A BIM-KNOWLEDGE (BIM-K) FRAMEWORK FOR IMPROVED DECISION-MAKING IN BUILDING CONSTRUCTION PROJECTS.

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DECLARATION

I declare that this thesis represents an original work carried out by me, except where due acknowledgement has been made in the text, and that it has not been submitted either in part or full for any other award than the degree of Doctor of Philosophy at London South Bank University (LSBU). Materials from other sources have been duly acknowledged and referenced in line with ethical standards, and the list of publications made from the thesis has been provided.

Signed: SIKIRU ABIOBUN GANIYU

Signature …………………………….

Date …………………………………

ABSTRACT

The construction industry is a knowledge-intensive industry, and knowledge has been identified as a vital resource for improving decision-making and a critical factor for increasing productivity and gaining organisational competitive advantage within the construction industry. Although, building information modelling BIM has been described as a 'shared knowledge resource for information' which forms the basis for 'reliable decisions during the lifecycle of a project', evidence from the literature indicate that current BIM implementation (BI) has not been able to effectively integrated knowledge into BIM. While BIM has significantly improved the quality of information available for use within the industry, capturing and integrating experiential knowledge (EK) into BIM implementation (BI) for improved decision-making in BIM projects is still very challenging. Knowledge management (KM) as a discipline can provide processes and tools/techniques for capturing and integrating EK into BI. Hence, leveraging KM processes and tools, this study develops a conceptual BIM-Knowledge framework for integrating EK into BI for improved decision-making in BIM projects.

The study adopts convergent parallel mixed methods based on a pragmatic paradigm, which combines both qualitative and quantitative methods concurrently in a single study. Pragmatism philosophical stance provides the flexibility required to address the complex nature of the research question, which explores how the integration of EK into BI could improve decision-making in BIM projects. The study starts with the review of extant literature to explore the key concepts in the study, culminating in developing a preliminary framework. The preliminary framework provides the basic constructs that were further explored and investigated using semi-structured interviews and questionnaire surveys. Semi-structured interviews were conducted with thirty highly experienced stakeholders within the UK construction industry to explore their lived experiences about the constructs. Transcripts of the interviews were subjected to content analysis using NVivo 11 to identify prevalent codes from the quotations. In line with the adopted research philosophy, constructs from the literature review were also put together in a questionnaire survey and distributed to industry practitioners via Bristol Online Survey (BOS) to investigate their opinions about the constructs. The questionnaire's responses were subjected to rigorous statistical and factor analyses using Statistical Package for the Social Sciences (SPSS-21).

Findings from the analysis of both semi-structured interviews and questionnaires were triangulated for corroboration. The triangulation results led to the development of a conceptual BIM-Knowledge (BIM-K) framework for integrating EK into BI for improved decision-making in BIM projects. The proposed conceptual BIM-K framework consists of three main components: the BIM-K Core, which forms the framework's nucleus; the SKI, which consists an inventory of the skills and knowledge important to key decision-makers in BI; and the Output, which is the improved decision-making in BIM projects. The BIM-K Core component consists of three layers of concentric circles: (i) the integration layer where EK from best practice, past mistakes and creative ideas from different project phases are integrated into BI, (ii) the KM process layer, where the five KM processes and their appropriate tools and techniques help facilitate the effective integration process, and (iii) the layer of impacting factors, where four categories of factors that could impact on the effectiveness of the integration process are domiciled. The conceptual BIM-K framework was partially validated with industry experts virtually to test its suitability for practical implementation. The framework will benefit all key decision-makers in BIM projects, especially the client, designers, the engineer, contractors and suchlike, by improving the quality of decisions regarding BI tasks and activities right from the pre-design phase of the project.

DEDICATION

To My Wife,

Hajia Anifat Abosede

for her prayers, patience and love

And My Children:

Anafsi-Mutmainah Oluwadamilola,

Jannatul-Firdaos Omoshalewa,

Ramadan-Dhikrullah Bankole

for their prayers, understanding and tolerance.

"He gives wisdom to whom He wills,

and whoever has been given wisdom

has certainly been given much good.

But none will grasp the Message

but men of understanding."

(Baqarah, Q2: 269)

"Say: 'Are those equal,

those who know and those who do not know?'

But only men of understanding will pay heed."

(Zumar, Q39: 9)

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LIST OF ACRONYMS

AIM - Asset Information Model
AIR - Asset Information Requirement
BEP - BIM Execution Plan
BI - BIM Implementation
BIM - Building Information Modelling
BIKM - Building Information Knowledge Modelling
BKM - BIM Knowledge Management
BREEAM - Building Research Establishment Environmental Assessment Method
CDE - Common Data Environment
CM - Change Management
CoP - Communities of Practice
CPD - Continuous Professional Development
DIKW - Data Information Knowledge Wisdom
EIR - Exchange Information Requirements
EK - Experiential Knowledge
ICT - Information Communication Technology
IPD - Integrated Project Delivery
KBT - Knowledge-based Theory
KM - Knowledge Management
KMO - Kaiser-Meyer-Olkin
KMP - Knowledge Management Process
KMS - Knowledge Management System
LEED - Leadership in Energy and Environmental Designs
OIR - Organisational Information Requirements
PIM - Project Information Model
PIR - Project Information Requirements
PoW - Plan of Work
RIBA - Royal Institute of British Architects
RQ - Research Question

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CHAPTER 1. INTRODUCTION

1.1 Background to the Study

The construction industry is a project-based industry and projects are complex activities involving many stakeholders from different organisations and diverse backgrounds. Evidence abounds in the literature suggesting that the construction industry faces many challenges (Crotty, 2012; Latham Report, 1994; Egan Report, 1998). These challenges include low productivity, labour shortage, safety, slow technology adoption, waste generation, among others. Construction projects are particularly suffering from a lack of effective communication and poor collaboration among various stakeholders involved in projects execution. Throughout the different project execution stages, these stakeholders often exchange information and share perspectives, ideas and experiences to achieve the required outcome by bringing to fore their different expertise and knowledge. The problems associated with ineffective communication and poor collaboration often resulted in resources wastage, cost overrun, project delay, abandonment, disputes and litigation.

One solution that has been drawing attention from both academics and practitioners is BIM. Digital Built Britain (HM Government, 2016) defined BIM is a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining built assets. BIM implementation (BI) on construction projects has increasingly gained global acceptance, as building clients and government from various countries are becoming the driving force for its adoption by mandating its use on their projects (Smith, 2014). Some studies projected BIM as mere software and technology (e.g., Al-Mannai, 2011); however, recent studies have argued that BIM is a new process of working, which involves communication and collaboration processes. It is more of a human approach to change the traditional process of designing, constructing and managing built assets.

As stated earlier, the construction industry is traditionally faced with the problems associated with poor communication and ineffective collaboration during project execution. Though previous studies have shown that BIM has potentials to address these challenges, however, current BI is still faced with challenges that have to do with technological, organisational and social issues. Presently, there is no agreement in practice on how best to address these challenges associated with BI. It is important to find out the role experiential knowledge (EK) could play in overcoming some of the challenges facing BI through integrating EK into BI. This integration suggests that EK could help execution of BIM project to be more effective.

Conceptualising BI as a social practice could facilitate the analysis of the integration between people's EK and BI. This analysis could enable a deeper understanding of BI's socio-technical issues and improve decision-making during BI. Given the concept of a social dimension to BI, this study adopts the concept of KM to show how the integration of EK into BI could improve decision-making in BIM projects. This study is not only interested in how and why organisations implement BIM, but also in how EK can be integrated into the process for improved decision-making. Therefore, EK is particularly a subject of interest in understanding BI. EK refers to knowledge tacitly or implicitly recalled from experience, which resides in peoples' head. It refers to knowledge gained from lived experiences through direct participation and engagement in BI, which is vital assets for strategic decision-making (Schubert & Borkman, 1994).

BI is seen as a path-dependant process where one decision leads to another, and the decision made at the early stage has implications on the rest of the phases. It refers to a series of decisions made regarding tasks and activities undertaken collaboratively at the early phase of building construction projects, in preparation for the BIM Execution Plan to be used throughout the project lifecycle. In the context of this study, BI refers to these series of decisions on how and why construction organisations implement BIM technologies and new processes today in their practices. Therefore, this research seeks to develop a framework that could help integrate EK into BI for improved decision-making in building construction projects. If the decision-making process can be improved and make more effective through the integration of EK, it makes sense that the challenges of communication and collaboration associated with BI during projects execution would have been significantly addressed.

1.2 Problem Statement

The UK construction industry is faced with many challenges. Previous researchers have identified some of the top challenges facing the construction industry to include low productivity and profitability, project performance, skilled labour shortages, and sustainability concerns (Agrawal & Halder, 2020; Mohd-Rahim et al., 2016). According to Crotty (2016), some of the challenges facing the UK construction that necessitate the adoption of BIM include arbitrary use of lines and symbols leading to ambiguous and misleading information; lack of internally consistent documentation; incomplete and uncoordinated information requiring human manipulation. These challenges are compounded by the industry's adversarial and fragmented nature, leading to poor communication and ineffective collaboration. Underscoring the importance of effective communication, statistics have shown that most employees spent two-third of their time communicating with others (Workplace Productivity and Communication Technology Report, 2017). The implication of this is that an average worker spent a significant time exchanging experience-based knowledge through communication and collaboration.

According to Sheehan et al. (2005), the construction industry is characterised by abundant EK of the senior staff. This unique EK that gives organisations their competitive advantage is hardly shared. Highlighting this issue, Marshall and Sapsed (2000) argued that knowledge gained through years of experience by the senior engineers resides in their head, which they do not always share because they considered 'knowledge as power'. Most of these senior engineers are about to retire with this wealth of EK without sharing them with the junior staff. Sheehan et al. (2005) identified effective knowledge sharing within teams, especially between experienced staff and new graduate, as a significant challenge facing the construction organisations. They suggested mentoring and apprenticeship relationship as the most straightforward and most effective approach to knowledge sharing. Therefore, it is imperative to develop a practical approach to capture and integrate as much as possible of this EK into organisation's way of working to minimise the ever-widening knowledge gap and prevent loss of valuable knowledge due to death or retirement of experienced senior staff.

Some studies have suggested that BIM adoption is a solution to the challenges associated with communication and collaboration on projects. Despite the adoption of BIM as a new way of working within the UK construction industry, the industry's challenges in terms of skill shortage, decreasing experience, poor knowledge sharing and ineffective communication have become more complex. This is because each project in the industry is unique with new challenges leading to the generation of new knowledge and lessons learned. Some of these challenges are around BIM technologies, interoperability, license, policy, data storage, among others. Other challenges have to do with the social and human dimensions around BI processes and practices, the reason and how construction firms implement new technologies in their practices. In this research, BI is seen as a path dependant process where one decision leads to another, and the decision made at the early phase of a project has implications on the rest of the phases. It refers to a series of decisions made regarding tasks and activities undertaken collaboratively at the early phase of the construction project, in preparation for the BIM execution (plan) to be used throughout the project lifecycle.

BI is about decision-making processes regarding the tasks and activities relating to construction projects and how construction organisations are using BIM technologies in their practice suggests there is a strong human and social dimension to BI. These human and social dimensions suggest that EK should be included in BI with potentials to addressing issues that have to do with how knowledge is captured and transferred within and across BIM projects to improve decisions. Unfortunately, experience-based knowledge is not usually adequately captured among project team members and integrated into BI for improved decision across projects (Egbu & Botterill, 2002). The temporary nature of construction projects does not encourage continuity of using the same project team members in future projects leading to significant knowledge loss (Shokri-Ghasabeh & Chileshe, 2014). Ability to capture and integrate EK to BI for improved decision-making remains critical for improving construction project performance (Lee & Egbu, 2004).

Therefore, it is essential to capture EK in the form of best practices and lessons learned from past mistakes and integrate them into BI to avoid reinvention of the wheel in future similar projects. In this way, knowledge could be dynamically applied to generate additional new sets of EK, leading to continuous learning and improvement. Accordingly, this study seeks to contribute to the attainment on the essence of adopting and mandating BIM in the UK through the development of a framework that integrates EK into BI for improved decision-making in building construction projects.

1.3 Justification for the Study

Despite the adoption of UK BIM Framework iso 19650 and the celebrated benefits accruable from its implementation, one of the significant challenges of current BI is its inability to effectively capture and share EK of BIM experts for use and reuse across projects (Wang & Meng, 2018). Research into the integration of KM and BIM is not new in the construction industry. However, many of the studies have focussed on the technological dimension of BIM to the detriment of the human and social dimensions (Ho et al., 2013; Lin, 2014; Motawa & Almaarshad, 2013; Motamedi et al., 2014). Meanwhile, the importance of people as drivers of technology and custodians of knowledge cannot be over-emphasised. While BIM can facilitate an effective decision-making process, the power to make the decision is still ultimately vested in the people who often rely on the available information, their tacit knowledge and experience to make decisions.

KM can help provide a lens through which changes to the way construction knowledge is managed in BIM projects (Malone, 2013). It can also provide some frameworks that can help ensure that focus is not narrowly put on the management of data and information to the detriment of the importance of knowledge processes essential to the effective decision-making for BIM project delivery. There are two concepts from KM that are very useful to BI (Malone, 2013). These are the data, information, knowledge and wisdom (DIKW) hierarchy (Ackoff, 1998; Cooper, 2014) and the distinction between tacit and explicit knowledge (Nonaka et al., 2000). While the DIKW hierarchical classification provides a progressive ranking in the level of understanding from data (as the lowest), followed by information, then knowledge and finally wisdom; the classification of knowledge into tacit and explicit makes a distinction between two types of knowledge, especially in respect to location and storage of knowledge. Explicit knowledge refers to knowledge which can easily be written down as words and numbers, captured in a database, codified, and documented in repositories (Nonaka, 1997; Brown & Duguid, 1998; Rashid et al., 2015). Tacit knowledge, on the other hand, refers to the knowledge that resides in the mind of the 'knower', which are difficult (if not impossible) to write down and codify but are very vital to decision-making and organisational success (Nonaka, 1997; Brown & Duguid, 1998; Bock et al., 2005; Malone 2013).

The present BIM models provide powerful tools for capturing, storing and managing explicit knowledge in forms of data and information. While explicit knowledge (in the form of data and information) can be easily contained and coordinated through BIM model, tacit knowledge which remains vital to decision-making for successful project delivery, can still not be fully captured during the BI (Liu et al., 2013; Latiffi et al. 2017; Likhitruangslip & Kiet, 2019). Although BIM models may not fully capture EK, BI as a collaborative decision-making process provides the opportunity for project teams to communicate, collaborate and share experiences to improve decision-making effectively. Recognising the importance of human dimension in BI and the role of EK in improving decision-making during BI, there is the need to develop a framework that can capture and integrate EK into BI for improved decision-making relating to BI tasks and activities in building construction projects.

1.4 Aim and Objectives of the Study

The overall aim of this research is to develop a conceptual "BIM-Knowledge" (BIM-K) framework that will integrate EK into BI for improved decision-making in BIM projects. In a bid to achieve this aim, the following objectives were proposed:

i. to explore the knowledge required for implementing BIM projects through investigation of the decision-making process in BI;
ii. to investigate how KM can help capture EK for integration into BI for improved decision-making in BIM projects;
iii. to map out a KM process that could enhance the integration of EK into BI for improved decision-making in BIM projects;
iv. to investigate factors that can impact on effective integration of EK into BI for improved decision-making in BIM projects;
v. to develop skills and knowledge inventory (SKI) of key decision-makers in BI; and
vi. to develop a conceptual BIM-Knowledge framework that enables the integration of EK into BI for improved decision-making in BIM projects.

1.5 Research Questions

In order to achieve the aim and objectives of this study, the following set of research questions will be answered:

i. What is EK and how can it be integrated/validated in a BIM environment to improve decision-making in BIM projects?
ii. What factors could impact on the effective integration of EK into BI for improved decision-making in BIM projects?
iii. What skills and knowledge are considered important to the key decision-makers in BI to be effective in their roles?

1.6 Research Methodology

This study adopts a pluralistic approach to achieve the specified aim and objectives. The essence is to tackle the research questions using more than one investigative perspective. The study starts with a comprehensive review of the extant literature regarding the study's key concepts to provide a theoretical background. Since the study's essence is the exploration of EK, the study adopted pragmatism, whose main principle is the emphasis on experience and action, rather than the argument about the nature of truth, as its worldview. Based on the pragmatic paradigm, the study employed in-depth semi-structured interviews and questionnaire survey to explore the experiences of key stakeholders within the UK construction industry who have been involved with BIM projects to collect relevant data for analyses. Analyses of the collected data involve textual analysis of the qualitative data from the semi-structured interview using NVivo 11 while quantitative data from the questionnaire survey were analysed with the aid of Statistical Package for the Social Sciences (SPSS-21). Figure 1. 1 presents a methodological flow chart for the study. Detailed explanations of the research methodology, including the research philosophy, data collection and analysis procedure will be carried out in chapter three of this thesis.

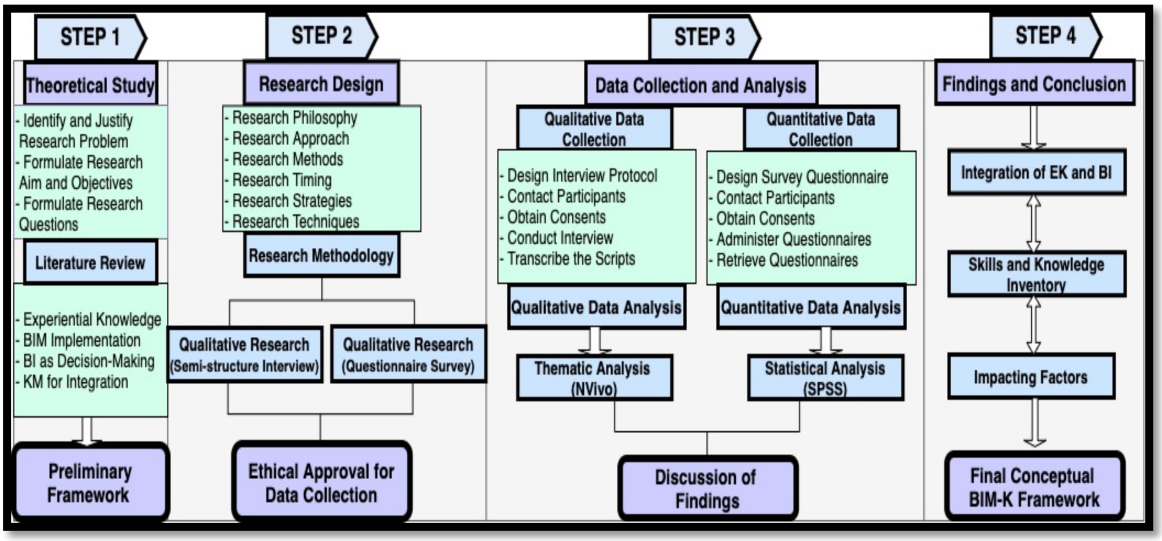


Figure 1. 1: Methodological Flow for the Study

1.7 Unit of Analysis

A unit of analysis refers to the primary entity examined in a research (Hopkins, 1982). It is the 'what' or 'who' that is being studied and analysed. It is imperative to identify the unit of analysis for a study to ensure that results are correctly interpreted, and the right conclusion is drawn (Trochim, 2006). According to Trochim (2006), proper identification of the unit of research analysis helps avoid either ecological fallacy or exception fallacy when conclusions are made. The ecological fallacy is committed when a conclusion is made on individuals based on analysis of group while exception fallacy occurs when group conclusion is drawn from exceptional individual cases. In social sciences, the unit of analysis of a study could be individuals, teams/groups, projects, organisations, industry, artefacts, society, communities, geographical entities, social interactions, depending on the focus of the study. However, within the construction industry, a unit of analysis could be one or more of the five levels of association within the industry as shown in Figure 1.2 below.

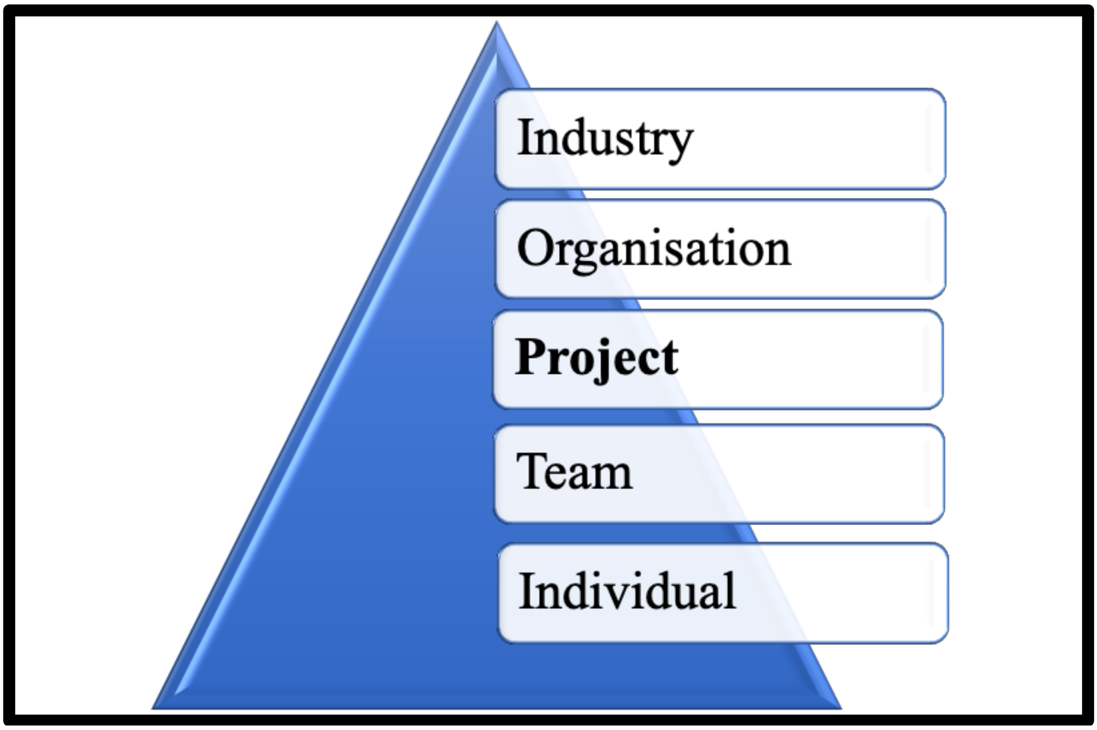


Figure 1.2: Levels of Unit of Analysis within the Construction Industry

Building construction is a project-based activity requiring critical decisions regarding BI tasks and activities at different phases of the project life cycle. Integration of EK into BI could improve the quality of the decision-making process regarding the key tasks and activities. Although the study also seeks to investigate the factors that can impact the effective integration of EK into BI, the ultimate goal of the integration is to improve how decisions are made during BI to enhance BIM projects' performance. Hence, the unit of analysis for this research will be the BIM project whose key BI tasks and activities are to be enhanced based on improved decision-making due to the integration of EK into BI. Accordingly, findings and recommendations from analyses of the data collected during this study will be applied to BIM projects within the UK construction industry.

1.8 Scope and Limitation

This study aims to develop a BIM-Knowledge framework that seeks to integrate EK into BI to improve decision-making in BIM projects. Accordingly, the study adopted an interdisciplinary research approach involving the integration of knowledge and methods from different disciplines, i.e., knowledge management (KM), digital technology (especially building information modelling - BIM) and building construction (BC). Therefore, the essence of this section is to define the extent to which these disciplines (KM, BIM and BC) will be explored in this study and specify parameters the research will be focusing on within these fields.

KM is defined as a discipline that promotes an integrated approach to identifying, capturing, evaluating, retrieving, and sharing all knowledge assets, including documents, policies, procedures, and previously un-captured expertise and individual worker's experience in an organisation (Duhon, 1998). Within the KM discipline, knowledge is categorised differently. Although the most common classification of knowledge in the literature is the one provided by Polanyi (1966), which classified knowledge into tacit and explicit knowledge, however, Harries (2012) gave comprehensive standard types of knowledge to include professional and expert, experiential, directive, institutional, social, and mega knowledge. In terms of knowledge type, the focus of this research will be EK. This is because EK is one type of knowledge that is rarely explored, especially within the construction industry. It refers to the understanding and expertise of particular things gained through life experience or perception. In terms of KM parameters, this research will be focussing on KM processes and KM tools and techniques that can facilitate effective integration of EK into BI.

Adoption of digital technologies is fast revolutionising the construction industry. Examples of such technologies include BIM, augmented virtual realities (AR/VR), internet of things (IoT), artificial intelligence (AI) among others. The essence of adopting these technologies is to make the delivery and operation of projects safer, more efficient, productive, and collaborative. As a collaborative way of working using digital technologies, BIM has improved construction processes drastically since its emergence. There are different elements, dimensions, maturity levels and aspects to the implementation of BIM. For example, BI can be represented as processes, policies, people, information or technologies. BIM can be implemented in any construction sector, such as railways, roads, bridges, structures, buildings etc. It can also be applied to phases of a construction project like pre-design/planning, design, construction, and post-construction/maintenance. Accordingly, BI in this research will be limited to processes and people/human aspects of BI as it affects decision-making. BIM parameters will be focussing mainly on decisions made regarding BI tasks and activities undertaken at different phases of building construction projects.

This study's data were collected from professionals and stakeholders who have good experience of BI within the UK construction industry. These professionals and stakeholders include BIM directors, BIM managers, BIM consultants, BIM coordinators/technicians, architects/designers, engineers, cost estimator/quantity surveyors, client representatives, asset/facility managers, information/knowledge managers, and project/construction managers with varying years of experiences within the industry. As such, the applications of the findings from this study should be limited to the UK building construction industry. However, findings of the study may be adapted to countries with similar BIM maturity level with the UK.

1.9 Significance of the Study

The construction industry is a project-based and knowledge-intense industry. A typical building project contains many tasks and activities, at different stages, and involves many stakeholders from different backgrounds/disciplines with varying levels of knowledge and experiences. Due to every project's unique nature, abundant knowledge is usually generated throughout the project's lifecycle (Dephpande et al., 2014), while putting previous experience-based knowledge into context. This experience-based knowledge of experts, referred to here as EK, is considered most vital for decision-making. EK by nature, is tacit, embodied in the knower and highly personalised. While BIM has improved the quality of information (Crotty, 2016), the management of EK within the present BI is still very challenging (Likhitruangslip & Kiet, 2019). For a project to be successful, key decisions regarding the identification of the client business case, development of the project goals and objectives, and the need and scope of BIM usage throughout the project lifecycle should be made at the very early stage of the project. For these decisions to be impactful, all stakeholders must share their EK from previous projects through effective communication and collaboration.

