the comments of validators regarding this aspect of the Tool (its effect) were particularly significant, and their feedback particularly meaningful in deciding the usefulness or otherwise of the DSS. The validation for this aspect consists of three questions, as described below.

In the first question, respondents were asked to what extent the Tool provided them with knowledge of risks and rewards when adopting BIM to deliver construction projects. Responses closely paralleled those in answer to the earlier question regarding level of information, described in the previous section (Section 7.1.2.5): a clear majority of respondents (54%) selected "Somewhat good", while 22% selected "Extremely good", 18% "Neither good nor poor", and only 6% "Somewhat poor". Once again, no respondents selected "Extremely poor". Responses are detailed in Chart 46 below.

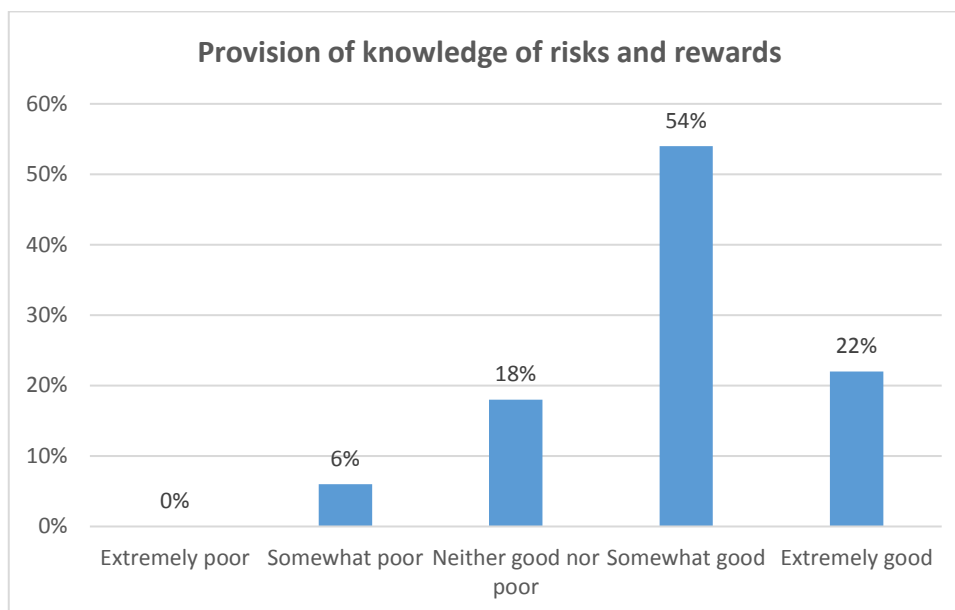


Chart 46. Provision of knowledge of risks and rewards

	Frequency	Percent	Valid Percent	Cumulative Percent
Somewhat poor	3	6.0	6.0	6.0
Neither good nor poor	9	18.0	18.0	24.0
Valid Somewhat good	27	54.0	54.0	78.0
Extremely good	11	22.0	22.0	100.0
Total	50	100.0	100.0	

In the second question, validators were asked whether the ability to personalise the risks and rewards would help them to make an informed decision regarding BIM adoption. A substantial majority of respondents (68%) rated such an added ability as either “Somewhat likely” to assist in decision-making regarding BIM adoption (44%) or “Extremely likely” to do so (24%). In contrast, only 12% of respondents felt it would be “Somewhat unlikely” to do so. Twenty percent of responses indicated that it would be “Neither likely nor unlikely” to do so; while no respondents felt that it would be “Extremely unlikely” to do so, as detailed in Chart 47 below

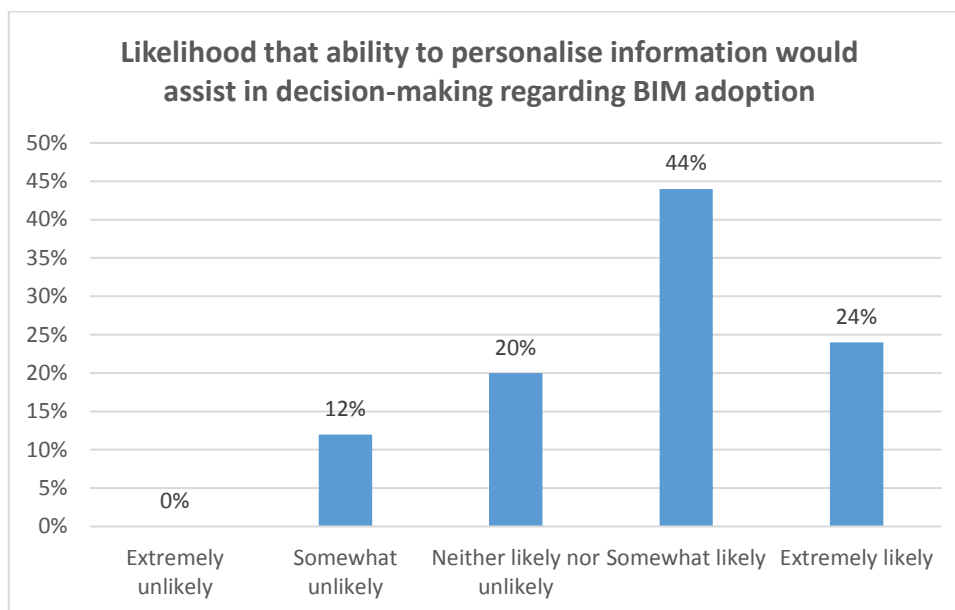


Chart 47. Likelihood that ability to personalise information would assist in decision-making regarding BIM adoption

	Frequency	Percent	Valid Percent	Cumulative Percent
Somewhat unlikely	6	12.0	12.0	12.0
Neither likely nor unlikely	10	20.0	20.0	32.0
Valid Somewhat likely	22	44.0	44.0	76.0
Extremely likely	12	24.0	24.0	100.0
Total	50	100.0	100.0	

In the third question, respondents were asked to what extent they had found the Tool useful in deciding whether or not to use BIM to deliver construction projects. All respondents had found it to some degree useful: to be precise, 16% of responses indicated “Slightly useful”, 22% “Moderately useful”, and 38% (the majority of respondents) “Very useful”. A further 22% had found it “Extremely useful” in this regard, as detailed in Chart 48 below.

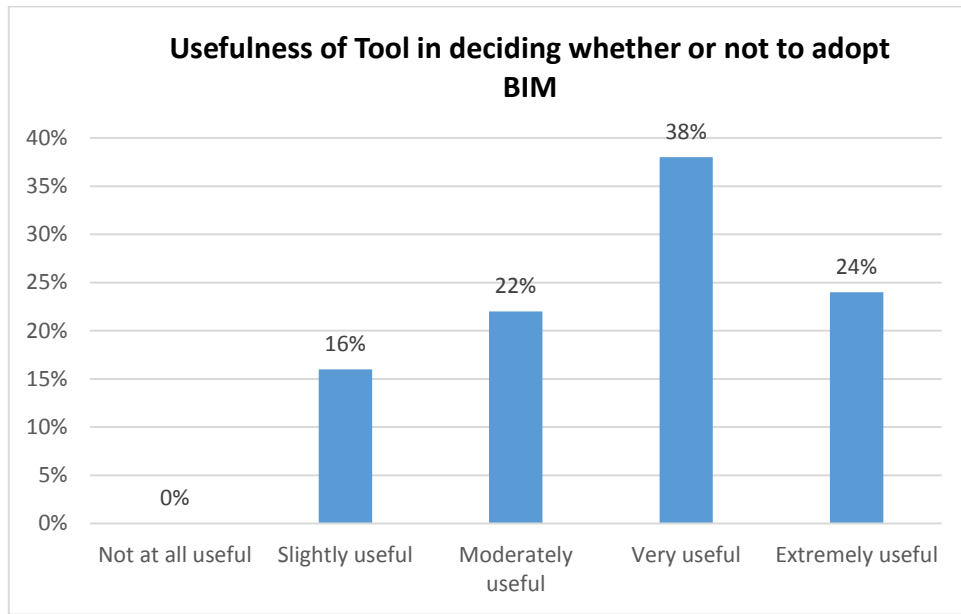


Chart 48. Usefulness of Tool in deciding whether or not to adopt BIM

	Frequency	Percent	Valid Percent	Cumulative Percent
Slightly useful	8	16.0	16.0	16.0
Moderately useful	11	22.0	22.0	38.0
Valid Very useful	19	38.0	38.0	76.0
Extremely useful	12	24.0	24.0	100.0
Total	50	100.0	100.0	

It can be seen from Charts 46, 47, and 48 that a large number of validators in this survey provided positive feedback on the DSS in regard to its positive effect on the decision to adopt BIM in project delivery. Chart 46 shows a total of 76% of respondents commenting “Somewhat good” (54%) or “Extremely good” (22%) when asked the extent to which the DSS provided them with knowledge of risks and rewards when adopting BIM. Similarly, as illustrated in Chart 47, a significant majority of validators (68%) appeared convinced that the ability of the DSS to personalise risks and rewards would assist in decision-making regarding BIM adoption: 44% of respondents considered this outcome “Somewhat likely” while 24% felt it to be “Extremely likely”. This functionality, then, would help users to make informed decisions regarding BIM adoption.

The most interesting results in this section were to be found in the answers regarding the usefulness of the DSS, as demonstrated in Chart 48. In all, 62% of validators stressed that

the DSS was either very useful (38%) or extremely useful (24%) in helping SMEs to decide whether or not to adopt BIM to deliver construction projects in their organisations.

Overall, from the results of the validation process, the DSS of this research can be assumed to constitute a useful tool, and one that has a substantially positive effect on SMEs in their decision-making as to whether or not to invest in BIM in their organisations. The DSS can also be expected to become a popular tool in the construction industry: when respondents were asked whether they would introduce the Tool to their colleagues, a most encouraging 78% stated that they would, with only 22% replying that they would not (Chart 49). Comments from those replying in the negative consisted of the following (only three) assertions:

- “Most people I work with already understand the pros and cons of using BIM on projects”.
- “This Tool is not really applicable to our organisation”.
- “We already implement BIM on all projects”.