Previous studies on BIM-based KM frameworks in the construction industry are either limited to a specific discipline (such as architecture, engineering or project management) or restricted to a particular phase of construction (such as design, construction, post-construction phase), without due consideration to all the activities and tasks involved in the whole project lifecycle. While these studies (e.g., Liu et al., 2013; Deshpande et al., 2014) indicated the possibility of managing and integrating knowledge within the present BI, a review of the existing literature on BIM-based knowledge framework revealed some knowledge gaps. Firstly, most of the existing frameworks focused on the technology aspect of BIM at the expense of the human aspect. This emphasis on technology merely considered BIM as a tool or software to manage knowledge as a system. Secondly, because knowledge was generally treated as a system, there was little or no consideration for EK. Lastly, none of the existing frameworks emphasised the importance of the pre-design phase of building projects despite its significance in decision-making. To fill the knowledge gaps, this study aims to develop a BIM-Knowledge framework that could facilitate EK integration into BI for improved decision-making in BIM projects.

This study contributes to the existing body of knowledge in BIM by providing a new perspective on the concept of BI. The new perspective considers BI as a path-dependant process where one decision leads to another, such that any decision made collaboratively regarding tasks and activities undertaken at one phase of the project has implications on the subsequent phases. The study, therefore, seeks to shift emphasis from the technology-driven perspective of BI to people-driven perspective. It advances the information component of BIM by integrating EK to improve the quality of decisions made during BI. The people/human aspect of BI underscores the important role of EK in decision-making. It argues that though BIM has significantly improved the quality of information available for use within the industry, the current BI still lacks the "animating judgement" required to make improved decisions (Crotty, 2016). The ultimate power to make final decisions and judgements lie with human beings who will need to exercise their discretion based on previous practical experiences. The integration of EK of experts involved with BI could, therefore, improve decision-making in BIM projects. To ensure an improved decision-making in BIM projects, this study developed a conceptual BIM-Knowledge framework that integrates EK into BI using a KM process. It also identified four categories of critical factors that could impact on the integration process. Besides, the study also developed an inventory of skills and knowledge considered to be important to key decision-makers in BI.

1.10 Structure of the Thesis

The thesis consists of nine chapters, ranging from introduction to conclusion, as shown in Figure 1.3. Chapter one sets the background and justification for the study, setting the scope and identifying the significance of the study. Chapter two contains a review of the extant literature relating to the concept of EK, BIM, BI as decision-making, and KM for integrating EK into BI. The research methodology and methods for the study are detailed out in chapter three. The chapter discusses the research paradigms, strategies, and the methods adopted for this study as well as the justification for their adoption. Chapter four to chapter seven presents and discusses empirical findings of the study, while chapter eight explains the development of the conceptual framework, guidelines for its implementation and the validation process. Chapter nine provides the summary, key findings, implications of the study as well as identifies areas for future research.

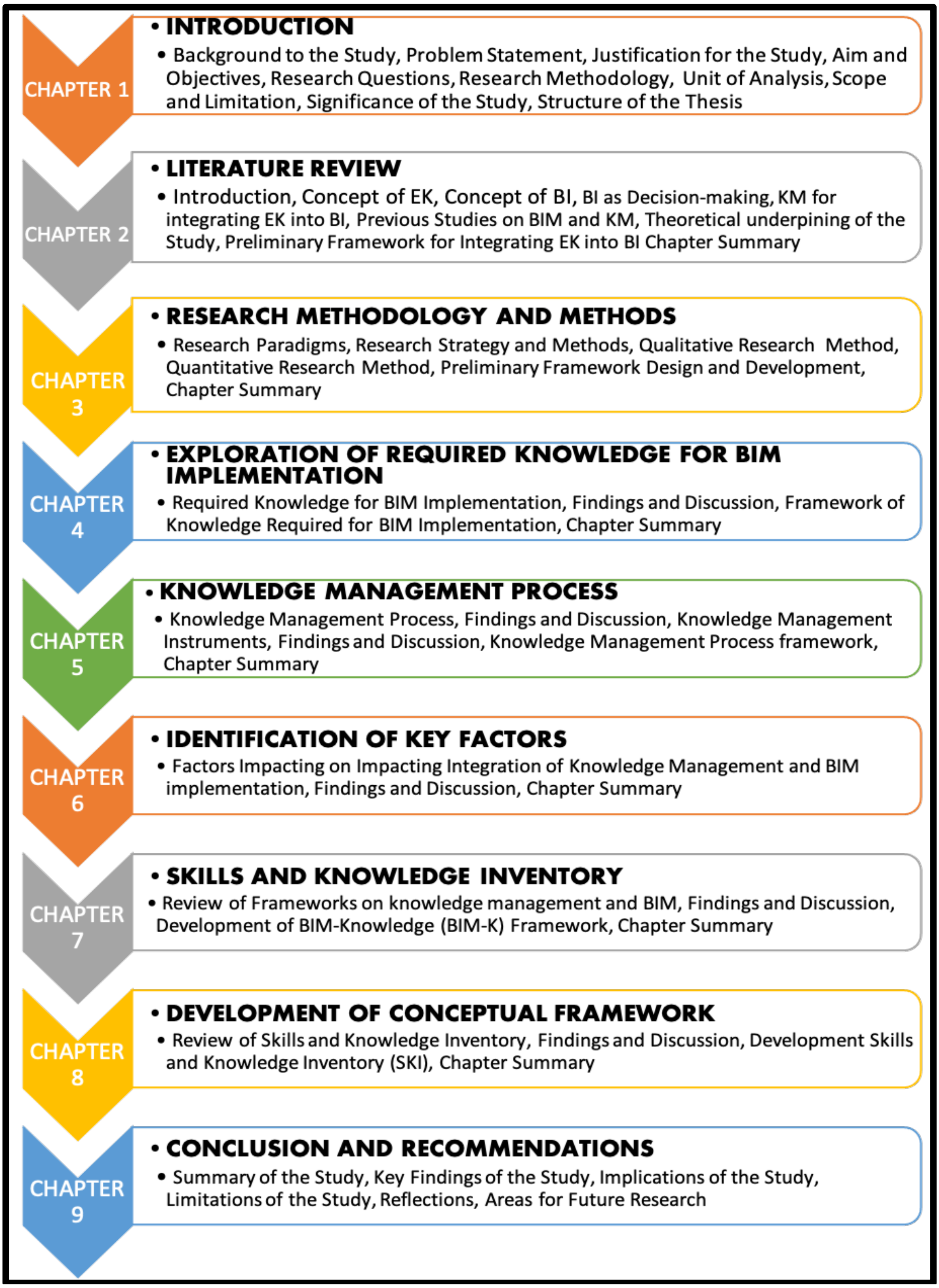


Figure 1.3: Layout of the Thesis

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter presents a thorough review of extant literature on various concepts associated with this research to understand existing research streams in BIM and KM. The review provides basis for understanding and developing various constructs that are used for the collection of empirical data for the study. The chapter opens with a discussion on BIM, its definition, its adoption within the UK construction industry, main drivers, enablers, benefits and challenges associated with its implementation. The concept of BI as decision-making was introduced with a view to investigate the decision-making process in BI. Key Tasks and activities for decision-making at various phases of BIM projects were identified along with decision-makers in BI. Despite the advancement in the quality of information provided in BIM model compared to drawing-based information, the review established the need to improve decision-making process in BI.

The next section introduces the concept of EK by defining and classifying knowledge into different perspectives. The nature of EK, its values and the challenges associated with it were reviewed as well as its role in BI. The need to integrate EK into BI to improve decision-making was identified. KM as a discipline provides the processes, tools and techniques for the integration of EK into BI for improved decision-making. The review of available KM processes suggests that the five-step KM process developed by the European Committee for Standardisation could facilitate the integration of EK into BI. Various KM tools and strategies for integrating EK into BI were reviewed, which produced a list of commonly used KM tools and techniques for knowledge integration. The section ends with a review of factors impacting on integration of EK into BI.

The review of previous studies on KM and BIM in section 2.6 revealed that there is a paucity of research on integration of knowledge and BIM at the pre-design phase of the building project lifecycle. It was also shown that most of the previous efforts at integrating knowledge into BIM have focussed on the technology component of BIM. A review of current BIM practice for capturing knowledge for decision-making was conducted. In Section 2.7 a review of theoretical underpinning the study indicates knowledge-based theory is relevant in providing basis for identifying skills and knowledge important to decision-makers in BI. The outcome of the literature review culminated into the development of a preliminary framework in section 2.8, which serves as the basis for understanding and developing the constructs that explored in the research.

2.2 Building Information Modelling (BIM)

Like every emerging innovation, there is yet to be a single universally accepted definition for building information modelling (BIM). In fact, the acronym "BIM" means different things to different people (Doan et al., 2019). Though popularly referred to as 'building information modelling', it is not uncommon to find some researchers referring to it as 'building information model' (a product) (Newton, 2012) while others describe it as 'building information management' (a process of managing information) (Doan et al., 2019). Better still, there are people who refers to it as 'better information management' (Nyvlt, 2018). These differences are not unconnected with the fact that many stakeholders interact using BIM, and each wants their perspectives reflected in the abstract meaning of the term BIM. This is the general nature of every new technological innovation in order to serve as "interdisciplinary organiser" that allows various disciplines "to articulate a roughly shared direction of interest and moral commitments" while retaining their own identity (Miettinen & Paavola, 2014; pp. 85). In order to appreciate the different perspectives and dimensions of BIM, this sub-section presents an overview of some common terminologies and definitions of BIM.

2.2.1 Definitions of BIM

Though the term BIM was first introduced by van Nederveen in 1992 (Nyvlt, 2018), the concepts behind it dated back to 1970, and variously referred to as 'integrated design database' (Eastman, 1978) or 'integrated design system' (Bijil, et al., 1979). Other terms commonly found in the literature, referring to the same system include Virtual Building, Virtual Design and Construction, Project modelling, nD Modelling, etc (Succar, 2009; Miettinen & Paavola, 2014). There exist in the literature many definitions of BIM, from both academic and commercial organisations, which have attempted to describe the expanding domain and meaning of BIM (Doan et al., 2019; Succar, 2010). As a 'buzzword', the definitions of BIM are so numerous that there are subject to variation and confusion (Eastman et al., 2011). Table 2. *1* presents some of the definitions of BIM from the review of extant literature.

Table 2. 1: Common Definitions of BIM

Definition of BIM	Reference/Source
"a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and improve the process of delivering the facility."	American General Contractors (AGC, 2006)

"process of creating and using digital models for design, construction and/or operations of the project"	McGraw Hill (2009)
"a digital representation of physical and functional characteristics of a facility...and serves as a shared knowledge resource for information about a facility forming the basis for decisions during its life-cycle from inception onward"	National BIM Standard Project Committee of the BuildingSMARTaliance (NBIMS, 2010)
"a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle"	Succar (2009)
"a digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its lifecycle, from inception to demolition"	CPIC/RIBA (2013)
"shared digital representation of physical and functional of any built object (including building, bridges, roads, etc.) which forms a basis for decisions"	BS ISO 29481-1 2010
"the development and uses of a multi-faceted computer software data model to not only document a building design but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting building information model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analysed to generate feedback and improvement of the facility design."	General Services Administration (GSA, 2008)
"a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining built assets. BIM embeds key product and asset data and a 3-dimensional computer model that can be used for effective management of information throughout a project lifecycle – from earliest concept through operation".	HM Government (2015)
"a collaborative-oriented methodology based on data acquisition, data and information sharing, collective knowledge creation among project participants through the project life cycle"	Ozturk & Yitmen. (2019).

An overview of the definitions revealed that three main concepts underpin BIM: collaborative process (collaboration and communication among stakeholders), technological product (BIM software, hardware and networking), and integrated data/information delivery through the project lifecycle, as shown in Figure 2. 1. However, others have expanded these concepts to include the human dimension thus: policy, process, people, and technology.

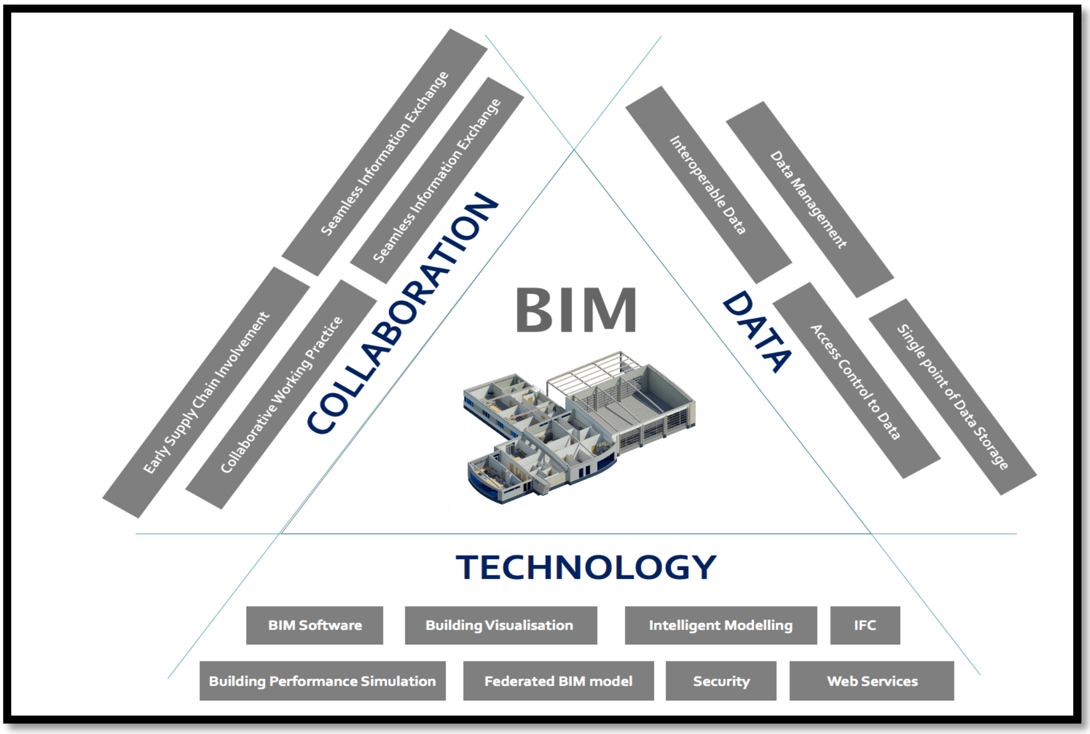


Figure 2. 1:The Three Major Concepts Underpinning BIM (Akinade, 2017)

However, two of the definitions above are considered very relevant to this study. The first one is the definition credited to the National BIM Standard (NBIMS) Project Committee of the BuildingSMARTalliance, which refers to BIM as *"a digital representation of physical and functional characteristics of a facility*" and *"serves as a shared knowledge resource for information about a facility forming the basis for decisions during its life-cycle from inception onward"* (NBIMS, 2010). Although this definition claimed that BIM serves as a shared resource for information and knowledge, researches have shown that the present BIM is yet to be able to fully capture knowledge (Latiffi et al., 2017). HM Government (2016) document of Digital Built Britain on Level 3 BIM Strategic Plan provides the other definition regarded as one of the most comprehensive definitions of BIM. It defines BIM as "*a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining built assets. BIM embeds key product and asset data and a 3-dimensional computer model that can be used for effective management of information throughout a project lifecycle – from earliest concept through operation*".

These two definitions provide the working definition for this study as they encapsulate the key concepts relevant to the study. These concepts include collaboration, shared knowledge resource for information, form the basis for decision-making, project lifecycle from earliest concept. Therefore, BIM is more of a collaborative way of working, involving early integration of many stakeholders, rather than a piece of technology or software (Eastman, et al., 2011). BIM provides the required platform and framework for the implementation of integrated project delivery (IDP) in AEC industry, which aim to streamline the construction processes by intensifying collaboration, communication and clear definition of project goals from the early phase (Mihic et al., 2014).

2.2.1 **BIM Adoption in the UK Construction Industry**

The UK construction industry has been described as highly fragmented and inefficient (Latham Report, 1994; Egan Report, 1998). The industry was characterised with a high profile, but low esteem. The industry structure is such that only a small percentage (less than 1%) employs over 24% of the workforce and generates over 35% of the output (Crotty, 2016). The industry's culture is regarded as opportunistic, conflict-laden and resistant to change (Rooke et al., 2004). The confrontational and adversarial relationship among the stakeholders is regarded as one of the critical barriers to improving quality and productivity (Latham Report, 1994). Previous reports on the construction industry suggested there are challenges with the industry. Murray and Langford (2003), summarised these challenges to include: dislocation between design and construction; short-term thinking; uncoordinated and incomplete design information; and lack of management skill. In addition to these challenges, Crotty (2016) identified four features of the construction industry that influences the adoption of BIM approach in the UK. These features include industry structure, self-analyses and the results of the industry history, changing roles and relationships in construction, and the industry's capacity for innovation.

Various recommendations were offered by various reports on how to improve the UK construction industry's performance. Radical changes to the processes through which projects develop had been advocated to change the negative perception and put the industry in the limelight (Egan Report, 1998). The most important recommendations from all the reports are that the industry should reduce its confrontational attitudes and embrace collaborative methods of working (Crotty, 2016). The call for paradigm shifts from the fragmented and adversarial culture within the construction industry to a more collaborative way of working is meant to put the industry on the path of modernisation and digitalisation through the adoption of BIM. The need for effective and efficient construction information management through digital technologies was also raised by

(Crotty, 2016). The path to the digitalisation of the UK construction industry via BIM adoption has evolved, as shown in Figure 2. 2. The BIM Maturity Levels and the UK BIM Framework will be discussed briefly to highlight the information requirements.

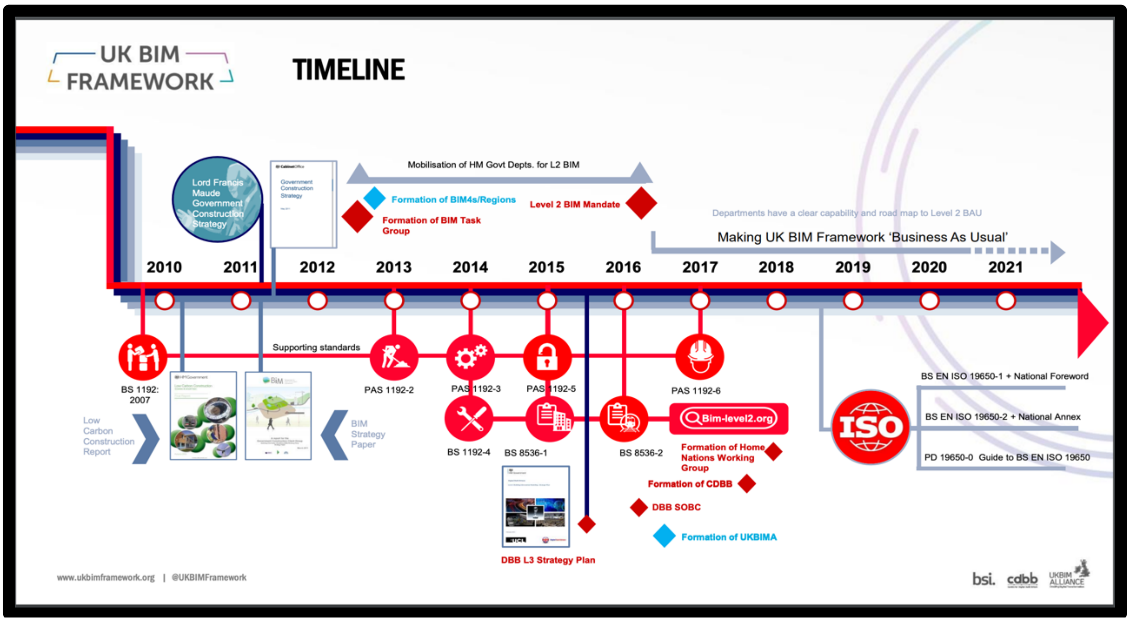


Figure 2. 2: UK BIM Timeline. Source: Paul_Wilkinson_UKBIMA.pdf (2020)

2.2.1.1 BIM Maturity Levels:

To reposition the industry, the UK Government announced in 2011 that they would be mandating BIM Level 2 on all centrally procured public projects with effect from 1st April 2016. The introduction of BI strategy was meant to transform the UK construction industry into a global BIM leader within a short period (Withers, 2012) and to attain the government's objective of achieving a 20% saving in the procurement costs (Cabinet Office, 2011). Towards realising these objectives, the UK government established a BIM Task Group to help facilitate BIM delivery by transforming the supply chain across the four maturity levels, as shown in Figure 2. 3.

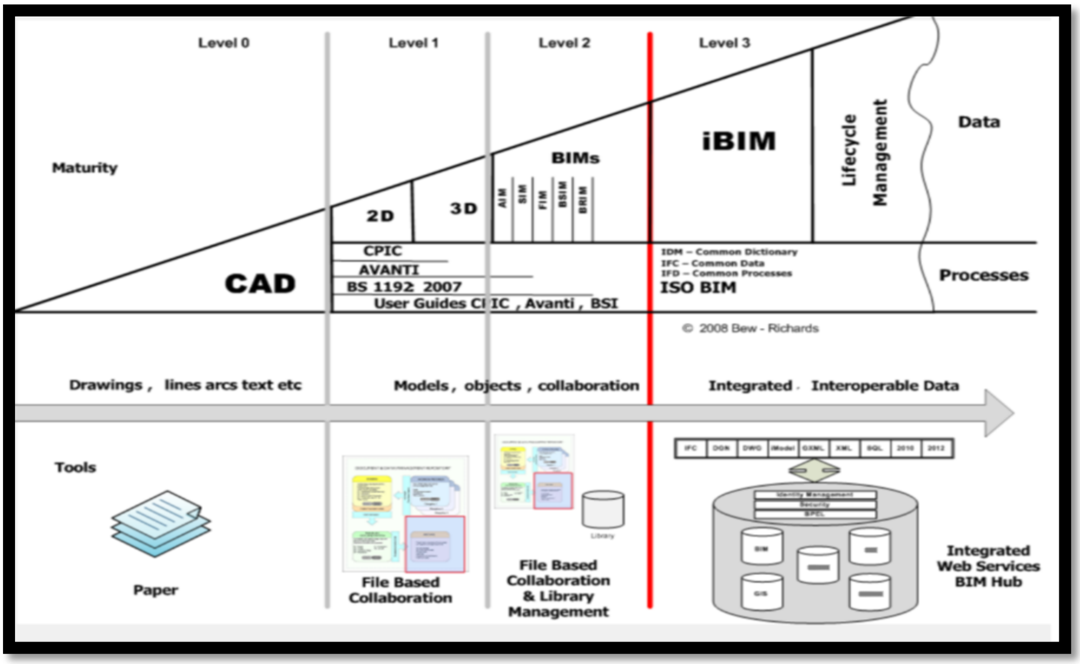


Figure 2. 3: BIM Maturity Levels Model. Source Bew and Richards (2008)

The BIM maturity model comprises of four levels from BIM Level 0 to BIM Level 3 as summarised below:

- **BIM Level 0 – Computer-Aided Design (CAD):** Effectively low or no collaboration. 2D CAD drafting only is used for production information. Output and distribution are via paper or electronic prints, or both.

- **BIM Level 1 – 2D/3D Models**: Comprises of a mixture of 2D and 3D. 3D CAD is used for concept work and 2D for drafting of statutory approval documentation and production information. CAD standard is managed to BS 1192: 2007, electronic sharing of data is through a Common Data **Environment (CDE),** usually managed by the contractor. No collaboration between different disciplines as each discipline publishes and maintains its own data.

- **BIM Level 2 – 3D Collaborative BIM:** Distinguished by collaborative working. all parties use their own 3D CAD models, but not necessarily working on a single, shared model. The crucial aspect of this level is how information is exchanged between parties. Design information is shared through a common file format where organisations can combine data with their own in order to make a federated BIM model and carry out interrogative checks on it. This collaboration was the minimum target set by the UK Government for all work on public-sector by 2016**.**

- **BIM Level 3 – Integrated BIM (iBIM):** This represents a full collaboration of all disciplines through a single model and data integration using Web services like IFC, IDM, and IFD. All parties can access and modify that same model. It removes the final layer of risk for conflicting information. This level is known as 'Open-BIM'.

BIM level 2 requires all the stakeholders to be able to exchange project data and information through a standard file format. This requirement ensures that all information about the facility can be accessed from one place, which makes the integration of different aspects of the project more effective. This requirement has now been replaced by UK BIM Framework.

2.2.1.2 UK BIM Framework ISO 19650

The recently published UK BIM Framework has now become the overarching approach to implementing BIM in the UK. The framework can be used for managing information provided by the ISO 19650 series. It includes all the published standards employed for implementing BIM in the UK. Within the UK BIM Framework, the new approach for capturing information for decision-making is by stating the information required, planning how and when to deliver the required information, and then delivering the information for approval. If the information is OK, it will be used for decision-making or else; it will be returned for processing again. The approach that captures the information flow in the UK BIM Framework is represented in Figure 2. 4.

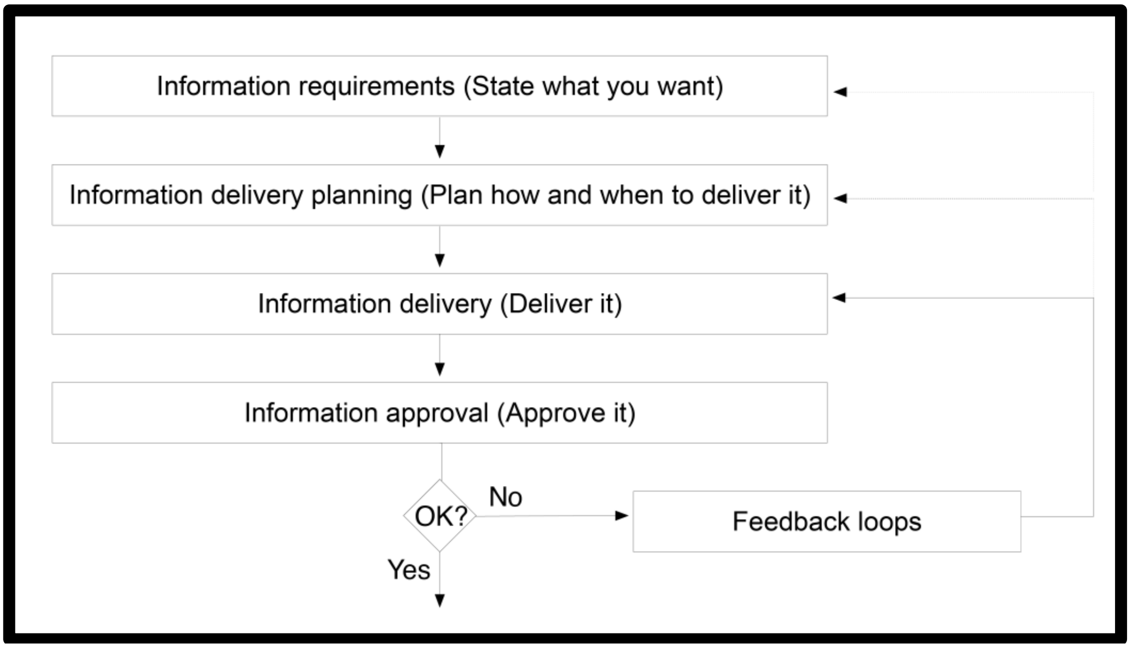


Figure 2. 4: UK BIM Framework approach to capturing information

The BIM maturity level model in Figure 2. 3 has now been modified in the UK BIM framework to reflect the information delivery cycle, as shown in Figure 2. 5. In the new UK BIM framework, the asset life cycle is divided into two based on the information model: Project Information Model (PIM) and Asset Information Model (AIM).