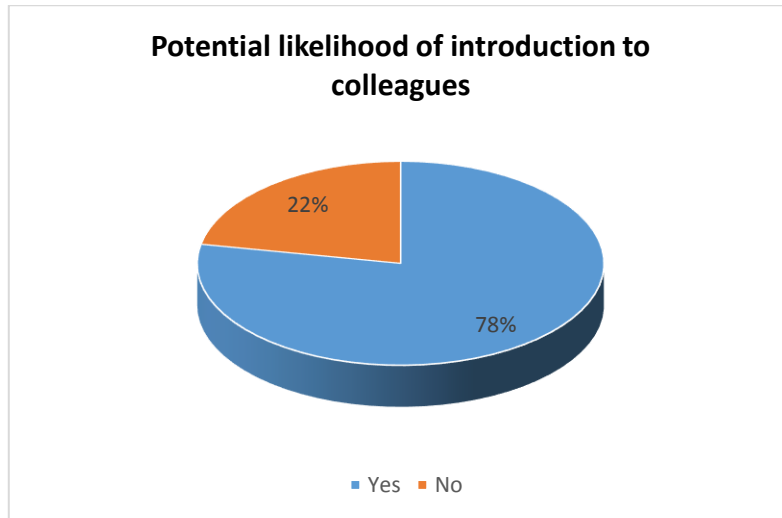


Chart 49. Potential likelihood of introduction to colleagues

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	39	78.0	78.0	78.0
Valid No	11	22.0	22.0	100.0
Total	50	100.0	100.0	

7.6.2.8. General comments from validators

Finally, the survey ended with comments section. In this question, respondents were asked to add any further comments they might wish, in order to help improve the Tool. The raw findings are detailed in appendix IV

It was clear from the responses to this question that while some respondents had benefited from BIM training and experience at university and at work respectively, others had had none. Many helpful comments were received; the usefulness of the Tool was clearly appreciated, as was the time spent developing it. Singled out for special mention were the coding and design, the value and helpfulness of the BIM information contained in the Tool, and the advisability for all small companies of adopting BIM. It was noted in particular that the Tool provided a good website for non-BIM users, allowing them to check relevant risks and rewards in order to help them to a better understanding of BIM in construction project delivery; and it was suggested that an excellent way forward might be development of the tool as a forum in order help users to exchange information and share knowledge together.

A number of extremely useful constructive criticisms were also evident in the comments received. It was noted, for example, that the tool was only in English, and that the results generated (and some of the texts) were too generic. Respondents recommended the removal of blank links, the use of a constant scale, and changes to the selector wheel – or an alternative, simpler selection mechanism – as it was found difficult to read rotated texts, which were in any case rated a little lengthy at times.

Clarity of overall presentation was also an issue for some respondents: For example, one participant expected to find a fifth option, not realising that there was a total of four. Differently coloured pages for each of the 4 options was suggested, since the pie charts were deemed so small that it was difficult to see whether one had clicked a different option. One user was disappointed not to be able to click on a pie-chart slice within the tool to learn more about the risk that the slice related to; this user was also unsure of how to use the weighting percentages. Clearer instructions, then, were considered necessary.

Other recommendations were that the charts needed to be more interactive and the Project Implementation section more flexible, and that the Tool will need regular updating given that risks and rewards always change over time. It was further recommended that the Tool

currently relying on data from one source or report at a fixed point in time could be made more bespoke, or tailored to individual needs, by allowing participants to input information about their business and to compare benefits and barriers for SMEs of a similar size and function; and by allowing each new participant to add to the data by asking them to complete the same survey.

7.7. CONCLUSION

This chapter has reviewed the fundamental elements deemed to be necessary for the development process of the DSS in this study. The outcomes of the DSS validation process are also presented.

The DSS of this study had been designed based on data collected from the framework validation process. To develop the DSS of this study, the software platforms PHP, HTML, and CSS were adopted, together with MySQL database management. The DSS was then uploaded to the internet with the access link <http://bimbroker.com>. Various screenshots of the DSS were also presented.

As with the process of validating the conceptual framework in the previous stage, the DSS validation in this stage adopted a quantitative research method, conducted through a structured online survey for the purpose of data collection. The outcomes of this process demonstrate that the DSS of this research is a useful tool in assisting SMEs in deciding whether or not to adopt BIM in their organisations.

Aside from a variety of positive comments collected from validators, the researcher also received other constructive feedback, which will be discussed in the concluding chapter.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

8.1. INTRODUCTION

The principle aim of this research has been to develop a decision support system (DSS) to help SMEs to anticipate the risks and rewards of adopting BIM for construction project delivery. This has been achieved by fulfilment of the seven objectives set out in Chapter 1. In Chapter 1 a problem statement was made, gaps in knowledge in the field of study were stated, the aims of the research were identified, and the objectives that needed to be achieved in order to fulfil the aim of this research were established. In addition, a research structure and thesis structure were also built up, to provide an overall view of the research process.

Chapter 2 presented a critical review of BIM and its adoption both nationally and internationally, with the aim of providing a holistic picture of BIM as well as of the risks and rewards of BIM adoption. In Chapter 3, the context of SMEs, and of BIM adoption in this sector of the UK construction industry, were investigated. In Chapter 4, key factors that affect SMEs in adopting BIM were identified, and a conceptual framework was developed to assist in the analysis of the risks and rewards for UK SMEs of adopting BIM. The analytical methodology used in this framework to decide between alternatives was also indicated in this chapter.

Chapter 5, concerned with the methodology of this present study, presented the research design as well as the methods used to collect data on the processes of Tool validation and DSS validation. Chapter 6 presented the findings of the framework validation and a discussion of it. Chapter 7 went on to describe how the DSS was designed and to discuss how useful it was found to be – its potential usefulness being confirmed by a validation process, the outcomes of which implementation were presented in section 7.7.2.

The final chapter, Chapter 8, summarises the key findings of the research, considers research limitations, and makes recommendations for future research.

8.2. CONCLUSION

In order to achieve the aim of this research, which has been to develop a decision support system (DSS) to help SMEs to anticipate the risks and rewards of adopting BIM for construction project delivery, a set of five objectives was established and their pursuance planned carefully. The fulfilment of objectives in this study are illustrated through the key findings presented in the following sections

8.2.1. Conclusion as to the fulfilment of Objective 1

The first objective of this research has been to critically review the challenges and issues related to adopting BIM in project delivery. In this regard, examination reveals that the concept of BIM was introduced early in the 1970s as a result of the appearance of computer software products to assist modelling for buildings. Thanks to wide-ranging development of the capabilities of BIM, it can be defined in a number of ways, for example as a process, a revolution in technologies, a technological and organisational solution, a new way of working, or a new way of deploying buildings. The extremely powerful capabilities of BIM have been verified through its application in the effective deployment of many different kinds of projects across the world. Recognising the huge benefits of BIM in the construction industry, governments across the world have set up plans to adopt BIM in project delivery. Moreover, BIM has gradually become a required method, replacing traditional ways of conducting construction projects, and aiming to reduce construction costs and project delivery times, and improve project quality. In the UK, a mandate to achieve BIM level 2, with a cost reduction target of 20%, was published in 2011. The intention is that from April 2016 onwards, no organisations that are not adopting BIM will be able to participate in public projects.

Investigation of BIM also indicates that together with the enormous number of benefits that BIM is able to offer project participants, the risks associated with adopting BIM to deliver construction projects also need to be taken into account in any comprehensive perspective of BIM in connection with innovation in the construction industry. These risks or disadvantages are perceived to be barriers, which result in a low rate of adoption of BIM amongst organisations.

Thus the fulfilment of this objective has generated a holistic review of BIM and created a fundamental foundation for the accomplishment of the other objectives in this research.

8.2.2. Conclusion as to the fulfilment of Objective 2

The second objective of this research has been to analytically examine SMEs BIM adoption in the UK construction industry, to determine the necessity of developing the DSS. The outcomes of investigation with regard to this objective indicate that AECs (national Architecture, Engineering and Construction sectors) play a significant role in national economic development worldwide, and the UK's AEC is no exception. The activities and output of a nation's AEC have been found to have a strong relationship with GDP in both developed and developing countries. However, the UK's AEC has experienced difficult periods in the past, the main reason for this weakness being fragmentation among sectors within it. Recognising the important role of the AEC in the development of the national economy, in recent years the UK government has established strategies to improve this sector through the adoption of new technology aiming to reduce project costs, and improve working cooperation and coordination. Typically, since April 2016 BIM adoption has become a priority for companies wishing to participate in public projects: future bidders on public building projects will be required to use BIM level 2. Moreover, this trend is likely also to affect privately procured building projects. Consequently, recent reports reveal that the use of BIM in the UK construction industry has increased significantly over the last few years. However, this adoption currently primarily concerns larger organisations, whereas smaller ones are still slow to embrace the new technology.

SMEs have lagged behind and felt ignored by policy makers, in the face of a lack of policy initiatives to support them. Efforts to support BIM adoption for project delivery have been made, including the development of BIM support groups, frameworks, standards and protocols. Nevertheless, these efforts have so far had little concern for SMEs and their adoption of BIM. Guidance and frameworks to assist SMEs in making informed decisions regarding BIM adoption are currently lacking. As a result, SMEs have not been able fully to recognise either the benefits or the risks of using BIM in project delivery. It has emerged that SMEs are pessimistic about BIM, feeling that it discriminates against small independent construction practices. The findings relating to this objective once again verifies the necessity of developing a DSS to help SMEs to foresee the risks and rewards of adopting

BIM to deliver construction projects. The DSS of this present study will, it is hoped, help to provide SMEs with the necessary BIM knowledge to enable them to make informed decisions as to whether or not to adopt BIM in their organisations.