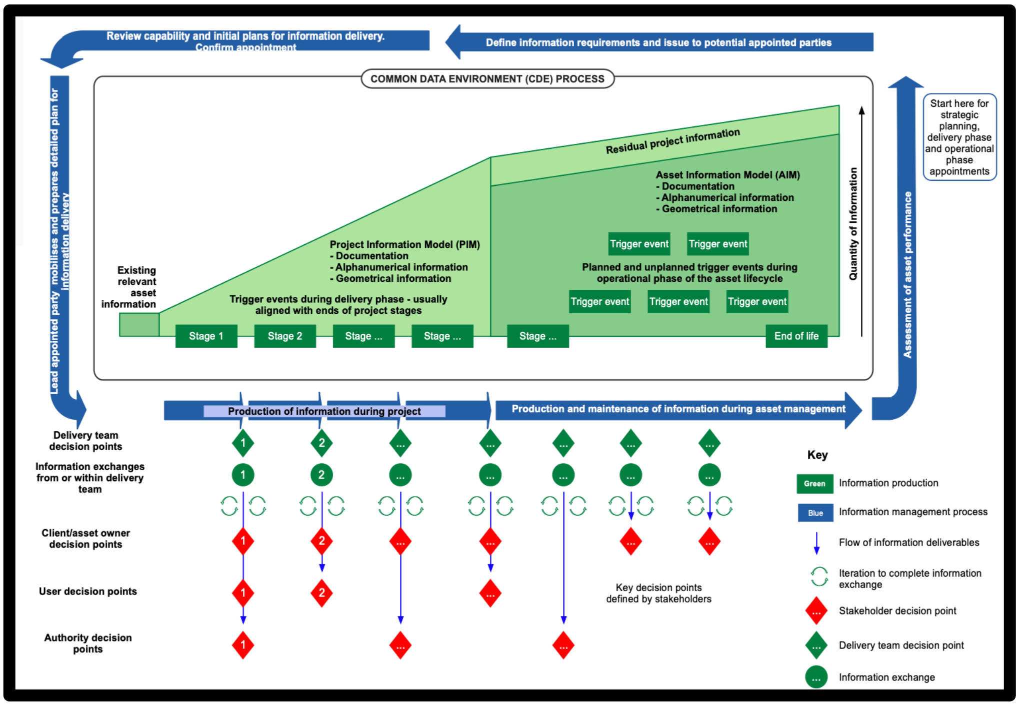


Figure 2. 5: The information delivery cycle in UK BIM Framework

The process of managing information within the common data environment (CDE) is as conceptualised in Figure 2. 6. This CDE concept indicates how information is managed among the various team from work in progress where it is archived for possible reuse.

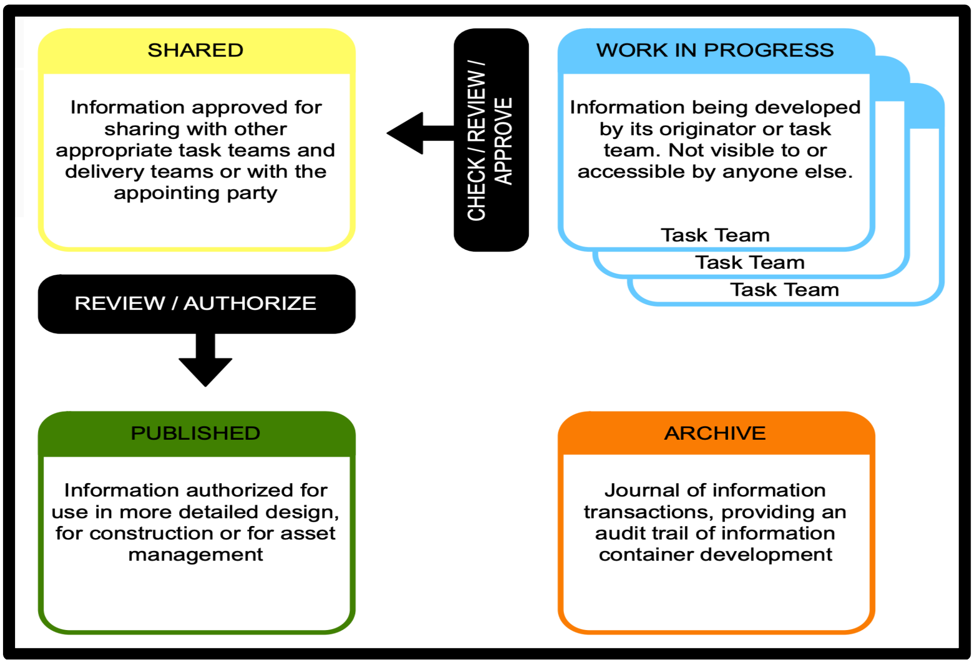


Figure 2. 6: The UK BIM Framework Common Data Environment concept

The next subsection will highlight the main drivers of BIM within the UK construction industry to appreciate the progressive and evolutionary approaches adopted for BIM adoption within the UK construction industry.

2.2.2 **Main Drivers of BIM Adoption in the UK Construction Industry**

The adoption of BIM, especially within the UK construction industry, was driven by apparent shortcomings associated with the conventional mode of managing construction information via drawings and written documents. Drawing-based design (either hand or CAD drawings) is the traditional communication mode among project team members. However, this method of communicating construction information was faced with the following challenges:

- the use of arbitrary lines and symbols leading to ambiguity and misunderstanding;
- difficulty in ensuring that individual document sets are properly internally consistent;
- difficulty in ensuring that related document sets are correctly coordinated; and
- difficulty in ensuring that the documentation is fully complete (Crotty, 2012).

Since information from drawing-based design cannot be used without being checked and validated leading to waste of time and resources, there has been a drastic shift from the craft component of the on-site operation to manufactured and assembled offsite components to be installed by site teams with the high level of narrowly specialist skills. There has also been a shift to the adoption of production-line manufacturing techniques where the basic production process was drastically de-skilled. The production line's design and management became more sophisticated, requiring a high level of skills concentrated in the hands and minds of engineers and managers. Hence, there is a shift from being craft-based and labour intensive to knowledge-based and capital intensive. According to Crotty (2016), the main drivers that contribute to BIM adoption in the UK construction industry include:

i. the idea of project teams as being the operational focus of decision-making and innovation in the industry;
ii. the industry's long tradition and active pursuit of improvement;
iii. its relatively malleable organisational structure; and
iv. its under-appreciated, but a very significant capacity for basic innovation.

After reviewing the strategic challenges facing the UK construction industry, Crotty (2016) submitted that the modern construction industry's defining characteristics include its inability to complete projects predictably and its chronic low level of profitability. These challenges were borne out of poor-quality drawing-based design information and inadequate communication. According to Crotty (2016), construction projects fail because of conventional project management methods and systems:

i. depend too much on an intuitive, subjective definition of work scope and progress assessment;
ii. are dangerously top-down in their operation, lacking systematic connection with the production level in projects;
iii. are inherently poor for forecasting and trends detection and analysis;
iv. provide no effective frameworks or methods for the capture, analysis and reuse of performance data.

The absence of effective frameworks and methods should not be limited to capturing, analysing, and reusing performance data alone, but should be extended to EK of individual people working on the project. After all, he confirmed that "The individual people who work on projects learn a great deal from every job they do (acquire experiential knowledge); but the company they work for learn almost nothing" (Crotty, 2016; p. 42). Therefore, it could be counterproductive to leave these great deals of EK while trying to improve projects performance. BIM-based model techniques, Crotty argued, have the capacity to do away with the problems of poor-quality design information and inadequate communication associated with drawing-based design methods. The need to improve construction projects performance (project predictability and firm profitability) using BIM-based model techniques instead of drawing-based designs is the main driver for BIM adoption in the UK construction industry. This study, therefore, aims to contribute to the improvement of BIM projects by developing a BIM-Knowledge framework that could help capture EK and integrate it into BI to improve decision-making. Given that BIM adoption within the UK industry was driven by the need to improve performance, the next section will discuss enablers of BIM adoption.

2.2.3 Enablers of BIM Adoption

Kivits and Furneaux (2013) identified three major factors that facilitated BIM adoption. These factors, referred to as enablers of BIM, include: 1. the advent of enhanced information technology (IT) infrastructure; 2. the creation of Industry Foundation Classes

(IFC) by the International Alliance for Interoperability (IAI); and 3. the increasing worldwide support for BIM, based on government policy as demonstrated by UK government directive for BI on all publicly procured projects by 2016.

- ***Advances in Computer Technology and Information Technology Infrastructure:*** With the advent and global access to internet technology, organisations that are geographically separated with different time zones can now work collaboratively on the same project. The continuous innovations in internet technology and IT infrastructure, coupled with enhanced capacity of computers, have collectively enabled the use and increased the performance of BIM. As BIM involves the storage and transfer of large files, the current trend in IT infrastructure, with the latest innovation of fibre optics cables, provides the opportunity to share such large data files among BIM users all over the world.

- ***Creation of Industry Foundation Classes for Interoperability:*** Interoperability is the "sharing and exchange of information via integrated technological solutions, no matter what project phase, discipline or participant role in the built asset life cycle" (AIA Document, 1997). The only open global standard recognised for sharing data and information across firms with various software tools is the one published by buildingSMART called the Industry Foundation Classes (IFC). Formed in 1994, buildingSMART's main objective is to "define, publish and promote specifications for IFC as a basis for project information sharing in the built asset industry" (Bazjanac, 2002). The IFC is the only model that is an international standard with a set of rules and protocols that describe and store-built asset information. The increasingly widespread use of IFC throughout the building industry enables the implementation of BIM in the industry, thus making sharing of data and information more accessible.

- ***Increasing Worldwide Support for BIM:*** There is increasing global adoption of BIM in the construction industry. In a survey conducted by the American Institute of Architects (AIA) in 2006, 16% of the firms owned by their members have acquired BIM software with 64% of these firms using BIM already for billable work (Riskus, 2007). In a more recent research survey into BIM adoption in the UK, published by the National Building Specification (NBS, 2016), owned by the Royal Institute of British Architects (RIBA), by April 2016 survey of 1,000 UK construction professionals revealed that BIM adoption had increased from 13% in 2010 to 54% in

2015. This sharp increment may not be unconnected with the UK government directive mandating BI on public projects from 2016. With the increase in the number of firms implementing BIM in the building industry, other smaller companies will be forced to adopt BIM for competitive advantage and to retain their partnership with the larger firms that require their services as subcontractors.

It is evident from the above that BIM rapid adoption and implementation has been enabled by the significant improvements in technological infrastructure, the development of the IFC for data and information exchange between organisations, and the government policy support for the adoption and implementation of BIM. The adoption of BIM in the construction industry has numerous advantages over the conventional drawing-based design approach. The next subsection will examine some of the benefits and advantages accruable from BIM adoption.

2.2.4 **Benefits and Advantages of BIM**

Several researchers have documented the benefits of BIM usage and implementation (Fox & Hietanen, 2007; Taylor & Levitt, 2007; Langdon, 2012). Taylor (2007) reported that BIM technologies allow collaboration among professionals and enable the development of a virtual building. In an environment like the construction industry where the collaboration and communication between different organisations and professionals are crucial throughout the duration a project, there is the need for a tremendous level of coordination (Alshawi & Faraj, 2002). Azhar (2011) reported that the benefits of implementing BIM include faster and more effective process; better design proposal through rigorous analysis and simulation; controlled whole-life costs and environmental data; better production quality; automated assembly of building components; better customer services through accurate visualisation; and lifecycle data that can be used throughout project lifecycle. BIM technologies can also lead to significant productivity improvements by integrating the work of the construction project network (Taylor & Bernstein, 2009). Langdon (2012) documented the benefits accruable from BI across the project lifecycle – from design to operations. The study proved that there are potential economic benefits in BIM return on investment through real-life case studies.

The UK BIM Framework enumerated the advantages of BIM from the design stage through construction to the operating stage. BIM enables a collaborative work among designers, owners and users during the design stage in other to produce the best possible designs that are tested on the computer before construction. It also allows for waste and error reduction through integration of complex components among engineers, contractors and suppliers at the construction stage. During the operation phase, BIM provides real-time information about available services to the users and maintainers can also use it to accurately assess the condition of the facility.

Kivits and Furneaux (2013) identified five benefits of BI to include: increase in utility and speed across all the phases of the project; enhance collaborations, especially at design and construction phase; better data quality throughout the various phases of the project; 3D visualisation of data; and reduction in conflict through clash detection. Meadati et al. (2010) highlighted some of the benefits of BI from planning to operation and maintenance phase. At the planning phase, BIM can provide easy and quick alternative analysis, quick quantity and cost estimate, and facilitate specification development. It can improve coordination, allows auto code checking and facilitate tracking of design change at the design stage. During construction, BIM can reduce interpretation problems, request for information, material waste, constructability problems as well as facilitate proper equipment selection. BIM can help resolve space management issues during operation as well as provide easy access to relevant documents and manuals for easy maintenance of the facility.

According to Crotty (2016), the main benefit of BIM during the design phase is that it drastically reduces dependency on drawings to communicate design ideas by replacing lines with components. With BIM, consultants can deliver fully coordinated, dimensioned, detailed designs, as the basis for procurements of the main contract. BIM enables the design team to create higher quality information than what is obtainable in the conventional drawing-based design. In comparison with the drawing-based design, Crotty (2016) submitted that BIM-based models provide several key benefits, including:

i. explicit representation of the object being designed; no dependence on cryptic forms or symbologies;
ii. inherent coordination of details between different views of the same components;
iii. direct, unambiguous association of different types of data with selected components, resulting in extremely data-rich models;

iv. easily generated 3D views, complex section views; rotations, walk-throughs and suchlike, to enable complex objects to be designed efficiently and understood intuitively.

In summary, BIM offers improved visualisation; improved productivity; improved performance in terms of project predictability and firm profitability; increased coordination of construction documents; embedding and linking of vital information (such as vendors for specific materials, location of details and quantities required for estimation and tendering); increased speed of delivery; and reduced costs. It helps to detect, right from the beginning, areas of collision and discrepancies. It envisages the virtual construction of a facility before its actual physical construction to reduce uncertainty, improve safety, work out problems, and simulate and analyse potential impacts. It can serve as a tool for managing knowledge throughout the building lifecycle (Nývlt & Prušková, 2017).

2.2.5 **Challenges and Barriers to BIM**

Despite the acclaimed benefits of BI to the construction industry, BI faces several barriers and challenges. Many previous reports have documented these challenges (Latham Report, 1994; Egan Report, 1998; Construction Sector Deal, 2019). These challenges cut across technology to human-related issues; organisation and commercial issues (Gu & London, 2010). The NBS National BIM Report (2014) identified five top barriers facing organisations (especially small sizes firms) that are yet to implement BIM to include: no client demand, BIM is not always relevant to projects they worked on, high cost of taking off, projects they are working on are perceived as too small to warrant BIM adoption, and lack of in-house expertise. Liu et al. (2013) also identified five categories of critical barriers to BI in the construction industry after a thorough literature review. These include lack of a national standard, high cost of application, lack of skilled personnel, organisational issues, and legal issues. According to Kivits and Furneaux (2013), BI's key barriers include issues regarding intellectual properties, liability, risks, and contracts; issue concerning users' authenticity; high costs; sociotechnical issues regarding new ways of working; and skill-related issues.

Findings of a research conducted by Khosrowshahi and Arayici (2012) while developing a roadmap to BI within the UK construction industry identified six critical challenges in BI to include resistance to change, and getting people to understand BIM benefits: adapting existing workflows to lean-oriented process; training people in BIM;

understanding the required hardware resources and networking facilities to run BIM application; required collaboration, integration and interoperability between professionals; and clear understanding of the responsibilities of different stakeholders. In addition to the identified challenges, the study also identified the need for an effective implementation strategy and professional guidelines for leveraging BIM. Newton and Chileshe (2012) reported most-highly-ranked challenges to BI: lack of understanding about BIM; costs of education and training; initial start-up cost; and resistance to change in the way firms do business. Criminale and Langard (2017) ranked time needed for hiring/training employees, cost of hiring/training employees, and lack of national standard/process to evaluate the use of BIM highest out of 37 barriers identified from a literature review.

A study conducted among design consultants by Navendren et al. (2014) categorised BIM challenges into design-specific, team-oriented, project-oriented, technology-related, industry-wide challenges and cost. Similarly, Aibinu and Vankatesh (2013) conducted a study on the status and BIM experience of cost consultants in Australia. The study revealed that learning time, cost of implementation, lack of knowledge, incomplete model, consultant attitude and change aversion are the significant challenges and barriers to BI among cost consultants. In a study on barriers to BIM adoption in developing countries, Oteng et al. (2018) categorised barriers to BIM adoption and implementation in Ghana into human resource, technical, contractual, financial and managerial barriers. The study shows that human resource barriers include a change in the work process, lack of BIM experts, unavailability of BIM specific clients and hesitancy to adopt new technology rank first. The confrontational culture within the industry has also been identified as a major barrier to BI (Watson, 2011).

Other major barriers and challenges facing BI as identified by various researchers include cultural division between designers and builders as well as between contractor and sub-contractors (Arayici et al., 2009; Eastman et al., 2008); contractual and legal barriers to collaborative BIM process (Sebastian, 2010); disruptions to workflow and lack of experts in the emergent new knowledge resulting from BI and skill gaps within the industry (Eastman et al., 2008); overcoming resistance to change (Khosrowshahi & Arayici, 2012); and training people in BIM, or finding people who understand BIM (Arayici et al., 2009). Becerik-Gerber et al. (2011) identified unclear roles and responsibilities, interoperability issues, lack of effective collaboration, cultural barriers towards new technology, organisational resistance, undefined fee structure, lack of a legal framework for accommodating clients' views in design and construction, and lack of real-life proof of positive return on investment as main challenges in implementing BIM. Implementation of BIM has also resulted in the emergence of new knowledge and skill gap within the construction industry (Nývlt & Prušková, 2017). Top-bottom and bottom-top approaches were used to identify challenges facing BI from public client perspectives to include intra- and inter-organisational challenges such as changing work practices, evaluating business value of BIM, creating incentives and new roles, and managing interoperability (Vass & Gustavsson, 2017).

After discussing the concept of BIM generally, including its definition, evolution, drivers, enablers, benefits, and challenges facing BIM adoption, especially in the UK context, it is, therefore, important to narrow down to the concept of BI. In the context of this study, BI is conceived as a path-dependant decision-making process. The next section will expatiate on the concept of BI as a decision-making.

2.3 The Concept of BI as Decision-making

2.3.1 The Concept of BI

Implementation refers to the process of moving an idea from concept to reality. According to bimdictionary.com, BI refers to the set of activities undertaken by an organisational unit to prepare for, deploy or improve its BIM deliverables (products) and their related workflows (processes). According to the online dictionary, BI comprises three phases: BIM readiness, BIM capability, and BIM maturity. There are several perspectives, views and dimensions to the concept of BI in the literature. Some studies (such as CIC, 2013; Jung & Joo, 2011; FIATECH, 2013) present BI as manuals or guidelines showing a step-by-step implementation approach to help companies work with BIM. Other studies (e.g. Eastman, 2008; Smith, 2014) represent BI as a series of processes operating at different levels concerning various stakeholders' perspectives. Stakeholders involved with BI include clients, contractors, subcontractors, architects, engineers, surveyors and suppliers. According to Morlhon et al. (2014), BI could be seen from a technological perspective, new functionalities perspective, or maturity perspective. In additions, some studies emphasised BI's operational and technical dimensions while others authors document approaches to BI and its maturity levels across different countries and regions of the world (e.g. Bernstein et al., 2013; Smith, 2014).

However, Neto (2016) divided the process of BI into three levels: project-based BIM, organisation-based, and industry-based BI. Implementation of BIM at the project level often involved the use of BIM software (e.g. Revit) for building modelling, simulation, clash detection, sustainability analysis and quantity take-off. The project-based BI can take place at the pre-design, design, construction and operation phases of the project. According to CIC (2011), the procedures for a project-based BI should include four processes. These processes are: identifying the aims of BI; mapping the BI process into a specific project; defining the process of exchanging information among project stakeholders; and defining the required infrastructural support for BI process. At the organisational level, BI encompasses collaboration among various disciplines to increase the productivity of the construction organisations.

Similarly, Gu and London (2010) also presented four steps towards BI process at the project level. The four steps include a clear definition of the project scope, purposes, roles, collaboration and phases; developing the task processes; identifying the technical requirement; and evaluating the skills, knowledge and capacities of the people. Beyond the technical aspect of BIM, these studies highlighted the strategic role of the people in BI, especially in the area of knowledge, skills and competencies.

Regarding the implementation of BIM at the organisational level, many studies discussed various dimensions for implementing BIM. For example, Succar (2009) developed a multi-dimensional framework for organisational BI, which comprises three dimensions: BIM Fields, BIM Stages, and BIM Lenses. The first dimension, BIM field dimension, was divided into three overlapping fields: policy field (rules and patterns), process field (implementation phases based on time and cost), and technology field (supporting infrastructure). According to the author, the second dimension, BIM stages, comprises of four stages of BI to include pre-BIM, modelling (object development), collaboration (collaborative work among stakeholders) and integration (net integration among disciplines). Succar identified three lenses for BI: disciplinary lens (e.g. design management, construction management); scoping lens (e.g. organisational scale, organisational size); and conceptual lens (BIM ontology). Organisations that incorporate these dimensions would have adopted an integrated project delivery (IPD) approach to BI.

On the other hand, some regarded BI as a form of change to organisational processes. For example, Miettinen and Paavola (2014) presented BI as an organisational change that impacts both management and contractual processes. They argued that strong organisational leadership support is necessary for BI to overcome the natural resistance to changes anticipated by BI. There is a need for a change in the business process models across the organisation for a successful BI. These studies advocated that the major challenge to BI is a management issue rather than technical issues.

Although there has been a conscious effort to adopt BIM within the construction industry globally, BI throughout the project lifecycle has been relatively slow (Syazwani et al., 2018). This is especially true when the construction industry is compared with other industries like manufacturing, despite the technology being around since the 1980s. Many studies have documented the maturity level of BIM from different countries across the world. For example, McGraw-Hill (2014) documented BI's level across different countries (including the USA, Brazil, Japan, South Korea, New Zealand and Australia). The study analysed different metrics for BI across these countries and concluded that discrepancies exist among these countries. Accordingly, researchers have begun to address issues relating to the BI within the industry (Brydea et al., 2013; Ahmad et al., 2013; Sack & Pikas, 2013) and highlight the benefits of practical implementation to stakeholders in the industry (Cook, 2014).

In practice, implementation of BIM can take place at different phases of the project life cycle. BI involves stakeholders from design and construction at the pre-design phase whose knowledge is required for effective decision-making through a collaborative process (Talebi, 2014). The collaborative decision-making at the early phase could help save construction costs at later stages by eliminating waste, delays, and reducing requests for change and additional information. BIM enables clients to perform value engineering for optimising business case for their investment. At the design and construction stages, BI can be optimised to honour clients' budget, reduce rework, detect and eliminate defects, fast-tract construction process, and minimise legal disputes (Talebi, 2014; Eastman et al., 2008). BI throughout the project life cycle is usually contained in a BIM project execution plan (Marzoul et al., 2010).

Another approach to BI implementation commonly found in the literature is the top-down, technology-push approach. According to the technology-push approach, business processes must be tailored along with the new BIM ways of working in order for them to be advantageous. This approach has been criticised for lacking considerations for BI's human dimensions (Hartmann et al., 2012). At the same time, Çıdık et al., (2013) observed that BI could be viewed from information technology, organisational and people perspectives. They argued that BI's present dichotomy between technology-centred and human-centred perspectives is problematic and called for human considerations in BI. Buttressing the point, Miettinen and Paavola (2014) also submitted that current BI's technological vision does not fully consider the human and social dimensions.

Aside from BI's technical and social dimensions, there is also the theory and practice dimensions to BI. Consequently, Çıdık et al. (2013) argued that human-perspective and people-related issues must be considered for successful BI. One of the vital people-related issues from the human-perspective is their personalised experience that gains from participating in BIM project. The people dimension and human-centred perspectives embedded within BI's process are very relevant to this study. More importantly, the inability to fully realise BI's potential value has been linked to human-related issues (Brewer & Gajendran, 2012). Though previous studies (e. g. Succar et al., 2013) have identified the need for stakeholders to improve their skills and competencies, not much has been done in EK and how it can improve decision-making process during BI in practice. EK is one of the issues that are strongly associated with the human mind. With several different approaches being used in BI, each seeking to tighten integration, this study seeks to develop a BIM-knowledge framework that will integrate EK into BI to improve decision-making in BIM projects.

However, for this research, BI refers to a series of decisions made regarding tasks and activities undertaken collaboratively at the early stage of the construction project, in preparation for the BIM execution throughout its lifecycle. This set of tasks and activities includes all the key decisions made at the early stages of the project, which considers all the other phases of the project lifecycle. Accordingly, BI is a path-dependant process where one decision leads to another, and the decision made at the early stage has implications on the rest of the phases. Details of these tasks and activities are discussed in section 2.3.4.

2.3.2 **Decision-making Process**

Decision-making is a cognitive process of selecting a course of action among several alternative possibilities based on pre-determined criteria (Çavuşoğlu & Cagdas, 2018). It is every day, every moment affair ranging from trivial issues to very serious matters, either at an individual level or at a corporate level. It is often regarded as a problem-solving activity terminating at a solution deemed to be satisfactory based on explicit or tacit knowledge. Decisions can be simple or complex depending on the nature of the decision, the number of variable factors involved, the environment in which the decision is to be made (certain or uncertain), and the available resources to obtain and measure the intelligence upon which decisions are to be made (Bryne & Cadman, 1984). Decisions can also be categorised as single-stage (terminal) or multiple-stage decisions. In a single-stage, decisions are made once and for all, based on information currently available to the decision-maker. In a multiple-stage, decision-making involves many sequence stages before arriving at the final outcome (Bryne & Cadman, 1984). Decision-making in construction projects is complex and multifaceted, considering various sets and stages of activities, number of stakeholders and professionals involved, number of alternative methods, and different risks associated with them.

There are various models and processes for decision-making in the literature. Turpin and Marais (2004) identified various models of decision-making including the rational model, bounded rationality (satisficing) model, incrementalist view, organisational procedures view, political view, garbage can model, individual differences perspectives, naturalistic decision-making, and multiple perspectives approach to decision-making. However, Foqué (2010) classified decision-making into two: rational or intuitive model. Others referred to them as rational (traditional) and bounded rational (behavioural) model (Frisch &Baron, 1988; Simon, 1979). Rational decision-making model provides a structured, sequence of steps/processes to decision-making while intuitive decision-making is instinctive, subjective and subconscious (Fredrickson, 1984; Papadakis et al., 1997). The rational model has the following features: the approach is logical and full of reasoning, clear identification of the goal and available means to get there, knowledge of various available alternatives and ability to evaluate them rationally, objectivity without any bias for any alternative, positivity attitude to reach the goal, and a clear understanding of existing environment.

However, Foqué (2010) argued that these models are not opponents but represent two poles between which realities are structured and decisions made. This study aligns with the position of Foqué by acknowledging the limitations, constraints and problems associated with decision-making in real-life situations, yet agrees that structuring decision-making along a rational approach can help reduce the complexity around BI. Since experience and intuitions play significant roles in project delivery and are critical to effective decision-making in many instances (Salas et al., 2010), it is, therefore, essential to integrate them into BI to improve decision-making in building projects. A rational model of decision-making could provide a framework for evaluating the impact of EK in decision-making during BI.

Different processes of rational decision-making have been proposed in the literature. According to Russo and Carlson (2002), the number of steps in the decision-making process ranges from only two to as many as 19 different phases. For example, Turpin and Marais (2004) proposed a two-phase decision-making process namely: a divergent (exploratory) phase where alternative solutions are generated; and a convergent phase where the number of alternatives is reduced for the decision to be made. Both Spragne (1980) and Simon (1960) proposed a 4-step process of decision-making that include searching for problems, identifying and analysing possible solutions, choosing a preferred solution and implementing the solution. These steps failed to recognise vital steps such as establishment of criteria for selecting the preferred solution and opportunity for feedback. Meanwhile feedback is regarded as one the critical features of decision-making (Çavuşoğlu & Çağdaş, 2018). Russo and Carlson (2002), on the other hand, developed a 5-phase decision-making process. Çavuşoğlu and Çağdaş (2018) proposed six decision-making processes applicable to early design stage in BIM-enabled project. The proposed 6 steps involve construction of the problem, compilation of the requirements, collection of relevant information, comparison of the alternatives, considering the factors and commitment to a decision. Though they claimed that BIM is able to support all these processes, however, the application of these processes was limited to only to the design phase of BI.

Public Relation at BSU (2017) provides 8-step decision-making process, which includes: define the problem, identify decision criteria, allocating weight to the criteria, developing alternatives, analysing alternative, selecting alternative, implementing alternative, and evaluating decision effectiveness. All the above processes are considered inadequate to capture the dynamic and complexity of implementing BIM throughout the project lifecycle. Building construction problems are complex, open-ended and construction projects are full of uncertainty and ambiguity. The ambiguous and uncertainty nature of construction projects requires a dynamic and comprehensive decision-making process beyond the simple steps identified above. Given the wide variations in the number of phases in decision-making processes discussed above and their inability to fully captured the dynamism and complexity associated with BI, it is important to develop a more comprehensive decision-making process for integrating EK into BI. The study, therefore, proposes an amalgamated and comprehensive ten-steps for decision-making process in BI. The reason for proposition is to develop a robust and comprehensive rational process that could capture and integrate EK into the BI, bearing in mind the nature of both EK and BI. Accordingly, the next subsection discusses the ten-steps adopted for the rational decision-making process in BI.

2.3.3 BI as Decision-making Process

The review of the extant literature regarding decision-making processes in subsection 2.3.2 revealed their inability to provide a comprehensive process that considers the complexity, ambiguity and uncertainty around BI in building construction projects. Consequently, a comprehensive, integrated cyclical 10-step decision-making process is now proposed for BI within the context of this study. The proposed 10-steps decision-making process builds on existing literature by amalgamating many of processes identified in the literature. The ten cyclical steps are briefly discussed below and will be used to collect data during the survey.

1. ***Identifying the problem to be addressed through BI:*** The first step towards making the right decision is identifying the problems to solve or the questions to answer. Each client and project have a peculiar problem that they want to address using BIM. The problem may have to do with assembling a good project team, preparing a robust brief, reducing waste, achieving energy efficiency, or timely completion of the project. Usually, the client is the one responsible for identifying and defining the problem. Whatever the case may be, it is crucial to clearly define the problem, how it should be solved and who will be responsible.
2. ***Establishing the goals and objectives for BI:*** After identifying the problem, the next step is to establish the BI's specific goal and objectives. This step has to do with setting a target to be achieved at the end of the process. Implementing BIM on the projects could be to address any of the problems identified in the first stage or to address other issues that are of interest to the client.
3. ***Gathering relevant data and information regarding BIM solutions to the problem:*** Once the goal for BI is well established, the next step will be to collect relevant data and information from all possible sources to support BIM solutions to the problem. The source of information can be internal (within the project team or the organisation) or external (outside the team or the organisation). EK can help

save time here as experts will know what data and information will be relevant and where to get them.

4. ***Determining the criteria to evaluate the alternative BIM solutions:*** For objectivity, it is necessary to determine the criteria for evaluating the various alternative BIM solutions to the problem. These criteria should include all the variables and factors that can influence the choice of the decision such as the degree of risk associated with each alternative, financial implications of each alternative, available time for decision-making and execution of the decision, available resources for implementing each alternative. For example, the criteria for determining the most efficient energy building could be based on the Building Research Establishment Environmental Assessment Method (BREEAM) or Leadership in Energy and Environmental Design (LEED) ratings.
5. ***Developing possible alternative BIM solutions to the problem:*** This step involves generating all possible and desirable alternative BIM solutions to the problem. One of the significant advantages of BIM is generating many alternatives for analyses and simulations quickly using BIM software. Since the essence of decision-making is to choose the optimum alternative BIM solution, it is essential to consider all possible alternative solutions to the problem.
6. ***Analysing all the alternative solutions based on BI's goals:*** all the possible alternatives should be analysed, based on the established criteria in step 4, to select the most suitable alternative. In analysing the alternatives, all the variables and factors that can impact the decision should be considered. BIM software may be very useful in analysing and simulating design alternatives based on given criteria. However, EK of experts becomes critical in understanding the implications outcome of the analyses.
7. ***Selecting the most suitable alternative solution within BI's context:*** This is the stage to make the decision. It is the most crucial stage in the decision-making process since the highest-ranked alternative may not necessarily be the best and optimal alternative. In selecting the most suitable alternative, the goal and objectives of implementing BIM should always be considered. Given other salient factors, the decision-makers' EK can play a significant role in selecting the most suitable alternative.
8. ***Implementing the selected solution in line with the BI goals:*** This is where the chosen alternative in step 7 will be implemented. For effective implementation, it

is essential to communicate the decision to all the stakeholders clearly and ensure they key into it into action.

9. ***Reviewing and evaluating the selected solution's effectiveness:*** After implementation, the next thing is to review and evaluate the impacts of the decision against the stated goal and objectives in step 2 and see if the selected solution solves the identified problem in step 1. The review/evaluation stage provides the necessary feedback to determine the effectiveness of the implemented decision. If carried out objectively, this step provides the basis for identifying the best past practices and lessons learned.
10. ***Capturing the lessons learned and best practices for future reuse:*** Based on the results from step 9, lessons learned from poor or wrong decisions (mistakes) and best practices based on good or right decisions are captured and documented in the appropriate formats for future use and reuse.

It is important to stress that these steps are cyclical and continuous throughout the project lifecycle. For example, in case the result of the review and evaluation process (step 9) of the selected alternative (step 7) failed to address the identified problem (step 1) after implementation (step 8), the whole process will start all over again and the lessons learned will be captured and documented (step 10) for learning as shown in Figure 2. 7. According to Stejskal (2017), the construction process comprises a series of decision-making that is made up of two things: experience and data. The more the experience and data, the better your decisions. While existing BIM can accommodate data and information to support decision-making, it is essential to integrate the experience into the BIM environment for improved decision-making in building construction projects. Experiences from previous projects could be used to address the uncertainty and ambiguity surrounding BI at different phases of the project's lifecycle.

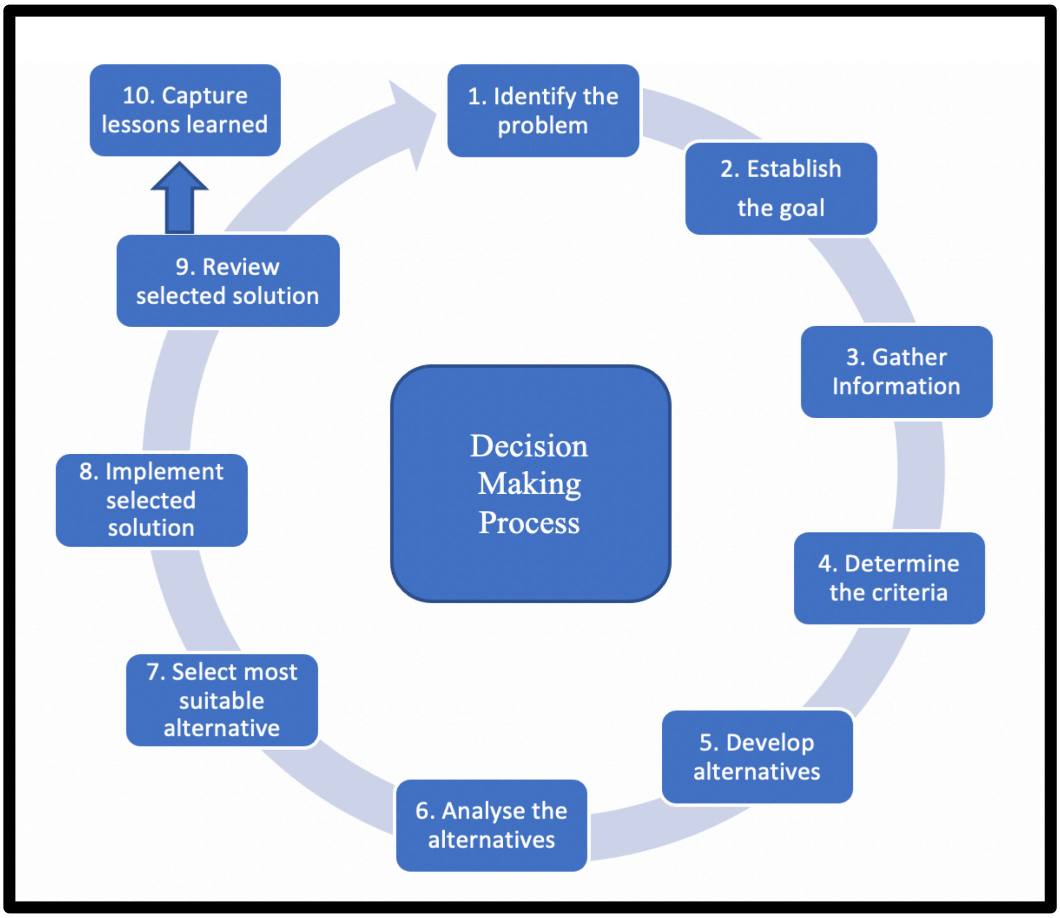


Figure 2. 7: Cyclical Decision-making Process

As a path-dependant process, there are various models for classifying the lifecycle of a building project during BI. The RIBA Plan of Work (PoW), first developed in 1963, is the most popular model for classifying building design and construction stages in the UK (RIBA, 2013). Initially, the Royal Institute of British Architects (RIBA, 2007) outlined five phases of the building project with eleven stages. The phases include Preparation (appraisal and design brief); Design (concept, design development, and technical design); Pre-construction (production information, tender documentation, and tender action); Construction (mobilisation to practical completion); and Use (post practical completion). However, in 2013, RIBA expanded the original PoW to eight stages, with clearly identified eight tasks bars, as shown in Figure 2. 8. The eight stages range from 0 – Strategic Definition; 1 – Preparation and Brief; 2 – Concept Design; 3 – Developed Design; 4 – Technical Design; 5 – Construction; 6 – Handover and Close-out; to 7- In Use.

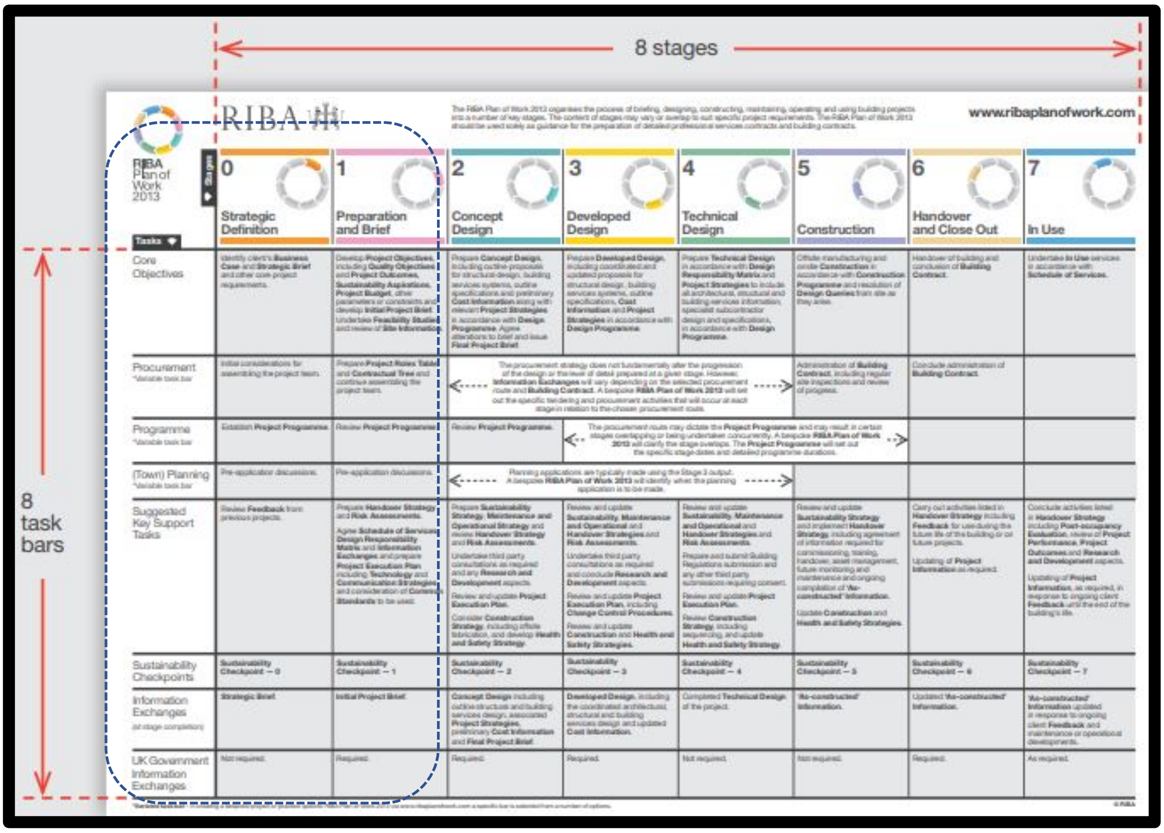


Figure 2. 8: The RIBA Plan of Work (2013) highlighting BIM Implementation Phase for the Study.

Similar to the RIBA PoW, the BIM Task Group and the Government Soft Landings proposed an alternative set of stages which comprise of eight stages: 0 – Strategy, 1 – Brief, 2 – Concept, 3 – Definition, 4 – Design, 5 – Build and commission, 6 – Handover and close-out, and 7 – Operation and end-of-life. The Construction Industry Class (CIC, 2013) adopted a scope of services involving six stages: stage 1 – Preparation, stage 2 – Concept, stage 3 – Design development, stage 4 – Production information, stage 5 – Manufacturing, installation and construction information, stage 6 – Post practical completion. Given the confusion that could arise from the stage classification, the study adopted a simpler and more compact phase classification proposed by Ajayi et al. (2014). Table 2. 2 maps out the common classifications of building project lifecycle into the phase classification adopted for the study.

Table 2. 2: Mapping the Common Classifications of Building Lifecycle into Phases

No	Ajayi et al. (2014)	RIBA PoW (2013)	BIM Tasks Group	CIC (2013)
	Phases 1 - 4	Stages 0 - 7	Stages 0 - 7	Stages 1- 6
1	Pre-design Phase	0 – Strategic definition 1- Brief	0 – Strategy 1 – Brief 2 – Concept 3 - Definition	1 – Preparation 2 - Concept

2	Design Phase	2 – Concept design 3 – Developed design 4 – Technical design	4 - Design	3-Design development 4 – Production information
3	Construction Phase	5 – construction 6 –Handover and close-out	5-Build and Commission 6 - Handover and close-out	5-Manufacturing, installation and construction
4	Post-construction Phase	7 – In-use	7 – Operation and end-of-life	6 – Post practical completion

Ajayi et al. (2014) compressed the stages 0 - 7 of RIBA PoW into four phases of Pre-design phase (stage 0 - 1); Design phase (stage 2 - 4); Construction phase (stage 5); and Post-construction phase (stage 6 – 7). Accordingly, the pre-design phase, which comprises of RIBA stages 0 and 1, is referred to as the BI Phase in this study. Stage 0 sets strategic issues, while Stage 1 builds on these strategic issues. Successful BI at this phase is central to achieving the overall aim of the project (Sinclair, 2019). Any change not considered at this phase could lead to exponential cost increase later in the project and may be difficult to implement, leading to project delay. There are two outputs from a successful BI at the pre-design phase: 1. a robust Initial Project Brief, and 2. a Collaborative Project Team (Sinclair, 2019). Based on RIBA PoW, details of key tasks and activities at this phase shall be discussed in the next section.

2.3.4 **Key Tasks and Activities for Decision-making in BI**

As mentioned earlier, BI in this study refers to the main tasks and activities regarding which decisions are made at different stages of the project's lifecycle. Stage 0, Strategic Definition, is when a project is strategically appraised and defined before a detailed brief is created. Stage 1, referred to as Preparation and Brief, subsume the tasks related to preparation and briefing in the RIBA PoW 2007. The RIBA PoW (2013) contains 'flexible' eight taskbars on the vertical axis and eight stages on the horizontal axis. The flexibility of the taskbars lies in selecting only relevant tasks, depending on the project's scope and nature. The eight taskbars are: Task Bar 1 – Core Objectives is a fixed bar that defines the principal activities for each stage. Task Bars 2 – 4 (Procurement, Programme, and Planning) contains activities that vary across project types and users are, therefore, allowed to generate their specific tasks from a pull-down list based on the type and nature of the project at hand. Task Bar 5 – Key Support Tasks is a fixed taskbar that provides an appropriate management and assistance level towards achieving the core objectives at each stage. It clarifies the activities required to achieve the sustainability aspirations required to embed BIM into the process; sets out key tasks relating to statutory requirements; and ensures proper composition of the project team and that other logistics are considered early in the process. Task Bar 6 - Sustainability Checkpoint is selectable as it may not be required for all projects. Task Bars 7 and 8 are Information Exchanges and Government Gateways, respectively. Task Bar 7 is fixed and contains guidance about information to be delivered at the end of each stage. This information includes the allocation of roles and responsibilities regarding who does what and when. Task Bar 8 is selectable and specifically introduced to take care of the UK Government requirement for information exchange as a principal client of the industry.

Accordingly, the key tasks and activities required for BI can be extracted from taskbars 1 and 5. The description of key tasks and core BIM activities presented in BIM Overlay to the RIBA PoW (RIBA, 2012) coupled with the core objectives and suggested key support tasks in taskbars (RIBA PoW, 2013) provides comprehensive key tasks and activities required for decision-making in BI for this study. Table 2. 3 presents the list of key tasks and activities for each phase of the project lifecycle. The table provides the basis for the formulation of the questionnaire during the quantitative data collection. While BI in this study refers to decisions regarding tasks and activities at the pre-design phase, the key tasks and activities at other phases were included because they also need to be considered during BI.

Table 2. 3: List of Key Tasks and Activities at each Phase of Project Lifecycle

Project Phase	List of Keys Tasks and Activities.
Pre-design Phase	Identifying client business case
	Developing project goals and objectives
	Preparing a strategic brief
	Undertaking feasibility studies
	Reviewing Site information
	Deciding the project budget
	Assembling a collaborative project team
	Determining BIM competencies of project teams
	Defining the roles and responsibilities of various stakeholders
	Agreeing on software tools and their interoperability issues
	Establishing project scope and BIM deliverables
	Establishing workflow and communication strategies
	Deciding on a common data environment (CDE) for data operations
	Defining the BIM tools and their interoperability
	Preparing handover strategy and risk assessments
Design phase	Preparing Concept, Developed and Technical Designs
	Developing the 3D model (Visualisation model)
	Finalising project brief and design alterations
	Integrating time schedule into the 3D model (4D)
	Integrating costs into the 3D model (5D)
	Preparing materials and components specifications
	Preparing sustainability analysis

	Preparing constructability analysis
	Submitting drawings for building permits
	Reviewing and updating the Project Execution Plan
	Discussing and agreeing on the model update
	Preparing and reviewing construction strategies
	Developing health and safety strategy
	Reviewing handover strategies and risk assessment
Construction phase	Contract administration
	Preparing onsite and offsite construction programme
	Prefabricating building components
	Resolving design queries from site
	Inspecting site and reviewing work progress
	Construction quality control
	Resource planning and procurement method
	Implementing the handover strategy
	Preparing the 'As-built model' for handover
	Implementing and updating construction strategies
	Updating health and safety strategies
Post-Construction Phase	Concluding the contract administration
	Handing over the building to the client
	Carrying out activities listed in the handover strategy
	Maintaining and repairing the building as scheduled
	Evaluating performance and providing feedback for future use
	Updating 'As-built' model with feedback information as required

2.3.5 **Key Decision-makers in BI**

After identifying the key tasks and activities requiring decision-making at different phases of the project lifecycle in section 2.3.4, this section seeks to identify the decision-makers in BI. The purpose is to identify those stakeholders who are responsible for making or influencing decisions during BI. Some previous studies attempted to identify the decision-makers in construction projects and their roles. For example, Chegu-Badrinath and Hsieh (2019) identified the critical decision-makers for each of the project phases to include the owners/clients, design managers, construction managers, project managers, and facility managers. Sebastian (2011) while discussing the changing roles of the clients, architects and contractors through BIM, identified the key stakeholders to include the clients, also known as owners, the architects, the engineers, the contractors, the facilities managers, and recently the model or information managers. The owners/clients may be individuals, organisations or consortium with a financial stake, but may delegate their managerial responsibility to others.

Latiffi et al. (2015) also listed the principal construction players in BIM projects to include the clients/owners, architect, engineers (C&S and MEP), contractor, quantity surveyors (QS), and facility managers. Jin et al. (2017) submitted that the list of possible stakeholders involved in construction projects is very extensive. According to Crotty

(2016), key decision-makers, on any major projects, at any material time should include client’s PM, cost consultant/PQS, project architect, structural and M&E design engineer, main contractor’s PM, and sub-contractors. There appears to be a consensus in the literature that clients are principal stakeholders in project delivery. This study will further explore the validity of this position in the course of the research.

2.4 Concept of Experiential Knowledge (EK)

2.4.1 **Meanings and Classifications of Knowledge**

Knowledge is a complex concept. There are different definitions and different ontology and epistemology to knowledge, which brings about several perspectives of knowledge and influence how it can be managed. This background is important to understanding how EK can be integrated into BI, given different knowledge perspectives. The different perspectives of knowledge present different approaches for the integration of EK into BI.

Knowledge is the process of translating information (i.e. organised data) and experience into a meaningful set of relationships which are understood and applied by an individual (Debowski, 2006). It gives us the power to do something with data and information (Schlussel, 2010). According to Schlussel (2010), knowledge is a 'flow of ideas', and it makes the difference between knowing how to do something and knowing what to do. Knowledge is also information in action (O' dell & Grayson, 1998). Knowledge is dynamic 'justified true belief', created by individuals and organisation interactions in society and increases individuals' capacity to take action (Nonaka et al. 2000). Fahey and Prusak (1998) consider knowledge as what the knower knows that does not exist out of the knower but somewhat shaped by one's need and one's initial stock of knowledge.

According to Stewart (1998), knowledge has become the most valuable resource and asset for companies today. It is a deterministic process, application of data and information, and it answers 'how' and 'why' questions (Ackoff 1999; Pasha & Pasha, 2012). Davenport and Prusak (2000) argued that knowledge is closely connected to doing and implies know-how and understanding. Knowledge is created through cognitive efforts and contains judgment compared to data and information (Tuomi 1999). The role of knowledge is to transform data into information through data interpretation, deriving new information from existing through elaboration, and acquiring new knowledge through learning (Aamodt & Nygård 1995).

While some see knowledge as a tangible intellectual asset, others like O'Dell and Grayson (1998) viewed it as a dynamic consequence of action and interaction of people in an organisation with information and with each other. Brown and Duguid (2000) argued that while knowledge is usually believed to be an individual's property, a great deal of knowledge is often generated as well as held collectively. Such knowledge is quickly generated when people work together in close groups, known as 'Communities of Practice' (CoP). According to Mclerney (2002), knowledge is the awareness of what one knows through study, reasoning, experience, association, or various learning types.

According to Davenport and Prusak (1998), knowledge is a fluid mix of framed experience, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and applies in the knower's mind and in the organisations; it is embedded in documents or repositories and in organisational routines, practices, and norms.' They argued that knowledge involves the link people make between information and its potential application. Hence, in their opinion, knowledge is closer to the action than data or information and corresponds to competence. This definition of knowledge by Davenport and Prusak shows that there are content and purpose for knowledge - the content of a framework within us and the purpose of evaluating new experiences. Gamble and Blackwell (2001) agreed with the above definition but added that it is also a 'grounded intuition' that provides the framework within us and the environment for evaluating and incorporating new experiences and information.

For this study, the researcher aligns with the definition provided by Nooshinfard and Nemati-Amaraki (2016) that knowledge is the 'skill, intuition and experience that can influence decision-making'. Therefore, knowledge is considered a familiarity, awareness, or understanding of something (facts, information, process or skill) which is acquired through experience, reflection, creativity, innovation, brainstorming or by processing information in a specific context or situation to improve decision-making. It includes intuition, perspectives, concepts and know-who. It can reside within the individuals, among team members or within organisations. Since the above definitions represent different perspectives of knowledge, it is necessary to examine these different perspectives to knowledge for a more precise understanding.

There are different perspectives on knowledge from the literature. Researchers from KM field have referred to knowledge as a state of mind (Schubert et al., 1998), an object (Carlson et al., 1998), a process (Zack, 1999), a condition of having access to information (McQueen, 1998), stocks or flows (Carlson et al., 1998), usable representations, the perception of a pattern (Lohuizen, 1986), a constitutive force in society (Beijerse, 1999), a basic human need (Maslow, 1970), and processed information. After a comprehensive review of extant literature, Alavi and Leidner (2001) categorised the different perspectives of knowledge definitions into five as summarised in Table 2. 4. These perspectives of knowledge provide bases for a better understanding of different views of knowledge as each of them points to different strategies for managing knowledge.