8.2.3. Conclusion as to the fulfilment of Objective 3

The third objective of this research has been to develop and validate the conceptual framework to guide the design of the DSS. The fulfilment of this objective are summarised as follows:

Step 1: Identify key factors to be used to develop the conceptual framework

In order to achieve this target, a two-step approach to the selection of relevant articles for inclusion in the study was adopted. For the first step, it was decided to screen the existing literature to identify sources developing methodologies for frameworks for BIM adoption. A total of 490 articles were identified through an online database search. Articles not meeting the objective of the research were eliminated. Those meeting the inclusion criteria were retrieved in full, then extracted and critically evaluated, in order to garner the relevant data therein.

As a result of this process, nineteen articles were identified. A systematic review of these studies identified four key factors, and within them eleven sub-factors, affecting SMEs with regard to BIM adoption:

- Involvement phase: this factor corresponds to the stage at which SMEs can maximise the benefits and minimise the risks when adopting BIM to deliver projects. It includes the design stage, the construction stage, and the operation stage.
- Project value: this factor refers to the budgets of projects in which SMEs typically participate. It ranges from less than £5m for small projects, through £5m–£50m for medium projects, to more than £50m for large projects.
- Source of funding: this factor relates to whether a project is sourced from the public sector or the private sector.

- Procurement route: this factor can be defined as the process whereby clients make decisions about how they will build. Each procurement route has its own characteristics, developed to suit different kinds and sizes of project. In the context of this research, this factor is subdivided into three methods or routes: the traditional procurement method, most suited for delivering small sized projects; design and build, typically used for projects of medium size; and integrated project delivery (IPD), for large and complex projects.

Step 2: Develop the conceptual framework which would guide the design of the DSS.

The conceptual framework was designed purposing to establish a fundamental structure for the development of the DSS. The accomplishment of this step is key, as it serves to fill one of the gaps in knowledge stated in Chapter 1, namely the lack of frameworks to help SMEs to foresee the risks and rewards of adopting BIM to deliver construction projects. However, the true value and comprehensiveness of this conceptual framework cannot be fully assessed until its validation process has been recorded completely.

Step 3: Validate the conceptual framework

This process was conducted by means of an assessment of framework criteria by a representative sample of SMEs. An online structured questionnaire survey was designed and sent to 960 BIM users across the UK, via the Qualtrics online survey platform. As the results recorded, 115 participants responded positively; however, only 93 participants completed all the questions in the survey, that is to say 96.8% of the target response rate of 96 responses.

This step was fulfilled by the results of the framework validation process. The validation of the framework revealed that of the four key criteria of the conceptual framework (Involvement Phase, Project Value, Source of Funding, and Procurement Route), Involvement Phase was the most important factor affecting SMEs when adopting BIM to deliver construction projects.

In addition, of the eleven criteria subsumed under the four key factors of the framework, evaluators identified the four most significant factors (criteria) in helping SMEs to maximise the benefits and minimise the risks in adopting BIM to deliver construction projects. These were:

- (1) The most important phase in which to participate in BIM projects is the design phase;
- (2) BIM is seen as beneficial or otherwise regardless of project value;
- (3) Private clients remain the main sector to which SMEs need to pay attention when conducting BIM projects;
- (4) Comparing procurement routes, BIM is seen to be of least benefit in the traditional procurement route. This finding is one to which SMEs need to pay attention. The best procurement method for BIM was found to be IPD. Therefore, the risks of using BIM to conduct construction projects under the traditional procurement method may be too great, and the rewards questionable. SMEs need to carefully consider alternative procurement routes before investing in BIM for their organisation.

The fulfilment of Objective 3 provides SMEs with informative intelligence to assist them in assessing the risks and rewards of adopting BIM to deliver construction projects. This intelligence includes indication of the best and the worst scenarios to which SMEs need to pay attention when adopting BIM. In addition, the achievement of this objective is significant in its confirmation of the value of the conceptual framework, and in its shaping of both the design and the performance of the DSS.

8.2.4. Conclusion as to the fulfilment of Objective 4

The fourth objective of the research has been to develop and validate a web-based DSS, based on the outcome of the framework validation. The DSS of this study was developed based on software platforms: PHP, HTML, and CSS, together with MySQL database management. To achieve the aim of the research, the DSS was developed as an online tool and implemented via the accessible link <http://bimbroker.com>; the purpose of this being to increase its accessibility as well as boost its dissemination, not only in the UK but also to SMEs across the world.

Similar to the conceptual framework, the DSS of this research was also validated after the design was completed. The aim of this step is firstly to evaluate the extent to which the DSS is beneficial in assisting SMEs to decide whether or not to adopt BIM to deliver construction

projects; and secondly to confirm that the DSS has been built robustly and appropriately for acceptance by its end users, as is the intention of the research.

The fulfilment of this objective was recorded in the outcomes of an online structured survey circulated among members of CNBR and LinkedIn groups working in the construction industry across the world.

In responding to the invitation to be involved in the survey, fifty-five responses were received. However, only 50 respondents completed all the questions. Of these 50, all work in the construction industry in clearly defined professions: 62% of them are BIM SMEs users, while 38% are BIM SMEs non-users.

Almost all of these validators reported that they had gained a good impression of the GUI and the ease of use of the DSS. In particular, the level and quality of information and knowledge provided by the DSS attracted the positive attention of the evaluators. The positive effects of the DSS on decisions regarding the adoption or otherwise of BIM in project delivery were confirmed. It is also hoped that the DSS may grow in popularity, with 78% of evaluators promising to circulate it to their colleagues. In addition, the usefulness of the DSS was determined by non-BIM SMEs although this group occupies only 38% of total validators.

8.2.5. Conclusion regarding research question and proposition

This study aimed to assist SMEs to anticipate risks and rewards of adopting BIM to deliver construction projects, which in turn can help the uptake of BIM. The central research question is to determine *What are the factors that enable SMEs to maximise the benefits and minimise the risks associated with BIM adoption?*

To address this question, an in-depth analysis of existing and emerging literature associated with the factors that affect SMEs in adopting BIM to deliver construction projects was undertaken. In addition, appropriated research methods were also adopted to ensure the valid of research findings. In this study, eleven key factors which enable SMEs to maximise the benefits and minimise the risks associated with BIM adoption. They are grouped into four main groups as follows:

- Involvement phase, which includes design stage, construction stage, and operation stage.

- Project value, which consists of projects less than £5 million, between £5 million and £50 million, and greater than £50 million.
- Source of funding, which is concerned with projects funded by either public or private clients.
- Procurement route, which deals with traditional method, two-stage design and build, and integrated project delivery.

Based on the findings of this research, design stage, projects valued between £5 million and £50 million, projects funded by private sectors, and integrated project delivery procurement are the most important factors that enable SMEs to maximise the benefits and minimise the risks when adoption BIM to deliver construction projects.

Regarding on the proposition of the study, which is “*an improved understanding of risks and rewards associated with BIM to deliver construction projects among SMEs could result in better decision-making regarding BIM adoption amongst SMEs*”, the results of the DSS validation of the study confirmed that by providing a comprehensive list of factors affecting SMEs adoption of BIM combined with a user-friendly GUI, a good ease of use, a high quality information, the DSS could assist decision-makers to make an informed decision and broker the risks and rewards associated with BIM adoption.

The next section of this chapter presents an overall conclusion to this present research study.

8.2.6. Overall conclusion

The aim of this research has been to develop a DSS to assist SMEs to broker the risks and rewards of BIM adoption in the UK. By investigating the large quantity of existing previous research on BIM, as well as the context of BIM adoption amongst SMEs in the UK, it has been possible to successfully develop a DSS which fulfils the aim of the study. Targeted at the earliest stage of the research, five objectives were established, requiring the author to achieve each in order to solve the problems stated in this research.

The author's commission has been completed, and all objectives have been achieved. More importantly, through its validation process a DSS has been developed that has attracted positive attention from users in the construction industry. The DSS promises to be a beneficial tool, helping SMEs not only in the UK but also in other countries to anticipate the risks and rewards of using BIM in construction project delivery. It is hoped that the rate of BIM adoption among SMEs may therefore increase, which will assist governments in achieving their aims in enhancing BIM adoption in construction sectors.

8.3. CONTRIBUTION TO KNOWLEDGE

BIM adoption amongst larger construction firms and innovators seems to be on the increase. However, there is evidence to suggest that small and medium sized enterprises (SMEs) in the UK are currently lagging behind and are losing out in winning publicly funded projects. Guidance and frameworks to assist SMEs to make informed decisions about BIM adoption are currently lacking. Therefore, it is necessary to develop a DSS to assist SMEs to anticipate the risks and rewards of adopting BIM for project delivery. The contribution of this research to knowledge is as follows:

- This study has provided a deeper understanding of the root causes of the lack of adoption of BIM by SMES.
- The research has identified key factors that affect SMEs when adopting BIM to deliver construction projects. They are involvement phase, project value, source of funding, and procurement route.
- One of the key achievement of this study is bridging a significant knowledge gap, namely a lack of frameworks and tools to help SMEs to broker the risks and rewards of BIM adoption to deliver construction projects.
- The research has also developed a comprehensive DSS, which enables SMEs to anticipate risks and rewards when adopting BIM to deliver construction projects.
- This research has contributed to enriching existing state of the art in this field, in terms of tools, frameworks and guidelines developed to support BIM adoption across the world.
- This study has also provided a guidance and support for research in terms of developing tools and frameworks for BIM adoption by SMEs.
- The outcomes this study have clear validity, both empirical and practical. Firstly, the DSS has been validated, and judged to be a useful tool in deciding whether or not to use BIM to deliver construction projects. Secondly, it is hoped that the DSS may become a popular practical tool amongst SMEs, and thus assist in enhancing BIM adoption amongst SMEs, not only in the UK but also in other countries all over the world.