Table 2. 4: Different knowledge perspectives and their implications

Perspectives	Meaning	Implications for KM
State of mind	Knowledge is the state of knowing and understanding	KM involves enhancing an individual's learning and understanding through provision of information
Object	Knowledge is an object to be stored and manipulated	KM involves building and managing knowledge stocks
Process	Knowledge is a process of applying expertise	KM focuses on knowledge flows and the process of creation, sharing and distributing knowledge
Access to information	Knowledge is a condition of access to information	KM focus is organised access to and retrieval of content
Capability	Knowledge is the potential to influence action	KM is about building core competencies and understanding strategic know-how

Source: Adapted from Alavi and Leidner (2001).

The perspective on knowledge as a state of mind, according to Alavi and Leidner (2001), focusses on enabling individuals to expand their knowledge and apply it to the organisation's need. On the other hand, knowledge as an object perspective believes that knowledge can be viewed as a thing to be stored and manipulated while knowledge as a process focusses on the application of knowledge by experts. The perspective of knowledge as a condition of having access to information posits that organisational knowledge must be organised to facilitate access to and retrieval of content. It is an extension of knowledge as an object with a particular emphasis on the accessibility of the knowledge objects. The fifth perspective of knowledge viewed knowledge as a capability with the potential for influencing future action. Building on the last perspective, Watson (1999) suggested that knowledge is not so much a capability for specific actions, but the capacity to use information, since learning and experience result in an ability to interpret information and to ascertain what information is necessary for decision-making (Alavi & Leidner, 2001).

These different knowledge perspectives have also led to different perceptions of managing knowledge (Carlsson et al., 1996; Liyanage et al., 2009). For example, viewing knowledge as an object will lead to a KM approach that focusses on building and managing knowledge stocks, whereas if knowledge is viewed as a process, the implied KM will focus on knowledge flow and the process of creation, sharing, and distribution of knowledge (Alavi and Leidner, 2001). Based on the above discussion, this study adopted knowledge perspectives as a process and a capability. Knowledge as a process provides a theoretical framework for developing KM processes for integrating EK into BI. On the other hand, knowledge as a capacity provides the basis for identifying skills and knowledge (competencies) required by key decision-makers in BI for effective decision-making.

There are various frameworks for classifying knowledge in the literature, depending on the researchers' domain and perspective (Pasha & Pasha, 2012). For example, in philosophy, knowledge is classified into four categories: logical, semantic, systemic and empirical. While many researchers, especially from the KM discipline, follow the categorisation of knowledge into tacit and explicit knowledge as proposed by Polanyi in 1960s and expounded by Nonaka in the '90s (Polanyi, 1962; Nonaka & Takeuchi, 1995). More importantly, Fieser (2019) classified knowledge into experiential (a posteriori) and non-experiential (a priori) knowledge. EK refers to knowledge generated from previous experiences, which are vital assets for organisations' strategic decision-making (Janse et al., 2011). It is a form of tacit knowledge as it resides in the head of the owner. Ng et al. (2005) posited that decision-makers in construction could capitalise on EK, successful and unsuccessful experiences, to avoid reoccurrence of similar errors. Non-experiential (a priori) knowledge, on the other hand, refers to knowledge gained from rational insight without experience. Table 2. 5 presents a summary of different classification of knowledge from the literature.

Table 2. 5: Classifications of Knowledge

s/n	Knowledge classification	Reference
1	Tacit and Explicit knowledge	Polanyi (1962); Nonaka, (1994); Nonaka and Takeuchi, (1995)
2	Practical, Intellectual, Pastime, Spiritual and Unwanted knowledge	Machlup (1980)

3	Procedural and Analytical knowledge	Zack (1999);
4	Individual, Project/structural and Organisational knowledge	Graham and Thomas (2007)
5	Exploratory and Exploitation knowledge	Naaranoja (2007).
6	Tacit, Explicit and Cultural knowledge	(Chii, 2002)
7	Human, Mechanized, Documented, and Automated knowledge	Jacques et al. (1996)
8	Know-how, Know-about, Know-why, Know-when, Know-with and Care-why	Kogut and Zander (1992); Quinn et al. (1996)
9	Internal and External; Consumer and Market knowledge	Alavi and Leider (2001); Butler (2003)
10	Embrained, Embodied, Encultured, Embedded and Encoded knowledge	Blackle (1995)
11	Experiential and Propositional knowledge	Baumeister and Newman (1995)
12	Procedural and Propositional knowledge	Fieser (2008, 2018)
13	Explicit, Tacit, Embedded, Embrained, Embodied, Encoded, and Encultured knowledge	Pasha and Pasha (2012
14	Professional, Expert, Experiential, Directive, Institutional, Social, and Mega knowledge	Harries (2012)
15	Scientific, Clinical and Experiential/layman knowledge	Baillergeau et al. (2016).
16	Experiential (*a posteriori*) and Non-experiential (*a priori*) knowledge	Fieser (2018)

What is evident from the above is that the debate about the classification of knowledge is an ongoing issue. Since this research intends to see how to capture and integrate EK into BI for improved decision-making in building construction projects, further discussions will be made on EK to explicate EK's abstract nature and the challenges associated with it.

Concerning the typologies of knowledge, early philosophers were sharply divided into two basic schools of thoughts: rationalism and the empiricism, each with its own ontological and epistemological perspective (Fieser, 2019). The rationalist believed that true knowledge could only be acquired innately and through reason; hence *deductive reasoning* forms the only basis of knowledge. In contrast to rationalism, the empiricists claimed that the only path to genuine knowledge is through experience. Accordingly, the only way to expand the knowledge-base is through *induction*, i.e. generalising from experience. However, other philosophers, such as Immanuel Kant, proposed a compromise between rationalism and empiricism. They argued that 'true knowledge' depends on a combination of experiential and non-EK. This fact indicates the important position of EK as a vital component of 'true knowledge'. Unfortunately, not much has been done in terms of EK as a component of true knowledge concerning construction in general and BI particularly. Therefore, it is important to discuss the concept of EK in details with respect to its meaning, sources, nature, value, and challenges associated with its management. The following subsections will address those issues.

2.4.2 Experiential Knowledge (EK)

According to Blume (2017), the term EK was introduced by Borkman in 1976. Though not a popular term until recently, the concept has now been widely used across disciplines (Blume, 2017). Borkman (1976) defined EK as truth learned from personal experience with a phenomenon instead of the truth acquired by discursive reasoning, observation, or reflection on information provided by another person. According to Storkerson (2009), EK refers to things recalled from experience, things tacitly or implicitly learned or acquired. In contrast to professional knowledge, EK was initially referred to as a primary source of truth for self-help groups or vulnerable groups in the health industry. However, its application now cuts across disciplines and beyond vulnerable groups and can be applied to decision-making, especially in a complex and uncertain situation. It is now seen as a resource or a guide to action with emphases on its contextual, subjective, unconscious and emotional properties (Boardman, 2014).

In the context of this research, EK refers to knowledge and insights learned from direct participation in BI, which resides in peoples' head. It is a form of tacit knowledge that has been acquired over some time by working on several BIM-enabled projects. Only a few studies (e.g. Ng et al., 2005; Vass, 2017) had ventured to study the importance of EK in connection to construction. This negligence may not be unconnected with the fact that EK is sometimes considered inferior to formal knowledge (Storkerson, 2009) and therefore, undervalued (Baillergeau & Duyvendak, 2016). In comparison with non-EK, Fazey (2006) highlighted some aspects of EK that may seem less valuable. These aspects include the changing nature and value of EK when made explicit as it loses it 'tacitness'; the difficulty in qualifying how and why people know what they know due to the way it is stored and processed in the brain; the difficulty in recalibrating it against other forms of knowledge; and the difficulty in determining the extent to which the EK is relevant to a specific situation. Despite this perception, EK's importance and value have been explored in other industries, such as business studies, sport, and health.

For example, Erikson et al. (1997) employed a behavioural approach to identify and delineate EK components in the internationalisation process of firms. The study aimed at finding the cost implications of lack of EK during the internationalisation process of business firms. According to the study's findings, the process of internationalisation involved seeking EK on individual clients and markets, as well as institutional factors like local laws, local governments and local culture. It was observed that EK is country-specific (i.e. context-specific) and may not be easily transferrable between firms or business units. Similarly, Sertic and Zavrski (2011) examined EK as a decision-making factor in the internationalisation of the construction business using institutional theory guidelines. On the other hand, Hilmerson (2014) examined EK's multidimensionality and identified four different profiles of internationalising small and medium-sized firms. The authors concluded that EK is fundamental for a better perception of the foreign market.

In the sports industry, Greenwood et al. (2012) adopted a qualitative method to gain insight into how EK of elite-level coaches could act as an essential source of evidence to aid understanding of sports performance. The study suggested the need for a more systematic and sustained approach to explore how EK can enrich understanding of sports performance. The study revealed that EK of the elite coaches is useful in enhancing sports performance and can support empirical research processes.

EK has also been widely explored in the health sector. Baillergeau and Duyvendak (2016) examined EK's use as a resource for coping with uncertainty in Netherland and developed a typology of EK. The authors demonstrated how EK could be used as a valuable resource by vulnerable people, in responding to new and complex social issues such as mental health, and as an indispensable ingredient for uncertainty and risk situations. Concerning mental health care, three EK dimensions were highlighted: survivors' experience, the experience of care institutions or treatment, and experience of labelling and associated stigma (Baillergeau & Duyvendak, 2016).

In the construction industry, Ng et al. (2005) conducted a study that capitalises on EK for guiding construction procurement selection (CPS). Using Case-based Reasoning (CBR) approach, they developed a prototype KM model and a mechanism for capturing and reusing EK for guiding CPS decisions. The prototype made provision for an adaptation strategy which allows for 'what-if' scenario that is useful for decision-makers in an increasingly uncertain environment like construction. With specific relation to EK and BI, Vass (2017) conducted a study on EK's impact on the perceived business value of BIM. The study aims to increase the understanding of individuals' perception of the business value of BIM in the construction industry across the globe.

The above discussion revealed how EK had been applied in different industries to address various issues, such as cost implications of firms' internationalisation, improved decision-making, enhanced understanding and performance, and reduced uncertainty. Construction can also leverage EK from previous projects to improve decision-making and minimise uncertainties associated with each project through effective integration into BI. After examining the meaning of EK and documenting its application across various disciplines, it is important to examine various sources of EK. Understanding the EK sources will help demystify its abstract nature and suggest how best to capture it for integration for improved decision-making in BI.

As mentioned above, EK is a type of knowledge that is acquired through experience (Fieser, 2019). EK aligns with empiricism as its epistemological perspective, which argues that experience is the only way to acquire knowledge and induction as its reasoning approach. Concerning EK sources, Fieser (2019) identified four sources to include: sensory perception, introspection, memory, and testimony. Fieser (2019) argued that EK could be acquired through the five sensory organs (sight, smell, touch, hear and taste), which serve as outlets to the real world. This perception involves a personal touch with reality as experienced by individuals. Introspection has to do with experiencing one's mental state. Memory is like a recorder that captures every experience for recollection. The recollection process of past experiences also constitutes another experience – a new knowledge. Testimony involves relying on narrations from others who had experienced a phenomenon through their sensory organ. These sources of EK can be manifested in BI in the forms of creativity (introspection), best practices (perception), lessons from past mistakes (memory), mentoring, brainstorming and communities of practice (testimony). In another study, Kivrak et al. (2008) indicated that the most important sources of knowledge required to be captured in the organisations are knowledge from the colleagues, company's experience, personal experience, company documentation, and current project documentation. Regardless of the source, EK has peculiar natures that should be understood, especially when it has to be integrated into BI.

2.4.3 **The Nature of EK**

After introducing the concept of EK and various sources of EK (section 2.4.2), it is important to discuss EK's peculiar nature to appreciate why and understand how it can be integrated into BI to improve decision-making. According to Nickols (2000), knowledge derived from experience (EK) can be categorised into tacit, implicit and explicit knowledge. Tacit knowledge refers to knowledge that cannot be easily articulated. Implicit knowledge, though can be articulated has not been articulated; while explicit knowledge is that knowledge which has been articulated. However, Fazey et al. (2006) separated EK into expert and non-expert knowledge. Expert knowledge refers to individuals' extensive knowledge through experiences that influence what and how they perceive, organise, interpret, and react to information compared to non-experts. Experts are able to foresee issues and make reasonable predictions based on experience, even if they are unable to explain how. Professionals who have participated in the implementation of many BIM-enabled projects will have developed a deep understanding of the process to exhibit the hallmarks of experts. Though it is possible to articulate some of the experts' EK, the real value of their knowledge manifests while faced with BI's real-life challenges in areas that they are well-experienced. Accordingly, Bransford et al. (2000) argued that experts' EK is beyond just memory and intelligence.

As proposed by Polanyi (1962) and expounded by Nonaka and Takeuchi (1995), the distinction between tacit and explicit knowledge has been projected as the most popular distinction within the field of KM. Tacit knowledge is a subjective and experience-based knowledge that cannot be easily articulated in words, sentences, numbers or formulas because it is context-specific (Nonaka, 1997). Tacit knowledge draws on the accumulated experience and learning of a person, which is hard to reproduce or share with others. It represents knowledge based on individuals' experience, which is expressed in human actions in the form of evaluation, attitudes, points of view, commitments, and motivation (Nonaka et al., 2000). It is the knowledge embedded in a person's memory that is difficult to extract and share with others (Abdullah et al., 2002). Therefore, EK is a form of tacit knowledge embedded in people's head based on sensory perception, introspection, memory, or narration from other people with personal experience with the phenomenon. This type of knowledge includes cognitive skills such as beliefs, images, intuition, mental models, and craft and technical know-how (Nonaka, 1997). It is regarded as the most valuable source of knowledge which is most likely to lead an organisation to breakthrough (Brown & Duguid, 1998) through effective decision-making. One of the peculiar natures of EK is it's 'tacitness'. EK's tacit nature makes it difficult for experts to easily articulate how and what they are doing. Figure 2. 9 shows the relationship and meaning of explicit and tacit knowledge.

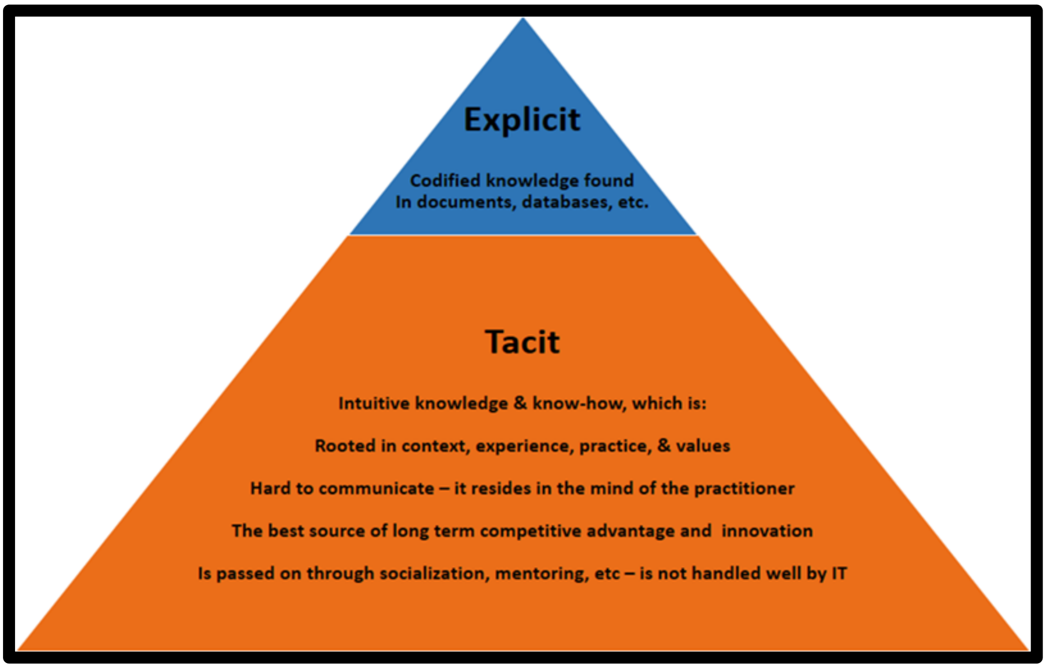


Figure 2. 9: Relationship between tacit and explicit knowledge. Source: Frost (2013).

Another peculiarity of EK is its abstract and sticky nature. EK is implicitly embedded in the head and mind of knower and difficult to separate. The abstract and sticky nature limits experts' ability to objectively translate their experiences into accurate, explicit information (Sterman, 2000). Since EK largely remains in individuals' heads, disseminating such knowledge in an organisation may involve the transfer of the knowledge carrier from one part of the organisation to another, i.e. from one project to another. This transfer poses some challenges within the KM community. The problems involve the risk, cost and time in transferring people from one location to another.

Nonetheless, leaving tacit knowledge in the head of individuals within an organisation also creates the risk of losing the knowledge if the person becomes incapacitated, retire from the organisation or bought over by competitors (Sanchez, 2012). Storing and processing EK in the brain makes it difficult to qualify why and how something is known, and difficult to recalibrate it against quantitative and other forms of 'scientific' knowledge (Bransford et al., 2000). Hence, there is a need to devise a means of capturing and sharing EK among professionals working together to improve the quality of decisions made within and across BIM-enabled projects.

According to Storkerson (2009), other EK peculiarities include intuitive, dependent on memory and recognition, heuristic, domain-specific, and holistic. Intuition refers to an expert's ability to make good judgement or decision based on years of practice and socialisation (Nimkulrat et al., 2015). EK is domain- and context-specific as it is based on a unique set of experiences within a specific domain or context. BI is a domain-specific discipline within the construction industry. Construction projects are unique and context-specific. This specificity of EK limits its application only to relevant domain and context. The difficulty in capturing and translating this knowledge into tangible product or process raises two issues for organisations: identifying holders of such knowledge and accessing the knowledge when needed (Debowski, 2006). Botha et al. (2008) concluded that there is a limit to which technology can help capture and transfer EK, which is tacit, abstract, sticky, context-specific, intuitive and resides in the human mind. Failure to understand EK's peculiar nature and difficulty in capturing and sharing EK accounts for little values people placed on it.

A good understanding of EK's nature suggests that it can provide alternative or additional perspectives to the way people perceive and respond to issues. Since people tend to place less value on EK due to its nature, the next subsection will review and document EK's values and why it is important to integrate it into BI to improve decision-making in building construction projects.

2.4.4 **The Values of EK**

Having highlighted EK's peculiar nature, this subsection will briefly discuss the potential values of EK that necessitated its integration into BI. Some researchers have documented the benefits accruable from integrating EK and BIM approaches to the construction industry. According to Bhatija (2017), integrating EK into BIM can facilitate effective projects management and team collaboration, increase efficiency and productivity by saving time and efforts spent on locating and reusing domain knowledge. Utilising experts' experiences can also reduce redundancy and rework in BIM projects (Jallow et al., 2013). Besides, the integration enhances effective communication among project stakeholders, allows capturing and sharing useful knowledge, compresses learning curves, and is useful in responding to uncertainties (Bhatija, 2017).

According to Ruess and Tatum (1993), transferring EK between projects can positively enhance project objective achievement in terms of cost, schedule, quality and safety. It can enable teams and organisations to repeat successful methods and techniques and avoid repetition of past mistakes and problems. EK's significance for decision-making has been recognised across many sectors ranging from individual to political decisions (Blume, 2017). Given the values accruable from EK in terms of response to uncertainty which often characterised building construction projects, it is imperative to integrate it into BI for improved decision-making. The next sub-section will provide an insight into the challenges associated with EK to harness the full benefits of EK.

2.4.5 **Challenges Associated with EK**

Regardless of the potential values accruable from EK, as discussed in subsection 2.4.4, it is essential to acknowledge and understand EK's challenges. EK's tacit nature suggests that it is held in human minds and or heads; hence, it poses a challenge regarding its extraction from the minds and heads of the people. As a product of human interaction with one another and people's interaction with the environment (Al-Hawamdeh, 2002), EK is challenging to articulate and codify. An attempt to make EK explicit will change its nature and lose its value as it may no longer be linked with humans. It may simply reduce it to mere information.

Meanwhile, implicit knowledge (otherwise known as know-how) of experts' experience, can be articulated and documented. Most of the experiences acquired by BIM experts during BI are very difficult to document. However, Fazey (2006) argued that rigorous qualitative techniques, such as observation and mentoring, can help overcome the challenges of capturing EK of experts. EK from previous BIM-enabled projects can be communicated through consistent and extensive relationships or interaction, such as the community of practice (Gemma, 2014). Such interactions should take place under circumstances that encourage people to share their ideas and develop new insights together, which will lead to the creation of new knowledge (Pasha & Pasha 2012).

Another challenge associated with EK is identifying who has it or estimating the amount (quantify) possessed by individuals. Since EK can not be articulated easily, and since people probably know more than they actually think they know (Polanyi, 1966), it is difficult to accurately and objectively identify who has sufficient experience to perform a task. Mahroeian and Forozia (2012) argued that unconsciousness and the inability to articulate EK effectively are responsible for its challenges. Since anybody to lay claim to EK, it is difficult to access and quantify it objectively. The fact that somebody claimed to have participated in many BIM-enabled projects is not necessarily a guarantee that he has sufficient experience to deliver on another project.

The inability to generalise experiences from a particular project over all other projects also poses a challenge to EK's application. Construction projects are regarded as very unique, each with a unique site, materials, procurement methods and project team.

For example, there are no two building projects with the same site conditions. The clients' taste and purse often determine the choice of building materials and construction methods. The tendency to disband project teams after every project presents a significant challenge to reusing their experiences in future projects. This disbandment often leads to knowledge loss.

Another critical challenge facing EK is the issue of culture. Culture is a broad term that encompasses the belief, norms and shared values among people. The construction industry is reputed for fragmentation, competitive and highly adversarial (Rooke et al., 2004). The culture of 'knowledge is power' encourages hoarding of valuable EK as people fear that sharing their knowledge may cause them to lose their competitive advantage. The competitive method often adopted for project procurement is also inimical to the sharing of EK as construction firms see themselves as rivals or competitor. This rivalry hinders the exchange of useful knowledge in the form of best practices and lessons learned from past mistakes, which are valuable forms of EK.

Despite the difficulties and challenges associated with EK, almost all organisations depend on it to ensure good-quality choices, judgements and breakthrough (Wellman, 2009). Regardless of the challenges attributable to EK, Storkerson (2009) argued that EK is still very useful for decision-making under uncertainty and provides effective judgments that are actionable in ambiguous situations, such as the ones obtainable during BI in the building construction projects.

2.4.6 **The Role of EK in BI**

The construction industry is a project-based and knowledge-intensive industry where abundant knowledge is generated. Accordingly, knowledge has been identified as a crucial asset for construction organisation as it forms the basis for effective decision-making, enabling competitive advantage (Rowley, 2007). However, construction projects are unique, and their uniqueness requires creativity and innovation on the part of the stakeholders for successful completion (Deshpande et al., 2014). According to Ferrada and Serpell (2014), creativity, ingenuity, and EK play a vital role in decision-making regarding BI's construction tasks and activities. Therefore, EK acquired throughout the lifecycle of a project remains one of the greatest assets of construction organisation involved in BI.

Although BI has been adopted as the standard way of working, the current BI approach still focuses on digital data management and information exchange. This approach limits the exploitation of experience-based knowledge generated from various projects during BI. According to Boyes (2016), EK could play a valuable role in BIM projects and improve decision-making during BI.

Managing EK appears to be an essential thing while implementing BIM on projects. Challenges exist with capturing and integrating experiences from different phases of a project and previous BIM-enabled projects to improve decision-making in other phases or future BIM projects. It is, therefore, important to device a mean for capturing and integrating this vital resource (EK), even it is only conceptually, into BI in order to improve the decision-making process in building construction projects.

2.5 KM for Integrating EK into BI

2.5.1 **Knowledge Integration**

Given the abstract nature of EK as discussed in subsection 2.4.3 and the complexity associated with BI (subsection 2.3.3), the process of integrating EK into BI remains a complex undertaking, requiring the development of a structured process that can facilitate the generation and integration of experience-based knowledge. According to Wethyavivorn and Teerajetgul (2019), the construction industry has no such structured process to capture valuable EK and lessons learned at project-level for integration into BI for future reuse. As a result of the absence of such process, costly and avoidable mistakes are often repeated on projects. However, KM as a management discipline has structures that can help facilitate the integration of EK into BI. These structures are known as knowledge management processes (KMPs). However, it is important to understand what is meant by knowledge integration in order to understand and appreciate the KMPs for the integration.

Previous studies have proposed different definitions of knowledge integration (KI) and identified various approaches to KI within the construction industry. Tell (2011) documented over 30 definitions of KI, in a study of knowledge integration and innovation conducted within the project-based organisations. Table 2. 6 presents some of the definitions and approaches to KI in the literature. However, for this study, *KI refers to a continuous process of identifying, generating, capturing, communicating, and applying* *experience-based knowledge generated within and across BIM-enabled projects, using appropriate tools and techniques in order to improve decision-making.*

Table 2. 6: Definitions and Approaches of KI

Definition	Approaches	Reference
synthesis of individuals' specialised knowledge into situation-specific system knowledge.	Organic approach	Alavi and Tiwani (2002)
an ongoing collective process of constructing, articulating and redefining shared beliefs through the social interaction of organisational members	Organic approach	Huang (2003);
is both the shared knowledge of individuals and combined knowledge that emerges from their interaction	Organic approach	Okhuysen and Eisenhardt (2002)
the process of transferring, translating and transforming knowledge between individuals involved within the same organisation	Mechanistic approach	Carlilo (2004)
a dynamic process which relies on the team's ability to iterate between a variety of specific KI mechanism, some of which are based on face-to-face interaction and communication and some of which are not	Mechanistic approach	Enberg (2007)
the process of jointly applying specialised knowledge held by various alliance partners at the project level	Organic approach	Tiwana (2008)
the process of bringing diverse knowledge from multiple sources to bear on a complex problem or task	Mechanistic approach	Haddad and Bozdogan, (2009)
the process during which individuals, who derived different solutions and experiences in specialised fields, contribute their expertise with the purpose of meeting a shared aim.	Organic approach	Ruan, et al. (2012)
the process of capturing, sharing, and transferring knowledge, both tacit and explicit, within and across the project in order to improve the project performance	Organic approach	Takhtravanchi (2017)
activities such as sharing, broadcasting, searching, or disseminating the knowledge produces by groups or individuals	Organic approach	Piyanut and Wethyavivorn (2019)

The review of the literature suggests that there are two main approaches to knowledge integration. The first approach suggests using tools and techniques such as frequent communication and extensive knowledge, while the second approach stresses the use of structural mechanisms (Enberg, 2012). The first approach, known as cross-learning approach (Schmickl & Kieser, 2008) or organic approach (Stahle, 1999; Pathirage et al., 2005), stressed the need to share specific knowledge. This approach requires substantial levels of associability, proximity, trust, supportive culture and internal bonding among project members to enable KI (Newell et al., 2004; Ruan et al., 2012). For effective KI to take place, project members should be able to capture each other's tacit knowledge through the process of observation, imitation and practice (Nonaka, 1994). KI from the first approach benefits from close interaction among project members (Carlile & Rebentisch, 2003), thereby requiring extensive communication (Enberg, 2012).

The second approach, the mechanistic approach, involves using structural mechanisms for KI (Pathirage et al., 2005). Regarding the second approach, Grant (1996) suggested common knowledge in the form of verbal language (codes) and symbolic communication (computer software) as requirements for KI. While developing a knowledge-based theory of the firm, Grant (1996) itemised four mechanisms for KI: rules and direction, sequencing, routines and group problem solving, and decision-making. The first three mechanisms seek to achieve the integration without the attendant costs of communication and learning cost while the fourth one entails costly communication and interaction, and therefore employed for vital tasks.

To achieve the aim of this study, it is important to ensure that the EK generated from BIM-enabled projects are carefully captured and shared amongst project teams, using the most appropriate tools and techniques. The knowledge captured at one phase of the project can be reused to improve decision-making in other phases of the same project or other future projects. This process of knowledge reuse will minimise repetition of avoidable mistakes and lead to continuous learning and improvement. Accordingly, the organic approach is considered more applicable to this study because it intends to use relevant tools and techniques to facilitate the integration process. This approach which relies on a high level of proximity, trust and internal bond is more suitable for capturing and integrating EK due to its tacitness. The approach relies on the use of appropriate KM process to facilitate knowledge integration. Therefore, the next sub-sections will review the KM processes, strategies, and tools required to effectively integrate EK into BI to explore the most suitable KM process. Various factors impacting on the integration of the EK into BI will also be reviewed.

2.5.2 **KM Processes for Integrating EK into BI**

According to Bigliardi (2014), KMPs provide the necessary structure to facilitate EK integration into BI. The essence of the KMP is to help organisations interested in managing their knowledge asset create, store, use, share and integrate individual and collective knowledge to improve productivity and enhance competitiveness (CEN, 2004).

Accordingly, this section seeks to review existing KMPs relevant to the construction industry with a view to adopting or adapting the most appropriate KMPs for this study. The review of extant literature revealed different taxonomies and categorisations for the processes of managing knowledge in organisations. Table 2. 7 presents a summary of different taxonomies and classifications for KMPs by different authors.

Table 2. 7: Different Taxonomies and Classifications for KMPs.

KM Processes/Activities	Reference
Knowledge creation, manifestation, use, and transfer.	Wiig (1993)
Applying, sharing, creating, identifying, collecting, adapting, and organizing	Arthur Anderson and APQC (1996)
Knowledge generation, codification, and transfer	Ruggles (1997)
Knowledge construction, dissemination, embodiment, and use	Demarest (1997)
Knowledge acquisition, indexing, filtering, linking, distribution, and application.	Alavi (1997)
Knowledge gathering, storage, communication, dissemination, and synthesis	Jackson (1998)
Knowledge creation, transfer, assembling, integration, and exploitation	Teece, (1998)
Knowledge acquisition, retention, search, maintenance, dissemination.	Wijnhoven (1998)
Knowledge generation, processing, storage, dissemination, and use/reuse	Pan and Scarbrough (1998)
Knowledge generation, codification, sharing and application	Davenport and Prusak (1998)
Knowledge acquisition, Refining, Storage and retrieval, Distribution, Presentation	Zack (1999)
Knowledge creation, knowledge retention, knowledge transfer, and knowledge utilisation	Brian and Conrad (1999)
Knowledge creation, distribution, sharing, capturing and codification	Laudon and Laudon (2000)
Knowledge generation, access, transfer, sharing, and codifying	Gottschalk (2000)
Knowledge initiation, generation, modelling, repository/storage, distribution and transfer, use, and retrospect	Lai and Chu (2000)
Knowledge identification; mapping; capturing; acquisition; storage; sharing; application; creation, generation or discovery.	Rastogi (2000)
Knowledge use, search, creation and packaging	Meso and Smith (2000)
Knowledge Sharing, Accessibility, Assimilation, and Application.	Tannembaum and Alliger (2000)
Knowledge acquisition, conversion, application, and protection.	Gold et al. (2001)
Knowledge creation, search, use, and packaging	Marwick (2001)
Knowledge generation, codification, transfer and realisation	Grover and Davenport (2001)
Knowledge creation, codification/representation, classification/indexing, search/filter, share/distribute	Tsui (2002)
Knowledge creation, capturing, sharing, transfer, implementation, exploitation, and measurement	Egbu and Botterill (2002)
Knowledge creation, processing, sharing, capturing and codification	Carrillo et al., (2004)

Knowledge identification, knowledge creation, knowledge store, knowledge sharing and knowledge use	CEN (2004)
Knowledge acquisition, Knowledge dissemination, and Knowledge responsiveness	Darroch (2005)
Locate and access, capture and store, represent, share, and, create new knowledge,	Ruikar et al. (2007)
Knowledge capturing, storing, reusing, and sharing	Kivrak et al., (2008)
Knowledge acquisition, Knowledge creation, Knowledge storage, Knowledge distribution, Knowledge use and maintenance	Fong and Choi (2009)
Knowledge discovery, Knowledge capture, Knowledge sharing and Knowledge application	Fernandez and Sabherwal (2010)
Knowledge creation, capturing and codification, distribution, sharing, use, protection, search and acquisition	Bigliardi et al., (2010)
Identifying knowledge, creating knowledge, storing knowledge, sharing knowledge and applying knowledge	APO (2010)
Knowledge creation, intra-organisational knowledge sharing and application, external knowledge acquisition, and knowledge storage and documentation	Andrea and Kianto (2011)
Knowledge creation, knowledge capture, knowledge transfer, and knowledge reuse	Sokhanvar et al. (2014)
Knowledge creation, search and capture; Knowledge organisation, storage and preservation; Knowledge distribution, transfer and sharing; Knowledge use, reuse and feedback	Bigliardi et al. (2014)
Knowledge capturing, sharing, and transferring	Mohammad (2017)
Knowledge acquisition, sharing, development, preservation, and application	Raudeliūnienė et al. (2018)

Table 2. 7 indicated that previous studies agreed on the need for a KMP to facilitate organisational knowledge management. However, as noted by Bigliardi (2014), it is equally clear that there is yet to be a definite and generally accepted KMPs within the construction industry. Accordingly, Ortiz Laverde et al. (2013) called for lexical standardisation of the available KMPs to avoid the apparent confusion, which could slow down the practical implementation of KM in projects. This study adapted the KMP framework developed by the European Committee for Standardisation (CEN, 2004) to develop its conceptual KMP map to integrate EK into BI effectively to avoid a further proliferation of existing KMPs. The CEN (2004) framework comprises of five integrated processes: identify the knowledge, create knowledge, store knowledge, share knowledge and use knowledge (see Figure 2. 10). After reviewing 160 KM frameworks globally, Heisig (2009) concluded that there is an agreement among KM researchers that these five processes constitute the core KM activities.

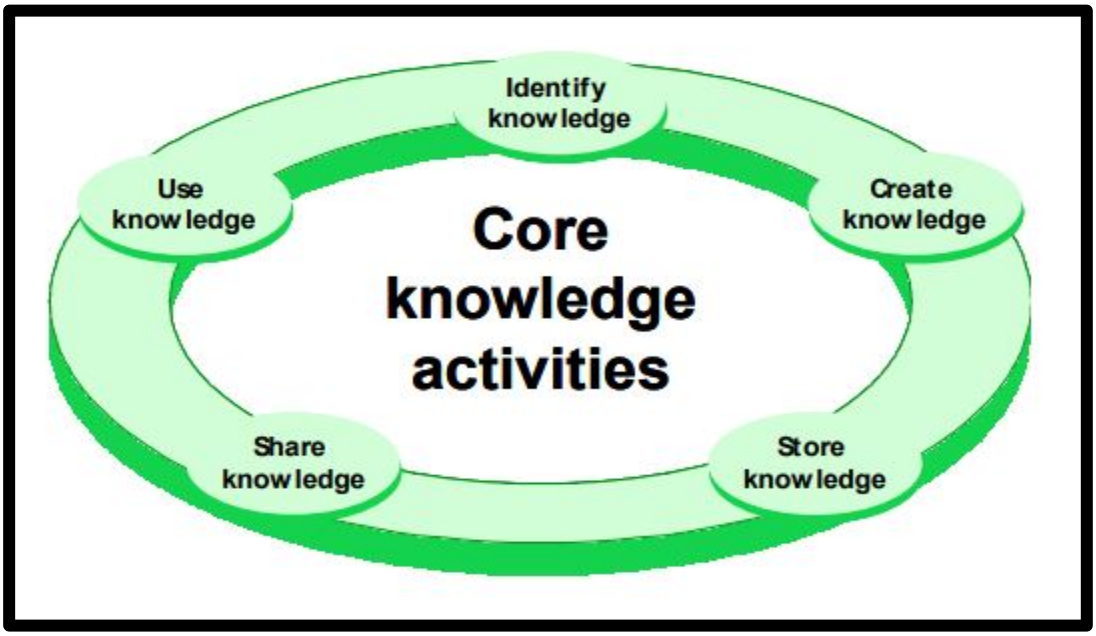


Figure 2. 10: Knowledge Management Process Framework by CEN (2004) adapted for the study.

The CEN 2004 KMP framework was adopted for a number of reasons. First, the framework was explicitly developed from the European perspective, where this study is domiciled. Two, CEN's framework has been described as one of the most effective KMP models ever developed (Dulgerler, 2015). Three, the CEN KMP framework captured the complexity associated with knowledge and aligns more with people's understanding (APO, 2010). Similarly, the Asian Productivity Organisation (APO, 2010) has also adopted the 5-step KMPs for the development of their own KMP. This study, therefore, aligns with the 5-step KM processes developed by CEN (2004). The proposed KMPs for this study are knowledge identification, knowledge generation, knowledge capturing, knowledge communication, and knowledge application, are briefly discussed below. These processes provided the framework with the basis for data collection and analysis regarding KM tools and techniques.

i. Knowledge Identification: This process is usually the first stage in KM. It is a crucial process whereby individuals and organisations consider what needs to be done and the knowledge required. The essence is to make visible available and needed knowledge assets within an organisation. It involves identifying the available knowledge asset, required or needed knowledge that may not be readily available, knowledge sources, and how to get the knowledge. It is useful for assessing the individual and organisation competencies. An organisation ability to leverage existing knowledge within the organisation will depend on its ability to identify available and required knowledge within an organisation effectively. Knowledge identification ensures the continuity of the process by identifying new knowledge to support decision-making during BI (CEN, 2004). Effective knowledge identification requires the use of relevant KM tools and techniques.

ii. ***Knowledge Generation:*** Knowledge generation involves the process of creating new knowledge or acquiring existing knowledge to improve decision-making or solve existing problems within the organisation boundaries (Semertzaki, 2011). Through this process, new knowledge is created or acquired from internal or external sources and added to the organisational knowledge base. It can bridge the differences between the various sources of knowledge in the organisation and the environment (Kraaijenbrink & Wijnhoven, 2008).

Knowledge creation often takes place within the context of social systems (Alavi & Tiwana, 2002). It can take place at an individual level through social interaction, joint problem solving, mentoring, or brainstorming (CEN, 2004; Garud & Nayyar, 1994); at team level through collaborative activities like communities of practice, knowledge network, brainstorming, and strategic communities (Kodama, 2005); or at organisation level through organisational learning (Argyris, 2004). On the other hand, knowledge acquisition involves the process of extracting, structuring, and organising knowledge from various specialities and expert networks (Singh, 2013). During knowledge acquisition, both the existing knowledge and the newly acquired knowledge should be synthesised such that reliable inferences could be drawn for effective decision-making (Singh, 2013). The goal is to generate new knowledge as well as synthesise existing knowledge to improve decision-making during BI. Knowledge acquisition involves the use of appropriate KM tools such as social interaction, internet, conference and communities of practice.

iii. ***Knowledge Codification:*** Another KM process proposed for the integration of EK into BI is knowledge capturing. Several studies have identified knowledge capturing as vital KM process (Carrillo et al., 2004; Kivrak et al., 2008; Dzekashu et al. 2014; Bigliardi et al., 2014). The temporary nature of construction projects and its project team requires that construction knowledge be adequately captured and stored for future reuse. However, capturing knowledge from construction projects is a tedious task (Kivrak et al., 2008) due to the tacit and experience-based nature of knowledge. Adequate knowledge capturing for reuse is critical to successful project execution, useful for decision-making and vital for organisational survival (Deshpande et al., 2014). Accordingly, many studies have been carried out on how to capture construction knowledge (e.g. Tsreng and Lin, 2004; Lin et al., 2005; Kivrak et al., 2008).

Storing knowledge requires that the generated knowledge is embedded within the organisation. EK often remains in people's brain or 'stored' in teams or organisational routines. EK can also be secured by institutionalising it within the organisation's structure, processes and culture (CEN, 2004). Knowledge capturing is considered a critical process for integrating EK into BI. Appropriate KM tools and techniques such as knowledgebases, intranet/extranet, mentoring, communities of practice, training can facilitate knowledge capturing (Hizar & Hassan, 2012; Al-Ghassani et al. 2002).

iv. ***Knowledge Communication:*** This process involves conveying knowledge from one place, person or ownership to another, resulting in accumulation or assimilation of new knowledge (Liyanage et al., 2009). Knowledge communication involves transferring or sharing the captured knowledge to the point of need. Knowledge transfer is often a one-way process of communicating knowledge, usually from mentors (the source) to mentees (the receiver). It involves the movement of knowledge across boundaries created by specialised knowledge domains (Carlie & Rebentish, 2003). On the other hand, knowledge sharing is a two-way process of knowledge communication (Ryu et al., 2003) between individuals who mutually exchange their knowledge (Truch et al., 2002). Knowledge communication can occur better in an informal setting through effective collaboration and networking, either physically (face-to-face) or virtually (online). The essence of knowledge communication is to disseminate knowledge, and methods can include interpersonal communication, mass media, and social networking outlets. According to Liebowitz (2002), the purpose of the knowledge communication process is to create a knowledge sharing and transfer culture through collaboration to enhance organisational innovation. Communication of EK requires informal social settings with a high level of trust between the members.

v. ***Knowledge Application:*** Knowledge application refers to the processes through which knowledge is turned into practical action (Alavi & Leidner, 2001) or use knowledge to effectively make decisions (Ortiz Laverde et al., 2013) and perform tasks (Becerra-Fernandez & Sabherwal, 2010). Knowledge identification, creation, capturing and communication do not guarantee improvement, nor do they create value unless applied where needed (Alavi & Tiwana, 2002). The extent to which organisation exploit and apply EK to their critical operations will determine the value derived from it (Alavi & Tiwana, 2002). This process should always serve as reference points for other processes since it determines the needs for the knowledge (CEN, 2004).

Knowledge application includes adaptation and utilisation of the knowledge. Knowledge adaptation involves innovative re-evaluation and reconfiguration of available knowledge for appropriateness to suit the current situation. This is because not all available knowledge is relevant or useful for decision-making. Knowledge adaptation becomes crucial because of the context-specific nature of every construction project. Knowledge utilisation, however, refers to the capability to make knowledge accessible and usable in such a way that it can be applied within the organisation or used for any other purpose as may be deemed applicable (Kraaijenbrink & Wijnhoven, 2008). Knowledge application requires appropriate KM tools and techniques such as job rotation, mentoring or seminar.

After identifying and discussing the KMPs for integrating EK into BI, it is essential to identify the KM tools/techniques that can support the integration. Consequently, in the next sub-section, a review of available tools and techniques used for managing knowledge is carried out to identify the appropriate KM tools and techniques that can support the integration of EK into BI for improved decision-making.

2.5.3 **KM Tools and Strategies for Integrating EK into BI**

There are few definitions for KM tools in the literature. Ruggles (1997) defined KM tools as the ‘technologies’ used to enhance and enable the implementation of the sub-processes of KM. Gallupe (2001) referred to KM tools as the primary technological building blocks of any specific KM system (KMS). KM tools are meant to serve as enablers for business processes that create, store, maintain and disseminate knowledge (Tsui, 2003). Therefore, a useful KM tool should be able to support each part of the KM process such as knowledge generation, capturing, storage, sharing, transfer, use, and reuse (Alavi & Leidner, 2001).

While most authors use the term ‘tools’ to refer to KM technologies (Egbu et al., 2003), Al-Ghassani et al. (2005) and Ruikar et al. (2007) made a distinction between ‘KM techniques’ and ‘KM technologies.’ They suggested that the term ‘KM techniques’ should be used for non-IT tools, while ‘KM technologies’ should be used for IT tools. In line with this suggestion, (Bigliardi et al., 2014) identified two different strategies to KM implementation, namely: an IT-centric (system-oriented) strategy and a people-centric (human-oriented) strategy. Tang et al. (2010) referred to these strategies as codification and personalisation strategies. The system-oriented strategy emphasised codifying and storing knowledge using technology (Choi & Lee, 2002). The strategy focuses on using IT tools such as electronic databased, ERP, internet and intranet, to facilitate the KM processes.

On the other hand, the human-oriented strategy emphasised dialogue through social networks for obtaining knowledge from experienced and skilled people (Choi & Lee, 2002). This strategy emphasises non-IT techniques such as brainstorming, meetings, direct observation, lessons learned on previous projects, as means to motivate and facilitate knowledge workers to develop, enhance and use their knowledge to achieve organisational goals (Bigliardi et al., 2014). Table 2. 8 summarises the distinctions between KM techniques and KM technologies.

Table 2. 8: Distinction between the two KM Tools

KM Techniques	KM Technologies
Require strategies for learning	Require IT infrastructure
People-centric strategy	IT-centric strategy
Affordable to most organisation	Expensive to acquire and maintain
More involvement of people	Require IT skills
Easy to implement and maintain	Sophisticated to implement and maintain
Focussed more of tacit knowledge	Focussed more on explicit knowledge
Examples include: Brainstorming, Face-to-face interaction, Training, Storytelling, Communities of Practice, Recruitment	Examples include: Data and text mining, Groupware, Intranet/extranet, knowledge bases, Taxonomies/ ontologies

Source: Adapted from Al-Ghassani (2005), Ruikar et al., (2007) and Bigliardi et al., (2014)

However, the third KM strategies perspective strikes a balance between system- and human-oriented strategies by integrating IT tools and non-IT (Choi & Lee, 2002; Tiwana, 2000). Given EK's abstract nature and the complexity associated with its integration with BI for improved decision-making, this study acknowledged the balanced perspective of KM strategy that integrated IT tools and non-IT techniques. Similarly, the pragmatic philosophical stance adopted for the study suggests that both the system and human-oriented perspectives along with their IT and non-IT tools can find relevance in this study. In essence, KM tools (either IT or non-IT based) are regarded as enablers supporting KM processes and facilitating effective integration of EK into BI. However, the stickiness and abstract nature of EK seems to align more the human-oriented strategy and therefore, can better be managed with non-IT techniques such as face-to-face interaction, brainstorming, mentoring and communities of practice.

Many studies have been carried out to identify appropriate tools that support different KMPs within and outside the construction industry, and across different countries. For example, Carrillo et al. (2004) investigated the main tools and techniques adopted by 170 UK construction firms and discovered that the tools and techniques were generally based on the concept of 'artificial intelligence' and were effective for decision support systems (DSS). The study also revealed that 90.5% of the companies use the intranet to support their KM process while communities of practice (CoP) is perceived as an emerging technique for KM, especially in large construction companies. Similarly, Kivrak et al. (2008) investigated the main tools for storing knowledge within Turkish construction companies. The investigation's result aligned with the findings of similar research conducted by Kasvi et al. (2003) in Finland.

Egbu and Botterill (2002) also carried out a study to determine the level of usage and effectiveness of technologies and techniques for KM among project-based organisations in the UK construction, manufacturing, aerospace and the utilities. The result of the study highlighted telephone, internet/intranet, documents and reports, and face-to-face meetings as the most frequently used techniques and technologies in the construction organisations. The most effective technologies and techniques are the telephone, face-to-face meetings, documents and reports, and interaction with the supply chain. However, the least ranked technologies and techniques are video-conferencing, groupware and knowledge maps. Fong and Choi (2009) carried out a similar survey in Hong Kong among the construction companies and examined the tools, techniques and sources of KM process adopted. The result revealed that the use of databases/libraries as the most adopted for maintaining knowledge.

In line with the previous studies developed within the construction industry, Bigliardi et al. (2010) identified information and communication technologies (ICTs) as the most useful tools to manage knowledge. They went further to classify the ICTs tools according to the KM process they support. In 2014, Bigliardi et al. repeated a similar study among 14 civil construction organisations in Italy to determine their KM processes and tools they were using. The study's result confirmed the use of both IT and non-IT tools as prevalent within the Italian construction industry. The Asian Productivity Organization (2010) compiled twenty KM methods and tools implemented by the most successful organisations worldwide within their KM implementation initiatives. The methods and tools were categorised as non-information technology (non-IT) and information technology (IT) methods and tools. For each of the KM steps, some KM methods and tools were suggested to guide its use. Table 2. 9 presents a summary of the KM tools and techniques considered to be useful for knowledge integration within the construction industry.

Table 2. 9: Summary of KM Tools and Techniques for Knowledge Integration

S/N	Tools and Techniques	References
01	Communities of Practice (e.g. BIM Hub)	APO (2010), Ruikar et al. (2007), Bigliardi et al. (2014),
02	Conferences and Seminars on BIM	Ruikar et al. (2007), Bigliardi et al. (2014), Plyasunov et al. (2017),
03	Job Rotation/Experience Swapping or Secondment of BIM Experts	Egbu & Botterill (2002), Fong and Choi (2009), Bigliardi et al. (2014)
04	Mentoring/Apprenticeship/Training on BIM	CEN (2004), Hizar & Hassan, (2012), Al-Ghassani et al. (2002), Bigliardi et al. (2014), Ruikar et al. (2007), Fong and Choi (2009)
05	Collaborative Workspace containing BIM Experts	Kodama (2005), APO (2010),
06	Brainstorming/Group Discussion regarding BIM	Egbu & Botterill (2002), Ruikar et al. (2007), APO (2010), Bigliardi et al. (2014), Plyasunov et al. (2017)
07	Storytelling/Oral Narrations about BIM Projects	CEN (2004), Kivrak et al. (2008), APO (2010)
08	Intranet/Internet/Website on BIM-enabled Projects (e.g. IMRB)	Egbu & Botterill (2002), Carrillo et al. (2004), Ruikar et al. (2007), APO (2010), Bigliardi et al. (2014)
09	Video Conferencing/Audio Conferencing among BIM Experts	Carrillo et al. (2004), Ruikar et al. (2007), APO (2010), Bigliardi et al. (2014)
10	Expertise Locators of BIM Experts (e.g. Yellow pages)	Carrillo et al. (2004), Ruikar et al. (2007), Fong and Choi (2009), APO (2010)
11	Electronic Chatroom for BIM Expert (e.g. Yammer)	Carrillo et al. (2004), Fong and Choi (2009),
12	Social Networking Tools for BIM Experts (e.g. LinkedIn)	APO (2010), Plyasunov et al. (2017), Bigliardi et al., 2014)
13	Interviews of BIM Experts	Egbu & Botterill (2002), Ruikar et al. (2007), Plyasunov et al. (2017), Bigliardi et al., 2014),
14	Questionnaire Surveys of BIM Experts	CEN (2004), Plyasunov et al. (2017), Bigliardi et al. (2014)
15	Post Project Evaluation of BIM-enabled Project	Ruikar et al. (2007), Egbu & Botterill (2002), Fong and Choi (2009), APO (2010), Bigliardi et al., 2014),

From the above discussions, it can be deduced that the integrated strategy will be more relevant to this study. However, EK's stickiness and abstract nature seem to align more the human-oriented strategy and, therefore, can better be managed with non-IT techniques such as face-to-face interaction, brainstorming, mentoring, and communities of practice. KM techniques are deemed most relevant to support the processes for capturing and integrating EK into BI. However, the role and relevance of some conventional KM technologies (such as telephone, intranet/extranet) are also acknowledged. This position lends itself towards the integrated perspective of tools and techniques (Pathirage et al., 2005), emphasising the KM techniques based on the nature of EK. Accordingly, the terms tools, techniques and methods are used interchangeably. After establishing the role of KM in integrating EK into BI using appropriate KMPs and KM tools, the next section will review factors impacting on the effective integration of EK into BI.

2.5.4 **Factors impacting on Integration of EK into BI**

Several factors can influence the ease and effectiveness of integrating EK into BI. Some authors have investigated and identified factors impacting on successful knowledge integration processes. For example, Jin and Kotlasky (2012) referred to these factors as antecedents of knowledge integration and classified them into four categories, namely: knowledge attributes, social factors, organisational capabilities, and task characteristics. The knowledge attributes have to do with whether the knowledge is internal or external, tacit or explicit, localised, embedded or invested in the practice. Social factors affecting knowledge integration include trust, culture/climate, structure (team, project, organisation or network), team identification, socio-cultural boundaries. Factors listed under organisational capabilities include experiences, expertise, extensible capacity, and technological capability, while task-related factors include contractual terms/strategic objectives, task complexity, and task uncertainty.

Lin et at. (2012) documented some factors impacting on knowledge integration from previous researchers to include: organisational structure, combinative capability, relational capital, and absorptive capabilities (Tiwana & Mclean, 2003); formal intervention (Okhuysen & Eisenhardt, 2002); principle, content, process, and fame (Ferrari & Toledo, 2004); coordination and socialisation capabilities within teams (De Boer et al., 1999); and frequent communication and team identification (O'Reilly III et al., 1989). The study concluded that social integration is an essential mediator between interpersonal attraction and knowledge integration in information systems development projects.

Shin et al. (2001) described organisations as a knowledge processing system and went further to identified appropriate organisational infrastructure, organisational culture, organisational structure, routines, incentives system, and management philosophy as factors influencing knowledge integration. Organisations' internal social capital, organisational culture, and organisational learning have also been identified as factors positively impacting knowledge integration (Xie et al., 2007; Zhou, 2007), while the individuals' willingness, teams and organisations can obstruct knowledge integration (Sabhewa, 2005). Since individuals, teams and organisations willingness has been identified as possible obstructions to knowledge integration, it would important to explore further these factors. More so that building projects are often handled by organisations using projects teams that comprise individuals to implement BIM.

In a recent study, Takhtravanchi and Pathirage (2018) classified the critical factors influencing knowledge integration within construction traditional procurement projects under three major themes: organisational culture, contractual boundaries, and KM system. Organisational culture encompasses open environment factors like mutual trust, willingness to share knowledge and enough time for KI activities. Contractual boundaries are influenced by the clear liability of project team for knowledge sharing throughout the project life cycle. KM system factors include the adoption of proper tools for KI, improving importance awareness of KI, building trust, incentivising team members to participate in KI, clear definition of objectives, among others. The study concluded that open environment and clear liability of project team for knowledge sharing are the two critical success factors influencing project managers during KI process within construction projects.