- Two research papers have been published, one a conference paper and a journal paper. This represents a meaningful contribution to knowledge of BIM among SMEs, and enrichments to existing body of knowledge related to BIM. The bibliographical details of these two papers are presented in the Section entitled **List of Publications**.

The next section of this chapter serves to present the limitations of this study.

8.4. RESEARCH LIMITATIONS

As other research studies, although this research has reached its aim, there were some unavoidable limitations that needed to be considered.

- Due to the nature of this research, data collection method used in this study is mono-mothed and conducted through a structured online survey. The outcomes of findings may be changed in the event of using other data collecting methods.
- As indicated in literature, the construction industry in the UK is complex and multi-faceted. Perspectives on BIM in the AEC are also various. Thus, the findings of research may be different in case of using different samples.
- Risks and rewards associated with adopting BIM to deliver construction projects are changed overtime. It also may be various and differ from different geographical locations, policies, and cultures etc., Therefore, key factors in the framework as well risk and reward profiles may be differ and need to be updated regularly. Auto-updated functionality of the DSS needs to be considered in future work.
- Although the DSS was validated carefully and got positive outcomes, there are some constructive comments that needed to be considered to improve the tool. Despite some of them were fixed, other comments which are out of the boundary of the research will be taken into consideration in future work and updated in new version of the DSS.

8.5. RECOMMENDATIONS AND FUTURE WORK

Based on the findings and conclusions of the research, the following recommendations have been proposed.

8.5.1. Recommendations for industry

Based on the research findings, the following recommendations are made for industry:

- The most significant phase to participate in BIM projects is the design phase. This stage is identified as the essential stage in which all the key decisions are taken. Early involvement in BIM projects is critical to maximise the rewards and minimise the risks. Stakeholders must use the opportunity to influence key decisions that have significant impact on projects during construction, and maintenance/operations.
- Regardless of project value, BIM is seen as beneficial in any case. Although projects valued between £5 million and £50 million seem the best choice for optimum BIM benefits, the gap between this type of project compared to other groups is very small. This finding is meaningful in encouraging and enhancing organisations working on different types of projects to invest in BIM in their organisations.
- Private clients remain the main sector that SMEs need to pay attention to when conducting BIM projects. The traditional close relationship between SMEs and private clients is changing. This is mainly because the demand from private clients in BIM implementation has increased in recent years, whereas SMEs are still slow in investing in BIM. Therefore, over-reliance on private sector works is not a viable option.
- SMEs should pay particular attention where traditional procurement is used, as the most popular method of deploying BIM projects. The study shows that this kind of method is the least beneficial for BIM compared to its counterparts. The highest ranked method is the integrated project delivery procurement route. Therefore, the risks and rewards of using BIM to conduct construction projects under the traditional procurement method may be

questionable. SMEs need to carefully consider alternative procurement routes before investing in BIM for their organisation.

The DSS developed as a result of this research is a useful tool in assisting SMEs to broker risks and rewards of adopting BIM to deliver construction projects.

8.5.2. Recommendations for future works

Although this research has successfully achieved its aim, the research findings and limitations mentioned in the previous section point to certain areas for future work in this domain, as outlined below:

- Use of alternative data collection methods to investigate how different the findings are;
- Development of the DSS as an open system, or forum, where users can:
 - o Input their own criteria, ones that they think may affect their organisations when adopting BIM to deliver construction projects;
 - o Input their own risks and rewards associated with the criteria that they have input or modified;
 - o Modify and/or update criteria, risks, and rewards, and then rank them according to their likelihood or otherwise of affecting BIM adoption decisions;
 - o Use an auto-updating functionality together with a VAHP analysis method to calculate the weights of criteria, risks and rewards, and from this extract reports based on the new information input by users;
- Activation of a user account function, such that individuals wishing to use the DSS need to register for an account. This functionality would assist administratively, in managing the accessibility of the DSS;
- Allowing users to choose appropriate positions on the tool in which to place the logos or banners of their own organisations, for advertising purposes, and a purchase functionality is also provided in this version of the tool.

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APPENDIX I: FRAMEWORK VALIDATION SURVEY QUESTIONNAIRE



A Web-based Decision Support System to assist Small and Medium Enterprises to broker risks and rewards for Building Information Modelling adoption.

As a part of my PhD research, this survey aims to collect data for validating the criteria of the framework I have developed to help Small and Medium Enterprises (SMEs) to foresee risks and opportunities when adopting Building Information Modelling (BIM) for construction project delivery. The proposed Decision Support System (DSS) assists SMEs in making a properly informed decision about whether or not use BIM to deliver building projects.

I am seeking helps from: SMEs (both BIM and non-BIM SMEs); BIM experts; and those who have experiences in construction industry; to help me to rank risks and rewards related to adopting BIM to deliver construction projects

Please be aware that all data collected within this survey is completely confidential and anonymous, and used for this research only.

I would appreciate it if you could spare 15 minutes of your precious time to answer my questionnaire in relation to your understanding of BIM and how it is affecting SMEs in construction project delivery.

Your acceptance to participate in this survey is agreed on your completion and return of the questionnaire.

Please feel free to forward this questionnaire to any other relevant persons within your organisation or professional network who might be interested in participating in this research.

If you have any further questions about this survey or the research please do not hesitate to contact me via email address: thanh2.lam@live.uwe.ac.uk



I understand the information I give will remain anonymous and confidential. I understand that participant is voluntary and that I may withdraw at any time without giving any reason for doing so

Yes

No



I have been briefed about this research and its purpose and agree to participate

Yes

No

Q1 How best would you describe your profession?



Q2 How many years of experience do you have in this profession?



Q3 How many years of experience do you have in Building Information Modeling?



Q4 How best would you describe your type of SME? Please specify your choice.



Financial: Banks, Lenders, Insurers, Accounts etc.



Legal: Lawyers, Claim Consultants, Adjudicators, Arbitrators etc.

Professionals: Architects, Engineers, Energy Consultants, IT Consultants, Project Managers, Specialist Consultants, Surveyors, Project Managers, Contract Administrators, etc.

Construction: Principal Contractors, Sub-contractors, Health and Safety Specialists, Specialist Engineering Contractors, Construction Support Services, etc.

FM - Facilities Management - Operators, Surveyors, IT, Users etc.

Supply Chain - Manufacturers, Suppliers, Hire Services

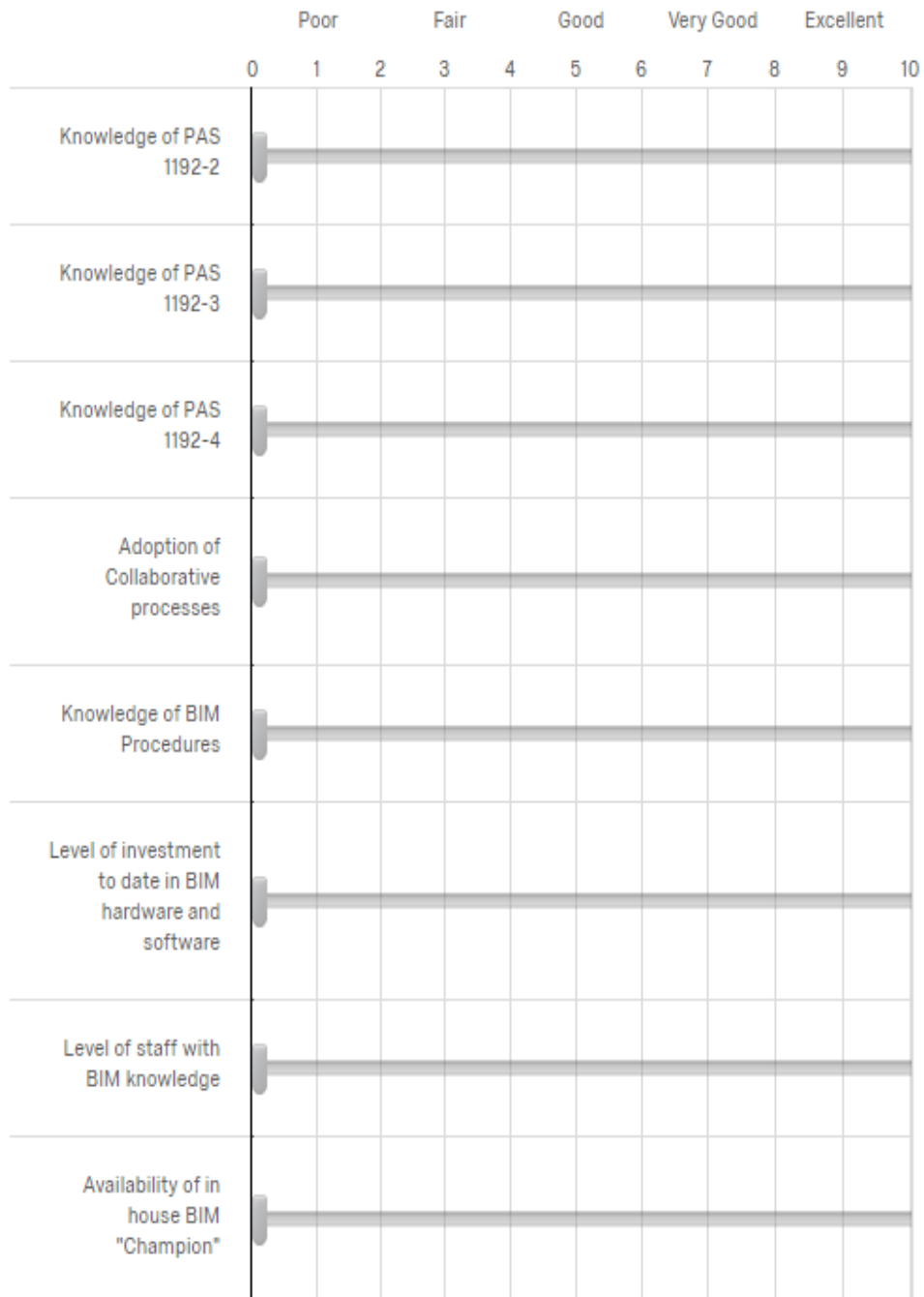
Others

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Q5 Please specify the size of your organisation