Wong (2005) proposed a model of 11 factors for KM in small and medium enterprises (SMEs) within the construction industry. The factors are management and leadership support, culture, information technology, strategy and purpose, measurement, organisational infrastructure, process and activities, motivational aids, resources, training and education, and human management resources. Fong and Chu (2006) conducted exploratory research of knowledge sharing in the tendering department of contracting companies in Hong Kong and the UK. The study ranked 15 critical factors affecting knowledge sharing in this order: time, funding, sharing space, technical support, practices or channels for sharing, common language, incentives and rewards, company's culture, trust-building between colleagues, experience colleagues, colleagues' awareness and attitudes, colleagues' participation and awareness, top management support and commitment, km policies and strategies, and understanding the benefits of knowledge sharing. All the above studies only emphasised the KM factors for knowledge integration. Since this study is interested in integrating EK into BI, it will be important to review the factors that are influencing BI.

Many studies have also been conducted on factors influencing BI. Antwi-Afari et al. (2018) reviewed publications on CSFs for BI between 2005 and 2015. The study suggested that five key CSFs for BI during the period were: collaboration among AEC stakeholders, early and accurate 3D visualisation, coordination and planning of construction work, enhancing the exchange of information, and KM and improved site layout planning and site safety. Amuda-Yusuf (2018) analysed the 28 factors earlier identified by Ugwu and Kumaraswamy (2007) within the Nigerian construction context. The result of the analysis, using the rotated component matrix method, grouped the 28 CSFs into five components: industry stakeholders' commitment and knowledge of BIM, Capacity building for technology adoption, Organisational support, Collaborative synergy among industry professionals and cultural orientation.

Ozorhon and Karahan (2016) conducted a study on BI's CSFs within the Turkish construction industry. The study's result revealed the most critical factors: availability of qualified staff, Effective leadership, availability of appropriate information and technology, coordination among project parties, training of employees, and experience level within the firm. The factor analysis of the 16 CSFs revealed the following underline factors: human-related, industry-related, project-related, policy-related, and resource-related factors.

It can be deduced from the above discussion that different sets of factors have been put forward for KI and BI by different authors. The analysis of these factors also revealed that their influence on the integration process could either be positive or negative. When they positively influence the process, they are regarded as drivers for the process while they serve as inhibitors or barriers if their influence negatively affects the integration process. However, there is a paucity of study on factors impacting on the integration of EK into BI. Previous studies have considered these factors separately. There is yet to be a study that considers the factors that impact integrating EK and BI. This knowledge gap suggests the need to explore factors that can impact the effective integration of EK and BI. In order to address this gap, the study grouped these factors into three: individual-related, team-related, organisation-related factors for easy investigation in a questionnaire survey. This classification is based on the framework developed by Lertpittayapoon et al. (2007) and adopted by Nooshinfard and Nemati-Anaraki (2012). The classification is also in line with Sabhewa's (2005) suggestion that individuals, teams and organisations factors can obstruct effective knowledge integration. Table 2. 10 presents the classification of the factors from the literature for data collection and analysis.

Table 2. 10: Classification of Factors Impacting on Effective integration of EK to BI

Factors	References
Individual-related Factors	
Level of face-to-face interaction among individual colleagues	Goh (2002); Amuda-Yusuf (2018); Antwi-Afari et al. (2018); Clarke and Rollo (2001), Maznevski & Chuboda, (2000), Cascio and Shurygailo (2008); Nesan (2012)
Willingness and ability of individuals to freely share experiential knowledge	Fischer (2013); Wu & Lin (2013), Pinto (2007); Manataki (2007); Adetunji (2005); Wong (2005); Goh (2002); Egan (1998)
Level of involvement and participation of individuals in decision-making	Fong and Chu (2006); Takhtravanchi and Pathirage (2018); Chong and Choi (2005); Nesan (2012)
Rewards and incentives for individuals involved in integrating experiential knowledge	Liebowitz (1999); Shin et al. (2001); Fong and Chu (2006); Bloice and Burnett (2016); Hsiu Fen (2016); Nesan (2012)
Effective and honest communication among individual colleagues	Shang and Shen (2014); Yaakob et al. (2016); O'Reilly III et al. (1989); Sebastian, (2007), Dainty et al. (2006), Armstrong (2001); CEN (2004); Nesan (2012)
Level of training, education and apprenticeship available to individuals	Ozorhon and Karahan (2016); Wong (2005); Chong and Choi (2005); Enegbuma and Ali (2011); Shang and Shen (2014); Yaakob et al. (2016); Nesan (2012)
Level of trust among individuals involved in integrating experiential knowledge	Arif et al. (2015), Lau and Rowlinson (2011), Lau and Rowlinson (2010), Khalfan et al. (2007), McDermott et al. (2005), Weber and Carter (1998); Goh (2002); Fong and Chu (2006); Shang and Shen (2014); McManus et al. (2016); Nesan (2012); Saini et al. (2017)
Individual's level of creativity	Baskerville & Dulipovici (2006), Baird & Henderson, (2001); Nesan (2012)
Project Team-related Factors	
Open and collaborative discussions among project team members	Clarke and Rollo (2001); Goh (2002); Antwi-Afari et al. (2018); Gold et al. (2001)
Availability of adequate time for activities to integrate experiential knowledge among project team	Fong and Chu (2006); Takhtravanchi and Pathirage (2018); Holsapple and Joshi (2000); CEN (2004); Nesan (2012)
A knowledge-oriented culture among the project teams that encourages creative and innovative ideas	Skyrme and Amidon (1997); Davenport et al. (1998); Lee and Choi, (2003); Chong and Choi (2005); Khorakian et al. (2015); Ayub et al. (2016)
Availability of appropriate KM tools for integrating experiential knowledge among project team	Liebowitz (1999); Takhtravanchi and Pathirage (2018);

Early composition of project team members and their continuity on the project	Takhtravanchi and Pathirage (2018); Nesan (2012)
Well-defined KMP for integrating experiential knowledge among the project team.	Skyrme and Amidon (1997); Tan (2012); Arif et al. (2015), Balasubramanian (2012), BIS (2011a, 011b), Khalfan et al. (2007), Wong (2005), Yusuf et al. (1999), Egan (1998)
Level of commitment to knowledge integration activities among the project team.	Al-Alawi et al. (2007); Du et al. (2012); Dulaimi (2007); Peet (2012); Wu and Lee (2016); McKenzie et al., (2001); Yongsun et al., 1996).
Level of mutual understanding and trust among project team	Arif et al. (2015); Lau and Rowlinson (2011); Lau and Rowlinson (2010); Khalfan et al. (2007); McDermott et al. (2005); Weber and Carter (1998); Goh (2002); Takhtravanchi and Pathirage (2018); Fong and Chu (2006); Shang and Shen (2014)
Project team motivation, and presence of motivational aids	Arif et al. (2015); Aiyewalehinmi (2013); Lau and Rowlinson (2011); Rose and Manley (2011); Lau and Rowlinson (2010); Tabassi and Bakar (2009); McDermott et al. (2005); Wong 2005); Goh (2002); Nesan (2012); Saini et al. (2017)
Level of complexity of the projects	Kanter, 1998); Jin and Kotlasky (2012)
Organisational-related Factors	
Organisation's leadership support for, and commitment to activities relating to the integration of experiential knowledge	Maier (2007), Wong (2005); Tiwana (1999); Egan (1998); Chong and Choi (2005); Arif et al (2015); Fong and Chu (2006); Humayun & Gang (2012); Issa and Haddad (2008); oonJain et al. (2007); Ruikar et al. (2005); Liu et al. (2015); Ozorhon and Karahan (2016); CEN (2004); McManus et al. (2016); Tsai et al. (2014); Saini et al. (2017)
Organisational culture (beliefs and values) that encourages activities relating to the integration of experiential knowledge (e.g. experimentation)	Shin et al. (2001); Newell et al. (2004); Fong and Chu (2006); Xie Hongming et al., (2007); Zhou Xiao, (2007) Ruan et al. (2012); Shang and Shen (2014); Yaakob et al. (2016); Ozorhon and Karahan (2016); Takhtravanchi and Pathirage (2018); Khosrowshahi and Arayici (2012)
Organisation's efficiency at leveraging experiential knowledge to improve decision-making	Wong and Radcliffe (2000); Egbu (1999); OST (1995); Lu et al. (2018)
Flexible organisational structure that encourages activities for integrating experiential knowledge through lateral communication	Lin et at. (2012); Shin et al. (2001); Tan (2012); Shang and Shen (2014)
Organisational reward systems that incentivise activities for integrating experiential knowledge	Fong and Chu (2006); Liebowitz (1999); Shin et al. (2001)
Organisational infrastructural systems that support the integration of experiential knowledge (e.g. open workspace)	Davenport et al. (1998); Shin et al. (2001); Wong (2005); Zhang et al. (2008); Chong and Choi (2005); McManus et al. (2016)
The size of the organisation (e.g. small, medium or large)	Ozorhon and Karahan (2016)
Organisational transparency and openness	Casimir (2012); Lee et al. (2010); O'Neil and Adya (2007); Smith (2005)

2.6 Previous Studies on KM and BI

Given the increasing importance of knowledge as a vital resource for organisational competitiveness and the adoption of BIM as the standard process of working within the UK construction industry, several studies have been conducted to explore the synergy between the two concepts (Li et al., 2019). This section reviews relevant researches aimed at integrating KM and BIM to identify the knowledge gap that this study seeks to feel.

Many previous studies have identified the need to develop means of capturing and sharing the vast amount of construction information and knowledge within the BIM platform (e.g. Wang & Meng, 2018; Zou et al., 2017; Boyes, 2016; Wang & Leite, 2015; Deshpande et al. 2014; Jallow et al. 2013). Most of these studies adopted the technological perspective in capturing and sharing information/knowledge within BIM. For example, Fruchter et al. (2009) developed an integrated system that demonstrates how to expand BIM to become a vibrant multimedia building knowledge model (BKM). The system integrated three software tools: TEKLA (a BIM software platform), RECALL (a KM software) and, TalkingPaper (a system that bridge the paper, speech, and digital worlds), using hyperlinks to allow the dissemination of knowledge into the BIM environment. The researchers noted that the BKM software environment could help reduce rework, increase project coordination, remove barriers to communication across discipline and minimise time wasted searching for data, information and knowledge. Though the study was very innovative, it was too technological biased with heavy reliance on software tools.

Moreover, most existing studies on knowledge integration into BIM concentrated on either the design phase (e.g. Nguyen & Toroghi, 2013; Park, 2013; Wang and Leite, 2015) or the construction phase (e.g. Ho et al., 2013; Lin, 2014) with a few on the facility management phases (e.g. Charlesraj, 2014; Motawa & Almarshad, 2015). Adequate attention has not been paid to BI at the pre-design phase, despite the importance of the phase. For instance, Charlesraj (2014) proposed a conceptual (K-BIM) framework which seeks to integrate KM, FM and BIM using ontologies. The proposed framework consists of three major parts: knowledge-base, K-BIM layer, and stakeholder interface, as shown in Figure 2. 11. It was an attempt to harness the strength of KM and BIM to enhance the FM processes. The framework was meant to help FM firms using BIM achieve competitive advantage and serve as a basis for the development of competencies for facilities managers. The framework's application was limited to the operation phase without consideration for other phases of the project life cycle. More importantly, it lacks the processes for capturing the stakeholders' knowledge and experiences at the operation phase.

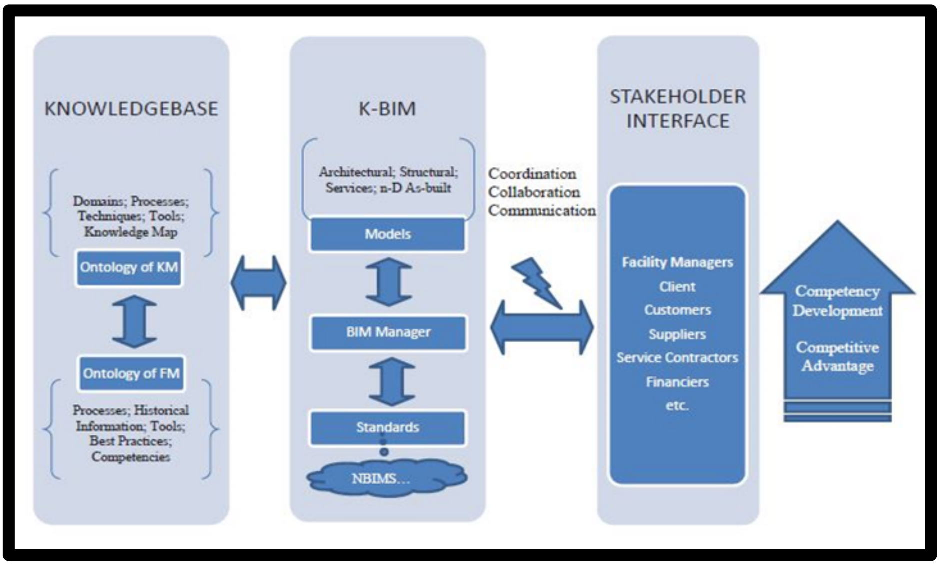


Figure 2. 11: K-BIM conceptual framework for FM. Source: Charlesraj (2014)

Similarly, Motawa and Almarshad (2013) developed an integrated knowledge-based system to capture information and knowledge of building maintenance operations when maintenance is being carried out. The aim was to understand how a building deteriorates and to support preventive/corrective maintenance decisions. The study adopted multiple studies and interviews of professionals from various building maintenance departments in public organisations as the research techniques. The developed system consists of two modules, namely: a BIM module for capturing relevant information (see Figure 2. 12), and a Case-based Reasoning (CBR) module for capturing knowledge (Figure 2. 13). The system attempted to transform BIM into BKM by capturing and retrieving previous information/knowledge about previous maintenance operations. However, the system lacks mechanisms to embed the new knowledge generated through the system back into the model, which still results in knowledge loss (Li et al. (2019).

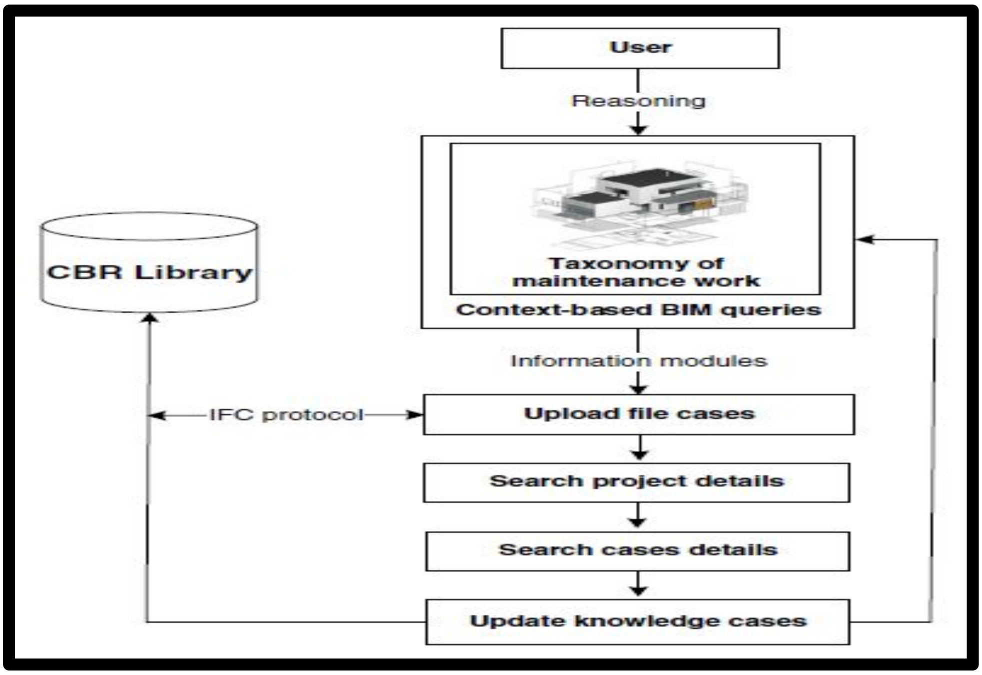


Figure 2. 12: BIM module for capturing information. Source: Motawa and Almarshad

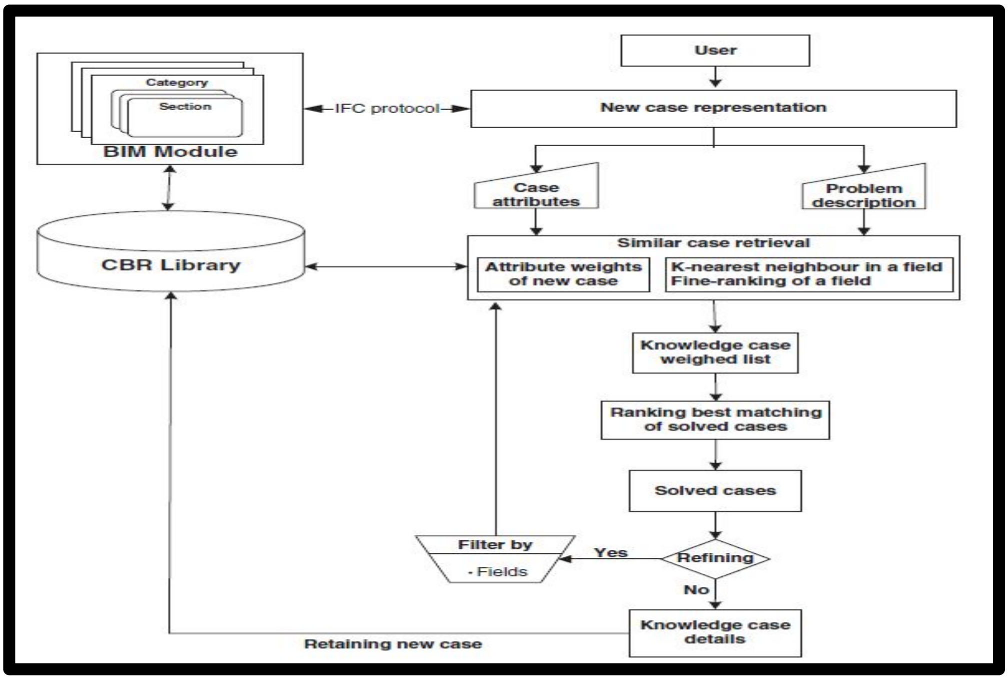


Figure 2. 13: Case-based Reasoning (CBR) module for capturing knowledge. Source: Motawa and Almarshad (2013)

In 2013, Jallow et al. (2013) proposed a framework for integrating knowledge into BIM (BKM framework) based on integrative and comprehensive literature review and the state-of-the-art of BIM and KM. The BKM framework (Figure 2. 14) was meant to enhance team collaboration through the integration of BIM and KM processes in the lifecycle of the facility.

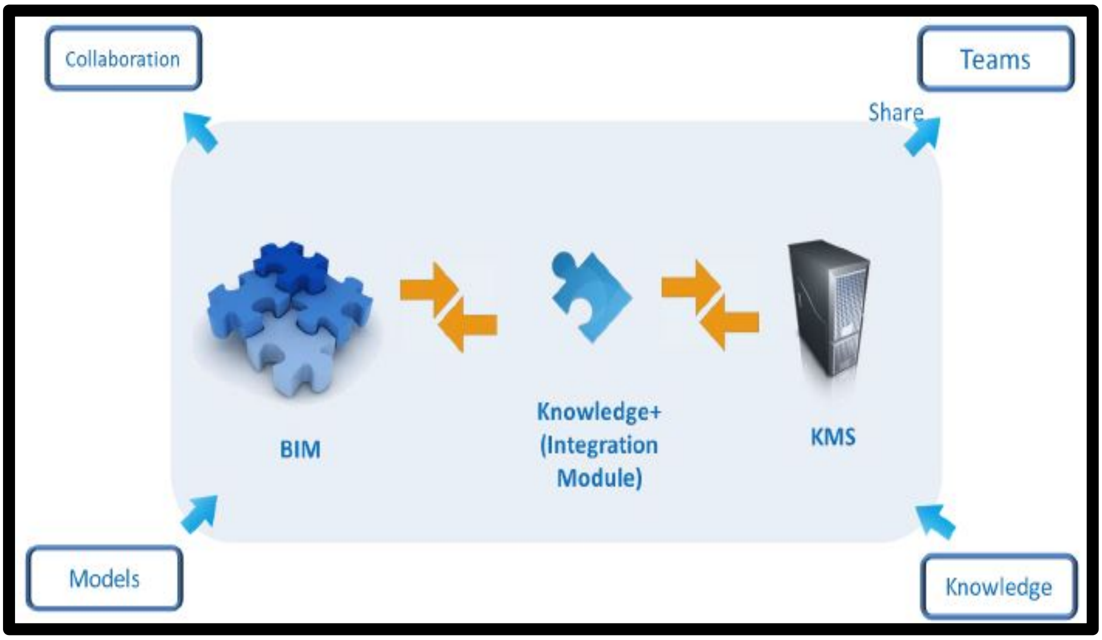


Figure 2. 14: BKM framework integrating BIM and KMS. Source: Jallow et al. (2013)

The framework employed an intermediate integration module (known as 'Knowledge+) which connects BIM application and KM system in order to capture lesson learned in BIM activities, facilitate communication between BIM and KM processes, and support knowledge retrieval and reuse in the lifecycle of a facility. The integration was expected to increase working efficiency and productivity by reducing the time and efforts wasted in locating domain knowledge. It also aimed at reducing redundancy and unnecessary rework by utilizing expert knowledge to facilitate project delivery. However, the BIM tools were restricted to Revit software, and the application of the framework was limited to energy-efficient projects.

In an attempt to expand and enhance BIM applications, Liu et al. (2014) also developed a framework for integrating change management (CM) with BIM for energy-efficient retrofits. The proposed framework allows communication between change KM processes and BIM Data Hub using the JSON file format. The mechanism of the framework as shown in Figure 2. 15 provides a workflow to capture and manage change information and demonstrates an automated mechanism to update changes on BIM models (Liu et al. 2014).

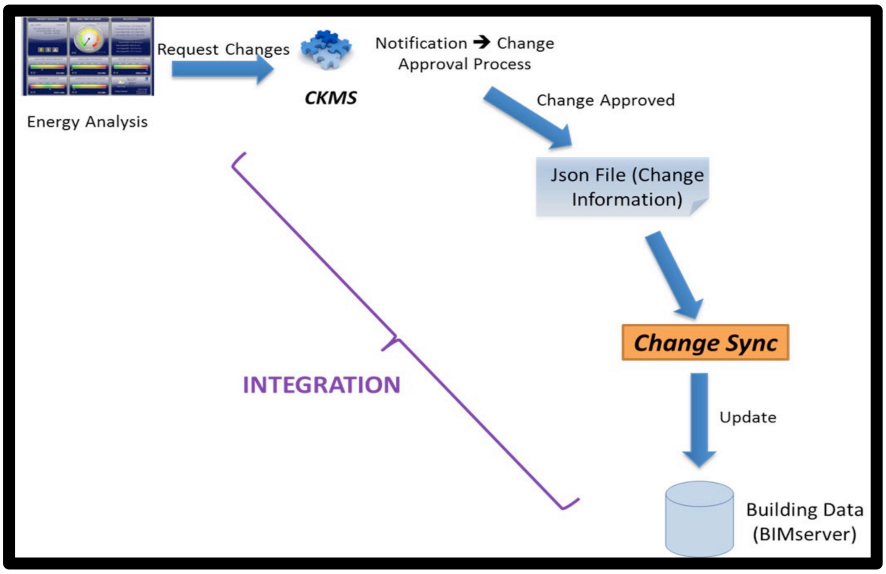


Figure 2. 15: Framework to integrate CM and BIM. Liu et al. (2014).

Deshpande et al. (2014) also proposed a framework, BIM-based KMS, for capturing and extracting knowledge during design and construction processes using parametric, object-oriented nature of BIM models. The framework (see Figure 2. 16) also proposed a classification method for the extracted knowledge based on specific functional specialisation of the organisation. UNI-FORMAT II classification was proposed for classifying lesson learned. The framework leveraged on the object-oriented and parametric nature of BIM models for capturing lessons learned, innovative ideas, and knowledge generated during the design and construction processes. However, the framework did not present a clear methodology for reusing the captured knowledge, and there was no consideration for other phases of the project lifecycle.

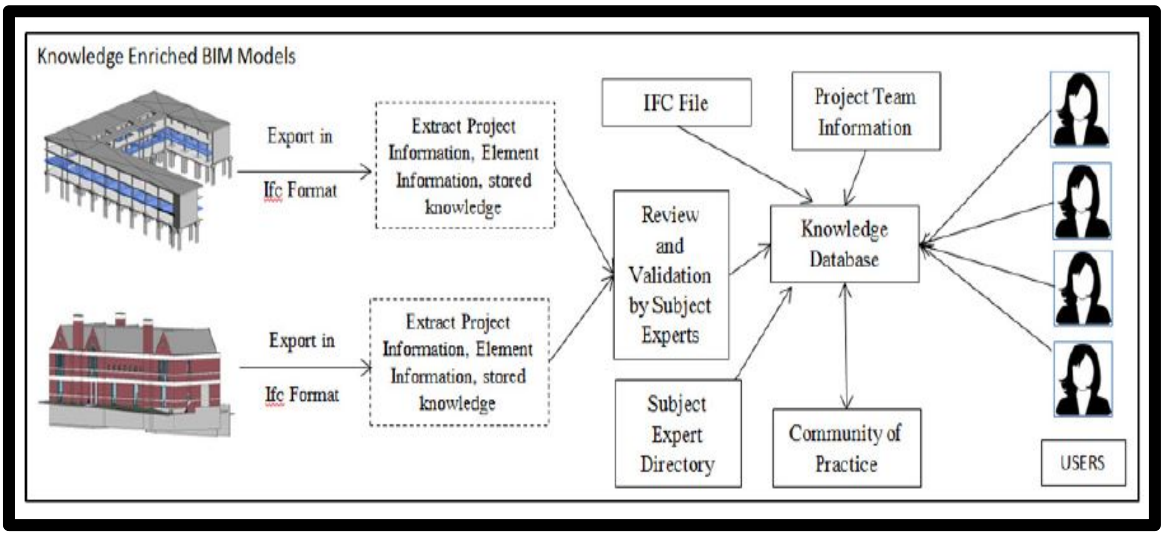


Figure 2. 16: Conceptual framework for BIM-based KMS. Source: Deshpande et al. (2011)

In a bid to address the application of KM at the projects' construction phase, Lin (2014) proposed a Construction BIM-based KM (CBIMKM) system for general contractors using 3D visualisation. The framework (see Figure 2. 17) employed 3D CAD-based knowledge maps integrated with a web-based KM system to track and manage knowledge and experience of engineers in a digital format. The proposed system was intended to provide an efficient and effective platform to enhance KM activities in a visualised environment, facilitate the use of a web-based KM system for construction, and enable the location of needed knowledge and experience from experts. Though the framework tried to capture EK in a digital format, the creation of BIM/CAD objects required by the system was considered too cumbersome and time-consuming for most users (Li et al., 2019). The digitised process of knowledge capturing was restricted as only one file format is supported.