- Micro: 1 - 10 employees
- Small: 11 - 49 employees
- Medium: 50 - 250 employees
- Large: More than 250 employees

Q6 Please move the following indicators to the appropriate position where you would expect them to be for an organisation claiming **BIM readiness at level 2**




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- Q7 Please rank (from the most to the least likely) the following **Rewards** for a "BIM ready" SME taking into account their likelihood of occurrence and level of impact
- 

- | | |
|--|---|
| Better customer services | 1 |
| More business in future | 2 |
| Improved cooperation and coordination in project delivery | 3 |
| More opportunities to compete with larger organisations | 4 |
| Improved communication amongst parties and relationship with upstream and downstream | 5 |
-
- Q8 Please rank (from the most to the least likely) the following **Risks** for a "non BIM ready" SME taking into account their likelihood of occurrence and level of impact
- 

- | | |
|--|---|
| Unable to bid for publicly funded projects from 2016 | 1 |
| Risk of losing business with private clients | 2 |
| Lagging behind competitors in terms of BIM readiness | 3 |
| Loss of visibility in the market place due to lack of professional working style | 4 |
| Disruption to working patterns | 5 |
-
- Q9 Please rank (from the most to the least likely) the following **Risks** for a "BIM ready" SME taking into account their likelihood of occurrence and level of impact
- 

- | | |
|-------------------------------|---|
| Legal risks | 1 |
| Technical risks | 2 |
| Contractual document risks | 3 |
| Managerial and cultural risks | 4 |
| Environmental risks | 5 |

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Q10 Please **rank** the following **stages of involvement** in project delivery from the most to the least likely to allow an SME to maximise the benefits and minimise the risks when adopting BIM

	Construction stage	1
	Operation/maintenance stage	2
	Design stage	3



Q11 Please rank (from the most to the least likely) the following **Rewards** associated with **Design stage** in project delivery in terms of their likelihood of occurrence and level of impact on an SME

		
	Reduction of time required to carry out design activities	1
	Improved predictability of construction and performance issues	2
	Increased accuracy and consistency from early stages and at any stage of the design production phase	3
	Significant improvement of the ability to control cost of design changes	4
	Collaboration between the architect, contractor, and engineers allows for better decision making that helps to improve quality and mitigate risk	5



Q12 Please rank (from the most to the least likely) the following **Risks** associated with **Design stage** in project delivery in terms of their likelihood of occurrence and level of impact on an SME

	Unclear protocol for data sharing upstream and downstream to various parties	1
	Failure to detect clashes	2
	Risks associated with the inaccuracy of cost estimates from model quantities	3
	Delay in model submission and approval	4
	Model not updated along with progress reviews	5



Q13 Please rank (from the most to the least likely) the following **Rewards** associated with **Construction stage** in project delivery in terms of their likelihood of occurrence and level of impact on an SME

	Early planning allows team members to use materials more efficiently, creating less waste	1
	Change orders are minimised	2
	Construction can be completed on schedule and on budget	3
	Fully coordinated design helps to reduce potential risk on site	4
	Reduced uncertainty over construction	5

Q14 Please rank (from the most to the least likely) the following **Risks** associated with **Construction stage** in project delivery in terms of their likelihood of occurrence and level of impact on an SME

	Inaccurate onsite construction information due to failure to detect errors in the model in design stage	1
	Failures in opening model due to different software platforms	2
	Ineffective and incompatible transition between design and constructability	3
	Duplication of content in the model affecting construction pricing	4
	Failure of updating the designed model to incorporate the BIM changes made during construction	5

Q15 Please rank (from the most to the least likely) the following **Rewards** associated with **Operation/maintenance stage** in project delivery in terms of their likelihood of occurrence and level of impact on an SME

	Better operations and facilities management	1
	As-built spaces and systems utilized as a starting point for maintenance and operations as well as a database for possible future retrofits	2
	Linking of building model to energy analysis to improve energy efficiency and sustainability	3
	BIM model helps organisations to better manage conditions, history and specifications of facilities and equipment	4
	Using BIM helps organisations to schedule all maintenance management activities in both long-term and short-term	5

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Q16 Please rank (from the most to the least likely) the following **Risks** associated with **Operation/maintenance stage** in project delivery in terms of their likelihood of occurrence and level of impact on an SME



Operation cost overrun	1
Operational revenues below expectation	2
Low operating productivity	3
Maintenance costs higher than expected	4
Maintenance more frequent than expected	5

Q17 Please rank the following sizes of project from the most to the least likely to allow an SME to maximise the benefits and minimise the risks when adopting BIM



Less than £5 million	1
Between £5 million and £50 million	2
Greater than £50 millions	3



Q18 Please rank (from the most to the least likely) the following **Rewards** associated with projects **Less than £5 millions** in terms of their likelihood of occurrence and level of impact on an SME





More opportunities to offer greater value	1
Easier and faster to turn from CAD to BIM	2
Quicker delivery	3
Greater profits	4
Fewer employees	5

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Q19 Please rank (from the most to the least likely) the following **Risks** associated with projects **Less than £5 million** in terms of their likelihood of occurrence and level of impact on an SME

	Risk of conducting remote location projects	1
	Not familiar with working on tight schedules	2
	Difficult to execute compared to large projects	3
	Lack of demand from clients	4

Q20 Please rank (from the most to the least likely) the following **Rewards** associated with projects **Between £5 million and £50 million** in terms of their likelihood of occurrence and level of impact on an SME



	Waste reduction	1
	Lower than usual cost growth in packages for service installation	2
	Saving in spending on administrative and coordinating staff time	3
	Faster return on investment	4

Q21 Please rank (from the most to the least likely) the following **Risks** associated with projects **Between £5 million and £50 million** in terms of their likelihood of occurrence and level of impact on an SME



	Complex and difficult to manage	1
	High initial cost for investment	2
	Failures in communication between parties	3
	Lack of trust amongst parties	4
	Project can be delayed due to different BIM competencies between parties	5

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Q22 Please rank (from the most to the least likely) the following **Rewards** associated with projects **Greater than £50 million** in terms of their likelihood of occurrence and level of impact on an SME

- | | | |
|---|---|---|
|  | Significant waste reduction | 1 |
|  | Significantly lower than usual cost growth in packages for service installation | 2 |
| | Significant saving in spending on administrative and coordinating staff time | 3 |
| | Significantly higher return on investment | 4 |
-

Q23 Please rank (from the most to the least likely) the following **Risks** associated with projects **Greater than £50 million** in terms of their likelihood of occurrence and level of impact on an SME



- | | | |
|---|--|---|
|  | More complex and difficult to manage | 1 |
|  | High initial cost for investment | 2 |
| | Failures in communication between parties | 3 |
| | Lack of trust amongst parties | 4 |
| | Project can be delayed due to different BIM competencies between parties | 5 |
-
-

Q24 Please rank the following **sources of funding for project delivery** from the most to the least likely to allow an SME to **maximise the benefits** and **minimise the risks** when adopting BIM



- | | | |
|---|------------------------|---|
|  | Private funded project | 1 |
|  | Public funded project | 2 |

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Q25 Please rank (from the most to the least likely) the following **Rewards** associated with projects **Funded by public sector** in terms of their likelihood of occurrence and level of impact on an SME

	More opportunities to win public projects	1
	Closer the relationship with contractors and suppliers	2
	Offered repeat business	3
	Improved satisfaction of public client's requirements	4
	More business due to company's visibility in market place enhanced	5


Q26 Please rank (from the most to the least likely) the following **Risks** associated with projects **Funded by public sector** in terms of their likelihood of occurrence and level of impact on an SME


	Risk of losing public contracts due to not satisfying requirements of clients	1
	Risk of disrupting the relationship with contractors and suppliers due to differing BIM knowledge and BIM deliverable	2
	Lack of legal framework on using BIM	3
	Lack of BIM experience in public project delivery	4
	Lack of knowledge about BIM documents	5

Q27 Please rank (from the most to the least likely) the following **Rewards** associated with projects **Funded by private sector** in terms of their likelihood of occurrence and level of impact on an SME

	More opportunities to win more business due to the company's visibility in market place enhanced	1
	More opportunities to win larger projects	2
	More opportunities to participate in public projects	3
	More opportunities to be offered repeat business	4
	Improved customer's satisfaction	5

Q28 Please rank (from the most to the least likely) the following **Risks** associated with projects **Funded by private sector** in terms of their likelihood of occurrence and level of impact on an SME

-  Risk of losing private contracts due to the increased the requirements of client on BIM 1

 -  Lack of opportunities to win larger projects due to low BIM competency 2

 - Lack of winning public projects due to lack of experience in these kinds of projects 3

 - Lack of BIM experience in project delivery 4

 - High initial investment 5
-


Q29 Please rank the following procurement routes from the most to the least likely to allow an SME to maximise the benefits and minimise the risks when adopting BIM


-  One-stage traditional procurement 1

 -  Two-stage design and build 2

 - Highly collaborative procurement 3
-

Q30 Please rank (from the most to the least likely) the following **Rewards** associated with projects adopts **Highly collaborative procurement routes (Framework, partnering, IPD,..)** in terms of their likelihood of occurrence and level of impact on an SME

-  Reduction in dispute 1

-  Sharing risks and rewards 2

- Improved quality and safety 3

- Improvement in design and construction times and certainty of completion 4

- Better working environment 5

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Q31 Please rank (from the most to the least likely) the following **Risks** associated with projects adopts **Highly collaborative procurement routes (Framework, partnering, IPD,..)** in terms of their likelihood of occurrence and level of impact on an SME



- | | |
|--|---|
| Risks of losing contracts due to not satisfying the requirements to deliver BIM project. | 1 |
| Risk of interrupted communication between parties | 2 |
| Difficult to set a lifecycle cost benchmark against traditional arrangements | 3 |
| Risk of single source of employment (too dependent on client) | 4 |
| Technical risk, due to engineering and design failures | 5 |

Q32 Please rank (from the most to the least likely) the following **Rewards** associated with projects adopt **Two-stage design and build procurement** in terms of their likelihood of occurrence and level of impact on an SME



- | | |
|---|---|
| Reduce the overall project cost | 1 |
| Reduce the overall project completion time | 2 |
| Improve the degree of build ability | 3 |
| Reduce claim due to separate design and construction and high collaboration among parties | 4 |
| Better project quality | 5 |



Q33 Please rank (from the most to the least likely) the following **Risk** associated with projects adopts **Two-stage design and build procurement** in terms of their likelihood of occurrence and level of impact on an SME





- | | |
|---|---|
| Greater potential for disputes among parties | 1 |
| Risk of creating significant cost management | 2 |
| Difficulty in comparison of tenders | 3 |
| Risk of difference in terms of BIM knowledge and BIM capacity among parties | 4 |
| Risk of disconnect between project stakeholders in the design and construction process and occupiers utilising the data from these models | 5 |

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Q34 Please rank (from the most to the least likely) the following **Rewards** associated with projects adopts **One-stage traditional procurement** in terms of their likelihood of occurrence and level of impact on an SME

	Greater cost certainty	1
	Low preparation cost	2
	Improved designed changes and better cost management process	3
	Higher tender quality	4
	Shorten lengthy time from inception to start on site	5

Q35 Please rank (from the most to the least likely) the following **Risks** associated with projects adopts **One-stage traditional procurement** in terms of their likelihood of occurrence and level of impact on an SME


	Disputation among parties due to the fragmentation between design and construction	1
	Project delayed in case of failure of clash detection	2
	Lack of ability to negotiate prices	3
	Lack of ability to apply in large project	4
	Risk of unskilled consultants	5

Thank you very much for your participation in this research. If you need further information regarding this research, please do not hesitate to contact me at the following email: thanh2.lam@live.uwe.ac.uk



Should you require to receive the result of this research, please provide your contact email in the box below.

APPENDIX II: DSS VALIDATION SURVEY QUESTIONNAIRE

Q1 

A Web-based Decision Support System Tool to assist Small and Medium Enterprises to broker risks and rewards for Building Information Modelling adoption.

As a part of my PhD research, this feedback form aims to collect data for validating the Tool I have developed to help Small and Medium Enterprises (SMEs) to foresee risks and rewards when adopting Building Information Modelling (BIM) for construction project delivery.

The Tool is designed based on the data collected through a survey of 93 respondents across the UK.
I am seeking help from SMEs. Please use Chrome or Internet Explore browser to access the Tool via:

- <http://www.bimbroker.com>
- User name: admin
- Password: 123



Please be aware that all data collected within this survey is completely confidential and anonymous, and used for this research only.

I would appreciate it if you could spare 5 minutes of your precious time to review my Tool and answer the following evaluation questionnaires to help further improvement to be made.

The work being undertaken will investigate if the Tool could become a useful decision support system to facilitate BIM adoption among SMEs across the UK.

Any advice or constructive criticism would be highly appreciated and valuable for the research.

Please feel free to contact me via email address thanh2.lam@live.uwe.ac.uk if you have any further questions about this feedback form or the research.

Q1   How best would you describe your profession (box)?

- Architect
- Engineer (civil/structure)
- Engineer (M&E)
- Engineer (other)
- QS
- Project manager
- Consultant
- Others

Q2 Please provide your area of business





Q3 Please provide the size of your organisation (number of employees)?



Less than 10



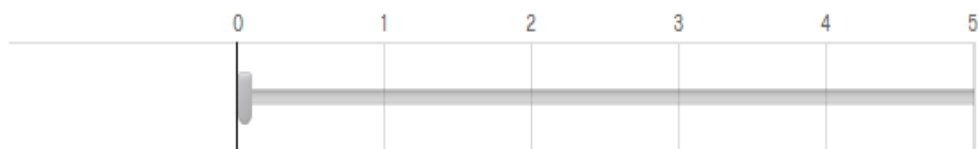
From 11 to 50

From 51 to 250

Q4 How is your first impression of the Tool in terms of graphical user interface?



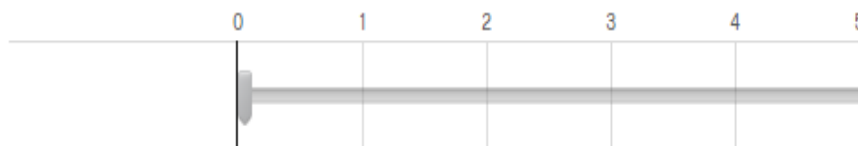
Terrible Poor Average Good Excellent



Q5 How straightforward is the tool (easy to understand)?



Extremely difficult Somewhat difficult Neither easy nor difficult Somewhat easy Extremely easy



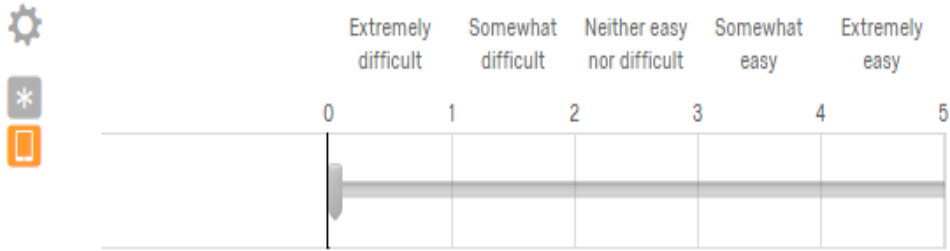
Q6 Do you find it easy to select criteria in the Tool?



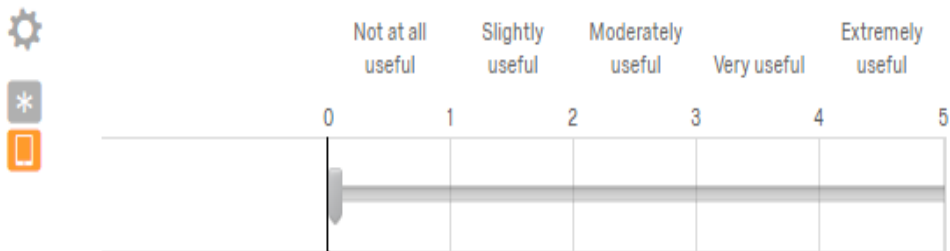
Extremely difficult Somewhat difficult Neither easy nor difficult Somewhat easy Extremely easy



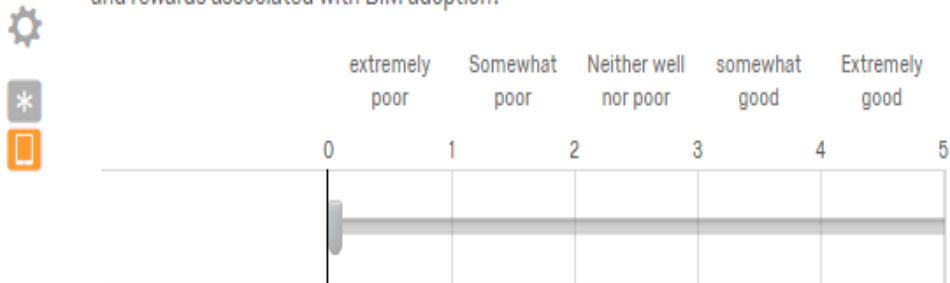
Q7 Do you find the entire process of using the Tool easy?



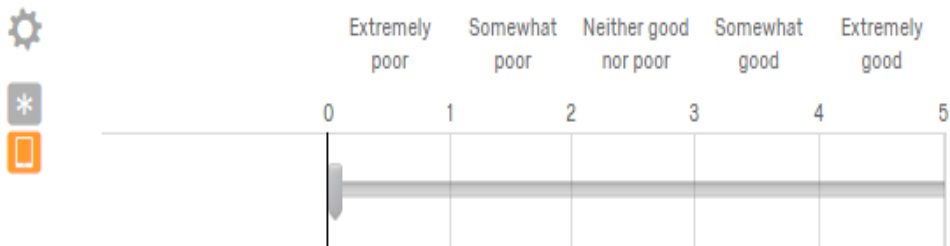
Q8 How would you rate the quality of information presented?



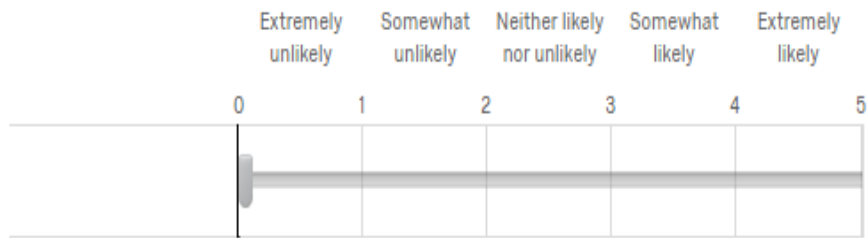
Q9 To what extent does the tool provide you with the appropriate level of information to assess the risks and rewards associated with BIM adoption?



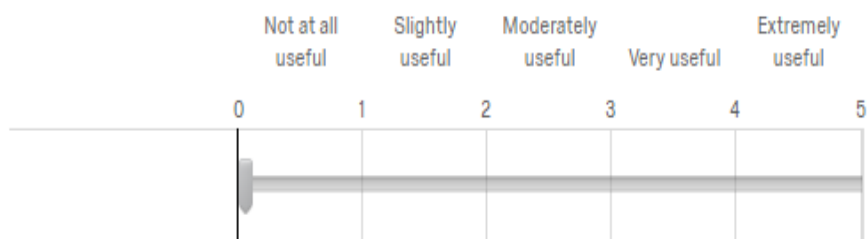
Q10 To what extent does the Tool provide you with knowledge of risks and rewards when adopting BIM to deliver construction projects?



Q11 Would the ability to personalise the risks and rewards help you to make an informed decision on BIM adoption?



Q12 To what extent has the Tool been useful in deciding whether or not to use BIM to deliver construction projects?



Q13 Will you introduce the Tool to your colleagues?

Q13

Yes



No (I do appreciate if you could give me your useful comments about this choice)



Q14 In order to improve the Tool, please provide any additional comments

Q14



Thank you very much for taking time to complete the questions.



APPENDIX III: THE ASSUMPTIONS ON BIM ADOPTION

Brief description of criteria	Assumption in using BIM
<p>You participate in BIM projects at the design stage: The design stage is considered the most important point, at which all design decisions for the projects are made. On average, this stage affects 70% of the life-cycle cost of buildings. It consists of concept design, developed design and technical design, which occur between the brief and the construction stage. Furthermore, this stage provides the best opportunity to influence the cost, time and budget of a project. Therefore, the adoption of BIM at this stage to deliver construction projects provides significant benefits to SMEs.</p>	<p>You have selected the design stage. According to the findings of this study, this is the most significant of all four stages in which to participate in BIM projects. It is the essential stage in which all the key decisions are taken. This indicates that the earlier you participate in BIM projects the greater the rewards that you are likely to gain. BIM provides an opportunity for better collaboration between architect, contractor engineers and other stakeholders in the design stage, leading to enhanced decision making, which helps to improve quality and reduce costs and time requirements of projects. In addition, BIM helps in the mitigation of risks in the subsequent stages of projects. Making consistent and accurate decisions at the early stages improves delivery efficiency in the latter stages of projects. However, there is also a likelihood of risks: risks related to BIM protocols for data sharing upstream and downstream to various parties, the risk of failure to detect clashes, and risks associated with BIM technical issues and challenges with hardware, software and infrastructure.</p>

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<p>You participate in BIM projects at the construction stage. This is the phase where contractors complete construction according to the conditions of their contracts. Work starts on site and visible progress is made. In this stage, the process of co-ordinating human resources, materials and machines is conducted. All issues in relation to health and safety, sustainability, and carbon emissions, and problems associated with such matters as changes of design, timing and waste materials, can present themselves at this stage. Therefore, it is essential to investigate the extent to which BIM could help SMEs to achieve benefits in project delivery at this stage.</p>	<p>You have selected the construction stage. According to the findings of this study, compared to the three other stages this stage is ranked second after the design stage in terms of maximizing rewards and minimizing risks. In this stage, all the conditions of the contract will come into force onsite. Processes associated with human resources, materials, machines, health and safety, sustainability, environment (carbon emissions), and such matters as changes in orders, timing, and waste materials, will be implemented. Therefore, it is important for organisations to seek solutions that will enable them to foresee the benefits and risks of participating in this stage.</p> <p>With the powerful support of BIM, fully coordinated design is enhanced. It enables your organisation to maximise its benefits and minimise its risks during the construction process. Firstly, clashes can usually be detected before construction begins, helping to reduce potential risks onsite. Secondly, early planning allows your organisation and other team members to use materials more efficiently, generating less waste. Finally, issues in relation to changing orders and uncertainty are minimised and construction can be completed on time and within budget.</p>
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	<p>However, when working on BIM projects in this stage, your organisation needs to pay attention to a certain risk with BIM of failure to detect clashes. Such failure may lead to incorrect onsite construction, project delays and/or increases in waste of materials. Also needing to be considered are risks associated with the exchange and updating of team members' files, and their uploading to the central model.</p>
<p>You participate in BIM projects at the operation and maintenance stage. In this stage, the handover of the building and the conclusion of the building contract occur, and organisations participating at this stage of a BIM project will undertake maintenance works in accordance with the schedule of services. Generally, over its whole lifecycle, the biggest costs of a project come from operation and maintenance. Therefore, to ensure that the target objectives, which are to maximise the use of the building and minimise risks as well as operational costs, are considered during this stage of project delivery, it is necessary to identify and have access to all equipment, information and maintenance history relating to the project. This becomes especially critical during an</p>	<p>You have selected the operation and maintenance stage. This stage is ranked last according to the findings of this study. Nevertheless, even used at this stage BIM provides great benefits for an organisation. By adopting BIM, your organisation can manage the operation and maintenance processes of buildings better and more effectively. Typically, BIM provides sufficient information about the building and its spaces, systems and components to enable your organisation to identify all equipment and information necessary for the processes of operation and maintenance. For example, your organisation can use as-built three-dimensional (3D) BIM models to view, search, filter, and highlight issues in the mechanical, plumbing, and electrical systems in a facility. This will help to generate lower operation and maintenance costs by taking the guesswork out of locating equipment for commissioning, repair or replacement. Thus performance in facility management can be improved.</p>

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<p>emergency or in the event of responsibility being transferred from one group of personnel to another.</p>	<p>However, in the event of BIM being incorrectly used at this stage, your organisation may face risks such as operation cost overrun, higher than expected maintenance costs, and/or operational revenues below expectations.</p>
<p>You participate in BIM projects valued at less than £5m. Given the nature of the research, all construction projects of values less than £5m are grouped together as so-called small projects. Characteristic of organisations working on this kind of project is that they are generally slower to adopt new technology. They also typically work exclusively in 2D, and have fewer staff compared to larger firms. Therefore, it is inevitable that they will lag behind their counterparts in the current highly competitive environment. With this in mind, it is necessary for SMEs involved in projects of this scale to consider adopting BIM in order to enhance their business competitiveness.</p>	<p>You have selected BIM projects valued at less than £5m. This selection is ranked last according to the findings of this study. In the context of this study, this kind of project is assumed to be a small project. Projects of this size can become more difficult to execute traditionally than larger projects, owing to tight schedules and the advent of new technology, among other issues. However, with the support of BIM, your organisation may potentially be able to obtain better value and benefit from greater efficiencies. Typically, investment in BIM will enable your organisation to increase its competencies, enabling it the better to compete with its rivals. In addition, because with BIM your organisation will be able to meet the requirements of owners or main contractors, your firm will potentially be able to take advantage of greater opportunities to participate in a wider range of projects, including larger projects. On the other hand, your organisation may have to contend with a lack of demand from clients who may not require BIM in their projects. This may lead to a need to wait longer before seeing a return on your investment. However, in the current climate of a</p>

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	<p>constantly developing construction industry, clients tend to seek solutions which can help them to execute projects more effectively; and as such the risk of lack of client requirement for BIM is not unduly problematic.</p>
<p>You participate in BIM projects valued at between £5m to £50m. Within the scope of this study, construction projects assigned to this group are referred to as medium-sized projects. Typically, in the construction industry, the supply chain consists mainly of SMEs which tend to collaborate to deliver major and complex construction projects, due to a lack of capacity or ability to conduct complex projects by themselves. Therefore, it is necessary to manage the collaborative performance of SMEs in conducting medium-sized construction projects, in order to ensure that projects are implemented successfully.</p>	<p>You have selected BIM projects within a value range of between £5m to £50m. This range of project values is ranked first according to the findings of this study. This means that in using BIM to conduct projects with values within this range, your organisation can potentially achieve the greatest benefits, in other words greater than the benefits brought by BIM for other, higher or lower project values. Typically, your organisation will have the opportunity to minimize waste and increase value through visualizing the entire building model at an early stage, which can help your organisation to avoid errors and omissions. Furthermore, within the high collaborative working environment of BIM, dramatic savings can be made in time spent on management and project performance. As a result, greater value is generated, which contributes to shortening the period before return on investment (ROI) can be seen.</p> <p>However, there are risks associated with managing large and complex projects, failures in communication and lack of trust between parties, which will be inevitable if your organisation does not have the competency to use BIM</p>

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	<p>correctly on projects of this nature. Besides, when working on this kind of project, your initial cost of investment is likely to be higher. This will depend on the current BIM competency of your organisation, and the collaborative arrangements with others that will be necessary for you to conduct large or complex projects. However, this risk can be easily mitigated, as ROI can be seen more quickly.</p>
<p>You participate in BIM projects of greater value than £50m. On the basis of the findings of this research study, this kind of project is categorised as large-sized, and is very complex due to the involvement of many parties. In general, the larger the scope of the project, the more complex the supply chain will be. This complexity may increase, as the suppliers are in turn supplied by other suppliers, and the subcontractors deal in turn with many other suppliers. Therefore, to manage a complex project effectively, it is usually broken down into smaller projects and manageable units. This breaking-down of large projects ensures that they can be completed on time and within budget, and meet the requirements of owners. It also offers qualifying SMEs (those</p>	<p>You have selected BIM projects of greater value than £50m. This kind of project is ranked second after projects valued between £5m and £50m, according to the findings of this study. Owing to the fact that many different kinds of participant become involved, project complexity has become the biggest concern of stakeholders. It is impossible to manage a complex project effectively without breaking it down into smaller, manageable units; however, traditionally this method has flaws associated with issues such as conflicts, overlaps and delays, which can affect the final outcomes of the whole project. For example, any hold-ups in materials delivery may have knock-on effects in slowing work, and if such delays are critical, the project will likely be delayed as a consequence.</p> <p>But among the many great benefits of BIM is the potential for a coordinative and collaborative working environment, in which all parties will be assigned their</p>

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<p>qualifying in terms of the project requirements) opportunities to become involved in projects of larger values than they have been accustomed to.</p>	<p>tasks in the early stages of a project, and will be able to check the progress of project implementation through the central BIM model overseen by the BIM manager. By means of such checks, all errors, omissions and risks can be identified and mitigated early. This can help parties achieve significant waste reduction across the whole project. Furthermore, working on large projects will offer SMEs opportunities to stimulate their organisations, and will ensure revenue for the development of growth strategies, up-skilling and workplace improvements.</p> <p>However, due to the high level of complexity of large projects, there is an obvious risk of failure in management in the event that BIM is used incorrectly. Failure to break large projects down into smaller units may also cost SMEs unduly large amounts of investment money. This risk undoubtedly accounts for the finding mentioned above, that large projects are ranked second after medium-sized projects.</p>
<p>You participate in public projects. This sector accounts for more than £37 billion per year, which represents 38% of all UK construction output. Clients in this sector are organisations that spend public money, such as central government, local</p>	<p>You have selected public projects. Although the UK government has stated that as of 2015, 25% of all public sector contracts should be awarded to SMEs, many SMEs are finding it increasingly difficult to win public work. They currently lag behind their competitors in the construction industry, a trend that</p>

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<p>government, housing associations and NHS trusts. They are required to follow sets of procedures and involve multiple participants, from contractors and subcontractors to project management firms and government agencies. However, although the UK government requires all public projects to be delivered to BIM level 2 by 2016, winning projects in this sector is not easy because of high levels of demand associated with economy, efficiency, quality, fairness and transparency.</p>	<p>may continue if they do not pay attention to the need for investment in new technology and reform of their organisations in order to meet with the requirements of the industry.</p> <p>By adopting BIM, all the aforementioned issues may be resolved. Typically, your organisation will have increased opportunities to win public projects and will in addition be offered repeat business. Moreover, relationships between contractors and suppliers will be closer; and satisfaction of public clients' requirements will be enhanced, as will business opportunities due to the company's visibility in the market place.</p> <p>However, alongside these benefits your organisation may also be faced with risks relating to losing out on business, or disruption of relationships with your partners, in the event that your organisation's BIM investment is insufficient or that BIM processes and procedures are not followed correctly.</p>
<p>You participate in private projects. This sector consists of private sector housing (e.g. residential, apartment, and subdivisions of development projects) and private sector commercial building (e.g. retail stores, manufacturing plants, businesses, restaurants, and warehouses). In contrast to public</p>	<p>You have selected private projects. Currently, clients in this sector are increasingly interested in using BIM to conduct their construction projects. According to the findings of this study, this is the sector that SMEs need to pay most attention to when conducting BIM projects. By using BIM to deliver construction projects, your organisation may potentially harvest a number of</p>

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<p>projects where owners have an obligation to spend the public’s money properly and wisely, following a set of rules and regulations, the private sector client, as owner of the project, is not controlled by any procurement rules as long as the process is legal and ethical, and has much more autonomy when proceeding with a project award. However, given the many and various changes within the construction industry, updating or equipping the parties involved with new technology constitutes a significant issue for both public and private sectors.</p>	<p>benefits. First of all, your organisation will potentially enjoy greater opportunities to win business due to enhancement of the company’s visibility in the market place. Furthermore, your organisation will potentially have greater opportunity to participate in larger value projects, and in projects of other values. In addition, BIM offers a good opportunity for your organisation to compete with other organisations in public project delivery. Finally, by adopting BIM your organisation can improve its levels of customer satisfaction and hence may garner repeat business.</p> <p>However, in the event of insufficient investment in BIM, your organisation may be faced with risks associated with loss of both public and private projects, lack of opportunity to participate in different kinds of projects, and higher investment costs leading to longer periods before ROI is seen.</p>
<p>You participate in projects using the traditional procurement method. The key feature of this type of procurement is the separation of design and construction. Typically, the client appoints consultants to design the project in detail, and then prepare tender documents including drawings, work schedules and bills of quantities. Constructors are then invited to submit tenders</p>	<p>You have selected the traditional procurement method for delivering BIM construction projects. According to the findings of this research, this procurement method is ranked last among the procurement routes examined. Nevertheless, with the support of BIM your organisation may potentially achieve certain rewards. Due to the fact that a building is effectively virtually constructed before the onsite phase is reached, participants are able to foresee all the key</p>

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<p>for the construction of the project. Due to the potential for legal liability, architects usually include relatively few details in their drawings or embedded language, which indicates that these drawings cannot be relied upon for dimensional accuracy. These practices often lead to disputes with contractors, as errors and omissions are detected and responsibility and extra costs reallocated.</p>	<p>components of the whole building as well as of their particular contractual spheres. As such, greater cost certainty is achieved, design change issues and design risks associated with contractor cost are minimised significantly, cost management is improved, higher tender quality is achieved, and the timescale from inception to start on site is shortened.</p> <p>However, in the event that the BIM process is not conducted correctly and effectively, fragmentation between design and construction cannot be minimised. In addition, there are several other risks to be considered, associated with distribution between parties, project delays, and failure of clash detection, unskilled consultants, and lack of the necessary competencies to participate in large projects.</p>
<p>You participate in projects using the Two-stage Design and Build procurement method. In this method, considered an improvement on the traditional method, the gap between design and construction is replaced by single-point responsibility. Typically, clients who wish to deploy a construction project will make direct contact with the contractors, and their total financial commitment will be pre-established. The contractor is then solely</p>	<p>You have selected the Two-stage Design and Build procurement method. This method is ranked second after the Integrated Project Delivery method, according to the findings of this study. This suggests that by adopting BIM to implement construction projects procured by the Design and Build method, your organisation will be able to use the BIM model to estimate the overall cost and timescale of projects earlier, and thus reduce this cost and timescale. As a result of this time saved, over the same period your organisation will be able to conduct</p>

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<p>responsible for design, construction and problem-solving during the building lifecycle. Currently, clients in both public and private sectors are demanding more from contractors, and it is therefore essential for principal contractors and sub-contractors to reform and improve their current project delivery methods in order to meet the strict requirements of fastidious clients.</p>	<p>more projects than it would with the traditional procurement method. Furthermore, cost savings can help fulfil strict cost requirements and attract the attention of clients in both public and private sectors. This will help to generate opportunities for your organisation to win more business in the future. Finally, by virtue of working with a central BIM model the collaboratively of working environments can be much improved, and as such project quality is assured, and claims and disruptions amongst parties are also minimized. However, alongside these benefits, your organisation will also be faced with risks associated with disputes among parties, difficulties in conducting projects due to differences in BIM knowledge and BIM capacity, difficulties in comparing tenders, and technical and cost management issues. Nevertheless, none of these risks are unduly problematic providing that BIM is applied correctly.</p>
<p>You participate in projects using Integrated Project Delivery (IPD) procurement. This is a new construction procurement approach that differs from the traditional and design-and-build procurement methods. IPD is defined as a project delivery approach that integrates people, systems, business structures and practices into a collaborative process. In this process, all project</p>	<p>You have selected Integrated Project Delivery (IPD) procurement. This is the best procurement route for conducting BIM construction projects. In this method, all participants including owners, designers, and contractors will be involved from the early stages of the design process and across every stage of the project lifecycle. Therefore, your organisation will potentially be able to minimize disputes among parties since all communications throughout the</p>

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<p>participants including facility managers, owners, contractors, and suppliers will become involved at the early stages of the design process. Thus by means of a process of highly collaborative and coordinated efforts, this method helps to optimize project results, increase owner value, reduce waste, and maximize efficiency throughout the design, fabrication and construction phases.</p>	<p>process will be clear. Your organisation will also be able to benefit from the sharing of risks and rewards between project participants, by virtue of the collaborative structure of project teams across contractual disciplines that IPD entails. Besides this, project design and construction times are calculated early and accurately, project quality and onsite health and safety are improved, and a better working environment is established. However, IPD is a collaborative working process and if your organisation does not fulfil certain requirements of BIM, you may lose out on business. Besides, in the event of insufficient investment in BIM, your organisation may be exposed to risks including interruptions among parties, greater difficulties in establishing a lifecycle cost than with the traditional procurement method, and technical problems associated with the BIM model.</p>
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APPENDIX IV: EXTENDED COMMENTS FROM VALIDATOR

Tool is only in English, results are too generic, but WOW, you invested some time in it.

I didn't realise the 4 options were the tool in total, I expected to click onto another page?

Implementation on Projects needs more flexibility in the tools

Remove blank links, keep constant scale, change selector wheel - it's impossible to read rotated text, shorten texts - they are quite generic and obvious, charts could be more interactive, but hey, again, great job with coding and design.

I advise to adopt BIM for all small companies

I am not sure about information presented in the tool as my organisation haven't adopted BIM yet and I do not know where should I start with BIM. Anyway, this tool provides lots of useful information about BIM.

It's a useful tool but need to be updated as risks and rewards always change overtimes. Good look on your research

This is a good website for none BIM users to check risks and rewards in order help them to better understanding about BIM in construction project delivery

It could be excellent if the tool can be developed as a forum in order help users to exchange information and share knowledge together

Clear instruction needed to be provided.

Change the colour of the page for each of the 4 options because the pie charts are so small it's difficult to see if you clicked a different option.

Make it bespoke. The data is from one source/report at a fixed point in time. Allow participants to input information about their business and allow them to compare benefits and barriers from SMEs of a similar size and function. Allow each new participant to add to the data by asking them to complete the same survey.

I do like the tool, it is useful to me

Once I discovered the drop-down selections, I got the two pie charts. I expected to be able to click on a slice to learn more about the risk. Secondly I am not sure how I am meant to use the weighting percentages. Overall not rewarding enough.

It is quite difficult using a wheel to select the answers. After the first two answers the text is upside down so very hard to read. I would propose a much simpler select.

Most training about it in universities, as well as at work.