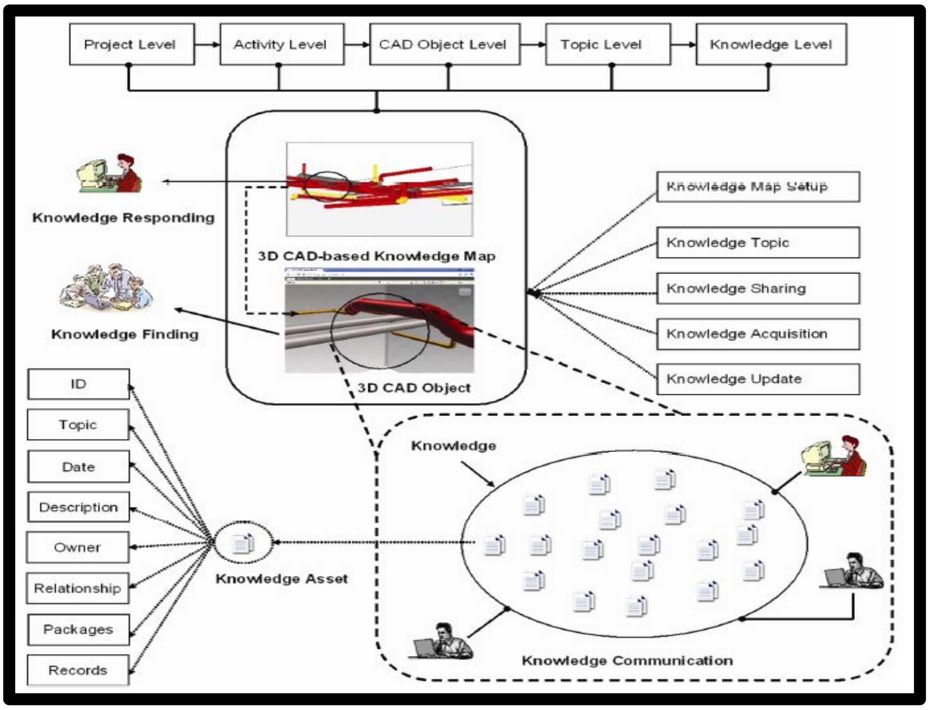


Figure 2. 17: Framework of Construction BIM-based KM system. Source: Lin (2014).

After (Bhatija, 2017) conducted a comprehensive review of literature on standalone approaches to BIM and KM, they came up with a theoretical model overlay of KM and BIM features over RIBA plan of works. It was another attempt to demonstrate the benefits in synergising the two approaches through integration. The proposed theoretical BKM framework, as shown in Figure 2. 18, promised a paradigm shift from information exchange to knowledge sharing by integrating KM and BIM features. The framework, despite its promises, remains a theoretical proposition, lacking implementation procedures.

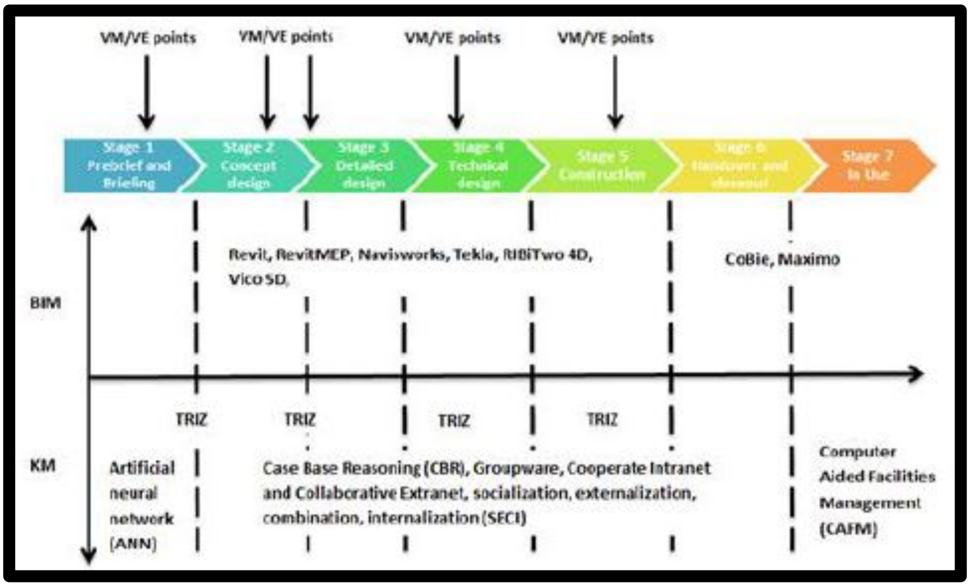


Figure 2. 18: Theoretical BKM framework layered over RIBA PoW.
Source: (Bhatija, 2017).

In a bid to develop a mechanism to manage the embedded knowledge within the n-D models across projects and companies, Li et al. (2019) presented a conceptual framework of a Building Information Knowledge Modelling (BIKM) system. The proposed KM mechanism for managing construction knowledge related to process contractual claims will be integrated with a Cloud-based BIM system. The study involved case studies and semi-structured interview of four Malaysian construction and IT companies specialising in BIM. The proposed system could facilitate better capture and reuse of information, files and 'higher-dimension' knowledge such as best practices lessons learned. Apart from the fact that the four case studies used are considered grossly inadequate for a significant deduction, the proposed application of the system is also limited to contractual claim. Table 2. 11 presented a summary of the current researches on BIM-based KM in construction projects.

Above literature review revealed that many researchers had shown interest in integrating KM and BIM to synergise the benefits of the two approaches. Different studies have employed different methodologies towards achieving the synergy at different phases of construction projects. Virtually all existing integrated approaches emphasised the technological aspect of BIM. Guo and Feng (2019) conducted a systematic mixed-method review of published articles relating to knowledge domains of BIM-based projects between 2008 and 2018. The analysis of 1019 publications confirmed that all the solutions provided to support knowledge integration in BIM-based construction projects are technology-oriented.

Table 2. 11: Summary of Researches on BIM-based KM in Construction Projects

Project phase	References	Proposed Model/Framework	KM Focus/Process	Tools/Techniques for Integration
Design	Fruchter et al. (2009)	BKM Framework	Knowledge capture	TEKLA; RECALL; TalkingPaper
	Kim and Grobler (2009)	IFC-BIM model	Knowledge representation	Ontology
	Park et al. (2013)	Proactive defect management framework	Proactive KM and knowledge retrieval	Augmented reality; ontology; database
	Nguyen and Toroghi (2013)		Knowledge representation	Criteria assessment
	Wang and Leite (2015)		Knowledge capture	Prototype system for knowledge capture; database
Construction	Jan et al. (2013)		Knowledge capture, sharing, storage and reuse	Web-based tool; database
	Ho et al. (2013)		Knowledge capture, sharing, storage and reuse	Web-based tool; database
	Lin 2014)	BIM-based KM (CBIMKM) system	Knowledge capture, sharing, reuse, storage and reuse and representation	Web-based tool; knowledge map; database
Design and construction	Deshpande et al. (2014)	BIM-based KMS.	Knowledge capture and storage	Shared parameter edition
FM	Liu and Issa (2012)		Knowledge sharing	Shared parameter edition
	Motawa and Almarshad (2013).	Integrated knowledge-based system	Knowledge capture and retrieval	Web-based tool; database; CBR
	Udeaja et al. (2006)	CKMS Framework	Knowledge capture and storage	Web-based tool; CAPRI.NET
	Charlesraj (2014)	K-BIM Framework	Knowledge representation	Ontology
	Motamedi et al. (2014)		Knowledge visualisation and representation	Fault tree; database
	Motawa and Almarshad (2015).		Knowledge capture and retrieval	Web-based tool; database; CBR
Full project lifecycle	Konukcu and Koseoglu (2012)	BKM Model	Knowledge sharing	KM mechanism
	Kivits and Furneaux (2013)	N/A	Collaborative and proactive KM	N/A
	Liu et al. (2013)	BKM Framework	Knowledge capture, sharing and reuse,	Knowledge repository

	Bhatija et al., (2017)	BKM Framework	Knowledge sharing	N/A
Others	Meadati and Irizarry (2010)	BIM Knowledge Repository	Knowledge capture and storage	Shared parameter edition
	Li et al. (2019)	BIKM System	Knowledge capture and reuse	Web-based tool
	Ozturk & Yitmen, (2019).	e-iBKM	9-KM Process steps	Online working systems, ICT, Cloud-based Knowledge

Source: Adapted and updated from Wang and Meng (2018)

After a comprehensive review of existing literature on integrating KM and BIM, it was observed that previous studies had not paid adequate attention to two areas. First, experience-based knowledge had not been given it pride of place within the construction industry. Other industries (e.g. medicine) had explored EK to improve and inform decisions. In construction, knowledge is often used as synonyms for data and information. This study will, therefore, emphasise the importance of EK as the bedrock of decision-making during BI. Secondly, the pre-design phase of the project's lifecycle had always been taken for granted in BI's scheme.

The review of previous studies shows that emphasis has always been placed on other phases, such as design and construction — none of the studies aimed to capture and integrate EK with BIM right from the pre-design phase where critical decisions regarding project execution are usually made. Therefore, this research seeks to develop a BIM-Knowledge framework for capturing and integrating EK into BI for improved decision-making in BIM projects.

2.6.1 Current BIM Practice for Capturing Knowledge for Decision-making

After reviewing previous studies that attempted to integrate KM and BIM, it is essential to address how information is captured in current BIM practices to improve decision-making. The issue of knowledge has been used and addressed in BIM practice from various perspectives. The review of the literature on BIM-based KM revealed that:

i. KM techniques that have been utilised with BIM technologies include ontology, case-based reasoning (CBR), fault tree, knowledge map, and criteria measurement and reporting.
ii. KM applications (RECALL and TalkingPaper) have been integrated with BIM in the design phase, bridging digital documents, paper documents, and speech to facilitate knowledge capture.
iii. BIM can potentially enable collaborative knowledge management in the design and construction phase, which will facilitate sustainability and asset management.
iv. A knowledge-based BIM system has been established for the maintenance phase, which helps solve current problems based on previous cases.
v. The visualisation function of BIM has been applied with various building knowledge types to explore the possible root causes of failures in facility management.

However, within the UK BIM Framework, the current practices of capturing information for decision-making start by stating the information required, planning how and when to deliver the required information, and then delivering the information for approval. If the information is right, it will be used for decision-making, or else, it will be returned (feedback loops) for processing again as shown in Figure 2. 19.

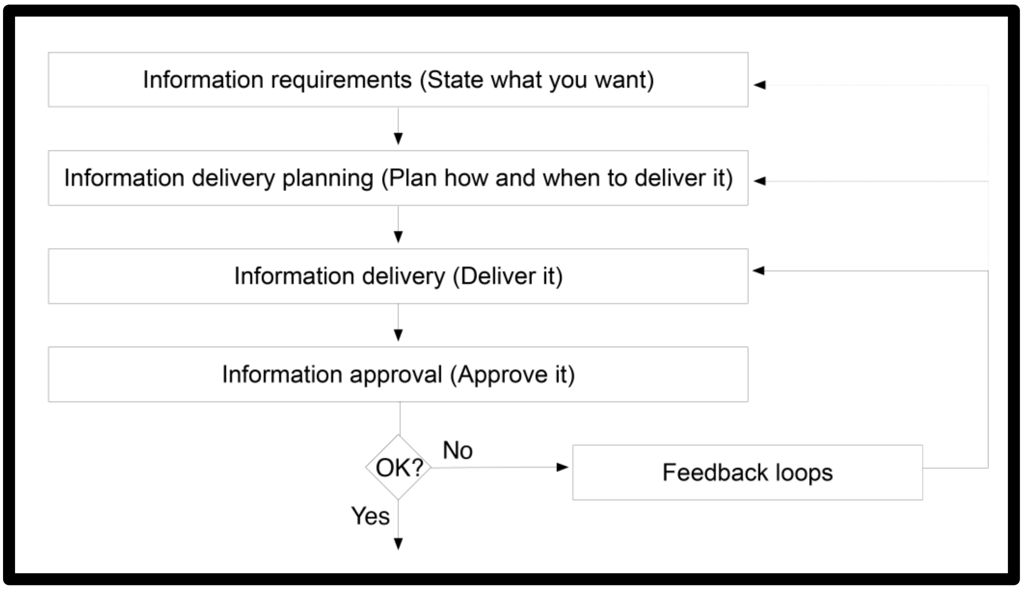


Figure 2. 19: Flow of information for decision-making in BIM practices. Source: UK BIM Framework

Since all phases of construction projects require a vast amount of conscious decision-making based on available information, Crotty (2016) argued that using information generated and communicated from BIM models improves the quality of decisions. This is because the quality of information extracted from BIM models is far better than the traditional, drawing-derived information. Accordingly, the level of human judgement (based on intuition, experience and imagination) required to use the information for decision-making should be lower. Although BIM provides higher quality information, Crotty (2016) argued that the 'animating judgement' required to make these decisions would continue to be provided by human beings. The 'animating judgement' required for effective decision-making on BIM projects will a function of their EK acquired over the time from BIM practices. Hence, there is a need to develop a framework that can further capture and integrate EK into BI practices to improve decision-making in BIM projects further. The next section will review the importance of theory in research to identify the most relevant theory to the study to put the study in proper perspective. The theory provides a framework for the identification of skills and knowledge important to the key decision-makers in BI.

2.7 Theoretical Underpinning of the Study

This section seeks to review and evaluate various theories that are considered relevant to this study. A properly postulated theory provides a framework to coordinate people in collective undertakings (Dubin, 1978). Theories are valuable tools that condense a knowledge area such that a novice could carry out an expert's work. While there is no single generally accepted theory within construction management (Ibrahim et al., 2010), it has been argued that theory formulated in a particular setting can be applied to another setting (Koskela & Vrijhoef, 2000; Love, 2002). This argument suggests that theories from other fields of study could be applied to understanding EK's integration into BI. After a thorough review of the literature, the knowledge-based theory (KBT) was considered most relevant for explaining the relationship between the study's concepts. Accordingly, the next sub-section (section 2.7.1) reviews this theory and its implications for the study while sub-section 2.7.2 discusses the skills and knowledge important to the key decision-makers in BI based on the adopted theory.

2.7.1 **Knowledge-Based Theory (KBT)**

The knowledge-based theory (KBT) emerged from several research streams: organisational learning, resource-based view, organisational capabilities and competencies, and innovation and new product development (Grant, 1996). Based on these streams' contributions, Robert Grant (1996) propounded the rudiments of the KBT, which comprises five underlying assumptions concerning knowledge and firms. The theory provides bases for identifying and analysing mechanisms for knowledge integration within the construction organisation. The five underlying assumptions are as follow:

1. In terms of contributing to added value and strategic significance of the firm, knowledge is the critical productive resources.
2. Knowledge encompasses information, technology, know-how (experience), and skills. There is a distinction between tacit and explicit knowledge.
3. Individuals acquire knowledge, and tacit knowledge is stored by individuals.
4. Individuals must specialise in their acquisition of knowledge, i.e. increased in knowledge depth can only be achieved by sacrificing breadth of knowledge.
5. Production (creation of value) requires the application of numerous different types of specialised knowledge.

Based on these assumptions, Grant (1996) claimed that since knowledge is the most critical resource of an organisation, and knowledge resides in a specialised form among individuals, integrating individuals' specialised knowledge remains the essence of organisational capability. Many other researchers (such as Krog & Roos, 1996, Teece, 2000, Pathirage et al. 2005) agreed with Grant that knowledge, especially tacit knowledge that is personal and experience-based, is the most productive resource for attaining organisational sustainable competitive advantage. The fact that EK is embedded and possessed by individuals rather than organisations makes the integration of this specialised, tacit and experience-based knowledge a critical condition for strategic competitive advantage and effective decision-making (Chen & Mohamed, 2010; Pathirage et al. 2005).

KBT provides a theoretical understanding and explanation for EK's unique nature and attributes as a strategic resource for sustainable competitive advantage and effective decision-making. It provides a platform for identifying necessary knowledge integration mechanisms and skills and knowledge required by decision-makers in BI. It offers the basis for identifying different kinds of skills and knowledge that are considered important to the key decision-makers in BI now and in the nearest future and provides directions for training and personal development of these critical decision-makers for effective decision-making. The key decision-makers' important skills and knowledge in BI to perform optimally will be reviewed in the next subsection. The review aims to develop an inventory of skills and knowledge (SKI) important to the key decision-makers in BI. Since it is not clear what competencies will be needed by these decision-makers in the future (Raiola, 2016), the SKI can then be used to benchmark the areas where training will be required in future (about five years from now) by the key stakeholders involved in BI.

2.7.2 **Skills and Knowledge Relevant to Decision-maker in BI**

According to Raiola (2016), most of the stakeholders involved in decision-making in BI still rely on the traditional skill sets. However, the need to acquire relevant skills, knowledge and competencies for managing construction activities has been advocated in order to improve productivity and efficiency (Egbu, 1999; OST, 1995). Despite several studies on skills, knowledge and competencies required by various construction industry professionals, there is yet to be any study documenting specifically on skills and knowledge important to decision-makers in BI. Such study's absence may not be unconnected with the relatively new adoption of BIM and the emergence of decision-makers in BI. Effective BI requires full collaboration and cultural change among all stakeholders; hence, the need to augment the traditional skills and competencies with BIM related skills and knowledge to facilitate effective decision-making during BI. Accordingly, the development of SKI relevant to key decision-makers in BI remains a cardinal objective of this study.

Boyatzis (1982) defined skills as the ability to perform a specific job or task. On the other hand, Sveiby (1997) defined knowledge as a capacity to act. According to Katz (1971), skill is an ability to translate knowledge into action, which is manifested in performance. The definition provided by Katz shows the relationship between skills and knowledge. Therefore, knowledge can lead to effective action which generates a desired outcome or result. In the context of the study, skills and knowledge refer to complementary sets of capacity and ability acquired by decision-makers, either through education, training or experience, which empowers them to make informed decisions with desired outcomes.

Skills and knowledge inventory for construction managers and professionals are well-researched and documented in the literature (Young, 1992; Egbu, 1999; Hwang & Ng, 2013; Raiola, 2016; Davies et al., 2015). For example, Egbu (1999) identified six most essential skills and knowledge out of seventy-five skills and knowledge for refurbishment managers to include: leadership, communication (oral/written), the motivation of others, health and safety, decision-making, and forecasting and planning. According to Fryer (1985), a good project manager must possess the following skills: social skills, decision-making skills, problem-handling skills, ability to recognise opportunities, and change management skills. Hwang and Ng (2013) identified eighteen competencies of project manager for green construction. They ranked cost management, communication management, scheduling and planning management, health and safety, risk management as the most critical knowledge area while decision-making, delegation, analytical, teamwork, and problem-solving were the highest-ranked skills.

In a study conducted by Edum-Fotwe and McCaffer (2000) on the knowledge and skills for developing and implementing project management, leadership, planning and scheduling, delegation chairing meeting and negotiation were ranked highest out of twenty skills and knowledge identified. In a similar study by Khamaksorn (2016) on project management knowledge and skills for the construction industry, scheduling and planning, delegation, leadership, decision-making, and problem-solving appeared as the necessary knowledge and skills. The roles of project managers involve decision-making, and their competencies can be adopted as a basis for developing the skills and knowledge required by decision-makers in BI. Bosch-Sijtsema and Glush (2019) had empirically shown that the competences of project managers are similar to that of a BIM actor.

Davies et al. (2015) conducted a study on the soft skills required by BIM practitioners in a project team in New Zealand, Australia and Netherland. The result highlighted communication, conflict management, negotiation, teamwork, and leadership as the most critical skills. These skills become critical due to the collaborative nature of BIM and the need to reduce the traditional adversarial nature of the construction project. Table 2. *12* compiled a list of twenty most cited skills and knowledge identified in the literature for project managers, BIM practitioners and professionals within the construction industry.

Table 2. 12: List of Most Cited Skills and Knowledge from the Literature

Skills and Knowledge	Authors
Strategic planning and schedule management	Heldman (2018); Egbu (1999); Hwang and Ng (2013); Dogbegah et al. (2011); Edum-Fotwe and McCaffer (2000); Khamaksorn (2016); Ling (3003); PMI (2008); Gushgar et al. (1997); Kerzner (1989); Bosch-Sijtsema et al. (2019); Kwofie and Botchway (2015); Rwelamila (2007); Bothma (2012); Ingason & Jónasson (2009)
Leadership	Egbu (1999); Odusami (2002); Raiola (2016); Ling (3003); Edum-Fotwe and McCaffer (2000) ; Gushgar et al. (1997); Davies et al. (2015); Hanna et al., (2018); Succar et al. (2013); Bosch-Sijtsema et al. (2019); Ali et al. (2016); Smith (2014); Succar and Sher. (2014); Succar (2010); Kwofie and Botchway (2015); Heldman (2018); Ingason & Jónasson (2009)
Communication (oral/written)	Egbu (1999); Hwang and Ng (2013); Raiola (2016); Gushgar et al. (1997); Odusami (2002); Dogbegah et al. (2011); Eduw-Fotwe and McCaffer (2000); Omidvar, et al., (2011); Bothma (2012); Forman and Argenti, (2005); Gorse and Emmitt, (2007); Dainty, et al, (2006); Kwofie and Botchway (2015); Kwofie et al. (2018); Hanna et al., (2018); Alroomi et al., (2012); Bosch-Sijtsema et al. (2019); Eastman et al. (2011); Heldman (2018); CEN (2004)
Human resource management	Hwang and Ng (2013); PMI (2008); Raiola (2016); Dogbegah et al. (2011); Kerzner (1989); Bosch-Sijtsema et al. (2019); Odusami (2002); Rwelamila (2007); Omidvar, et al., (2011); Kwofie et al. (2018)
Procurement and material resource management	Hwang and Ng (2013); Dogbegah et al. (2011); Kerzner (1989); Raiola (2016); Kwofie and Botchway (2015); Edum-Fotwe and McCaffer (2000); Odusami (2002); Rwelamila (2007); Omidvar, et al., (2011); Kwofie et al. (2018)
Time management	Odusami (2002); Edum-Fotwe and McCaffer (2000); Rwelamila (2007); Ahadzie et al. (2009); Rwelamila (2007);

	Kwofie et al. (2018); Succar et al., (2013); Kwofie and Botchway (2015); CEN (2004)
Conflict management	Hwang and Ng (2013); Dogbegah et al. (2011); Kerzner (1989); Davies et al. (2015); Hanna et al., (2018); Bosch-Sijtsema et al. (2019); Heldman (2018)
Change management	Succar et al. (2013); Bosch-Sijtsema et al. (2018); Eastman et al. (2011); Smith (2014); Succar and Sher. (2014); Gillies and Howard (2010); Bosch-Sijtsema and Gluch (2019); Liao and Teo (2018)
Financial management	Hwang and Ng (2013); Odusami (2002); PMI (2008); Dogbegah et al. (2011); Ling (3003); Gushgar et al. (1997); Rwelamila (2007); Eduw-Fotwe and McCaffer (2000); Bothma (2012); Omidvar, et al., (2011); Kwofie and Botchway (2015); Kwofie et al. (2018);
Risk management	Hwang and Ng (2013); PMI (2008); Dogbegah et al. (2011); Egbu (1999)
Project management	Eduw-Fotwe and McCaffer (2000); Rwelamila (2007); Bothma (2012); Kwofie et al. (2018); Hanna et al., (2018); Succar et al., (2013); Hua (2013); Succar and Sher. (2014); Ingason & Jónasson (2009)
Quality management	Odusami (2002); PMI (2008); Dogbegah et al. (2011); Ling (3003); Gushgar et al. (1997); Omidvar, et al., (2011); Bothma (2012); Hanna et al., (2018); Smith (2014); Edum-Fotwe and McCaffer (2000)
Teamwork/collaboration	Hwang and Ng (2013); Edum-Fotwe and McCaffer (2000) ; Ling (3003); Raiola (2016); Davies et al. (2015); Kwofie and Botchway (2015); Omidvar, et al., (2011); Odusami (2002); Rwelamila (2007); Heldman (2018)
Negotiation	Hwang and Ng (2013); Odusami (2002); Edum-Fotwe and McCaffer (2000); Bosch-Sijtsema et al. (2019); Gushgar et al. (1997); Davies et al. (2015); Kwofie et al. (2018); Heldman (2018)
Multi-tasking and organisation	Bosch-Sijtsema et al. (2019)
Software (IT) management	Odusami (2002); Ling (3003); Raiola (2016); Dogbegah et al. (2011)
Motivation	Egbu (1997); Odusami (2002); Chen et al. (2018); Edum-Fotwe and McCaffer (2000); Sebastian and van Berlo, (2010)
Critical thinking and Analysing	Hwang and Ng (2013); Bosch-Sijtsema et al. (2019)
Policy knowledge (Standard specification and documentation)	Succar and Sher. (2014); Kwofie et al. (2018); Odusami (2002); Omidvar, et al., (2011); Bothma (2012); Kwofie and Botchway (2015)
Construction management	Raiola (2016); Edum-Fotwe and McCaffer (2000)
Chairing meeting	Hwang and Ng (2013); Edum-Fotwe and McCaffer (2000)
Top management relationship	Edum-Fotwe and McCaffer (2000); Dogbegah et al. (2011)
Supply chain management	PMI (2008); Raiola (2016)
Health and safety management	Egbu (1997); Hwang and Ng (2013); Dogbegah et al. (2011); Ling (3003)
Stakeholder management	Hwang and Ng (2013); Dogbegah et al. (2011); Ling (3003);
Decision-making	Hwang and Ng (2013); Edum-Fotwe and McCaffer (2000); Gushgar et al. (1997)
Problem solving	Hwang and Ng (2013); Odusami (2002); Gushgar et al. (1997); Bosch-Sijtsema et al. (2019);

Delegation	Odusami (2002); Edum-Fotwe and McCaffer (2000); Gushgar et al. (1997)

The KBT adopted for the study provides the basis for identifying the knowledge and skills important to the decision-making in BI. The identified knowledge and skills will be further explored and subjected to rigorous analysis to develop an inventory of knowledge and skills for BI's key decision-makers. Based on this comprehensive review of the literature, the preliminary conceptual framework for integrating EK into BI will be proposed in the next section.

2.8 Preliminary Framework for Integrating EK into BI

A framework refers to a systematic set of relationships or conceptual schemes, structures, or system, and a conceptual framework brings together a series of related concepts to explain or predict a phenomenon under investigation (Imenda, 2014). The conceptual framework can be in graphical or narrative form (Miles & Huberman, 1994). It involves joining together small pieces, known as concepts, to form a bigger map of likely relationships, or provide a comprehensive understanding, regarding a phenomenon. The preliminary conceptual framework developed from the extant literature review on KM and BI is presented in Figure 2. 20. The major components (concepts) of the framework are 'EK' and 'BI'. However, these main concepts are 'integrated' together using KM processes and tools. The effectiveness of integrating the system could be impacted by several factors (IF) to improve decision-making.

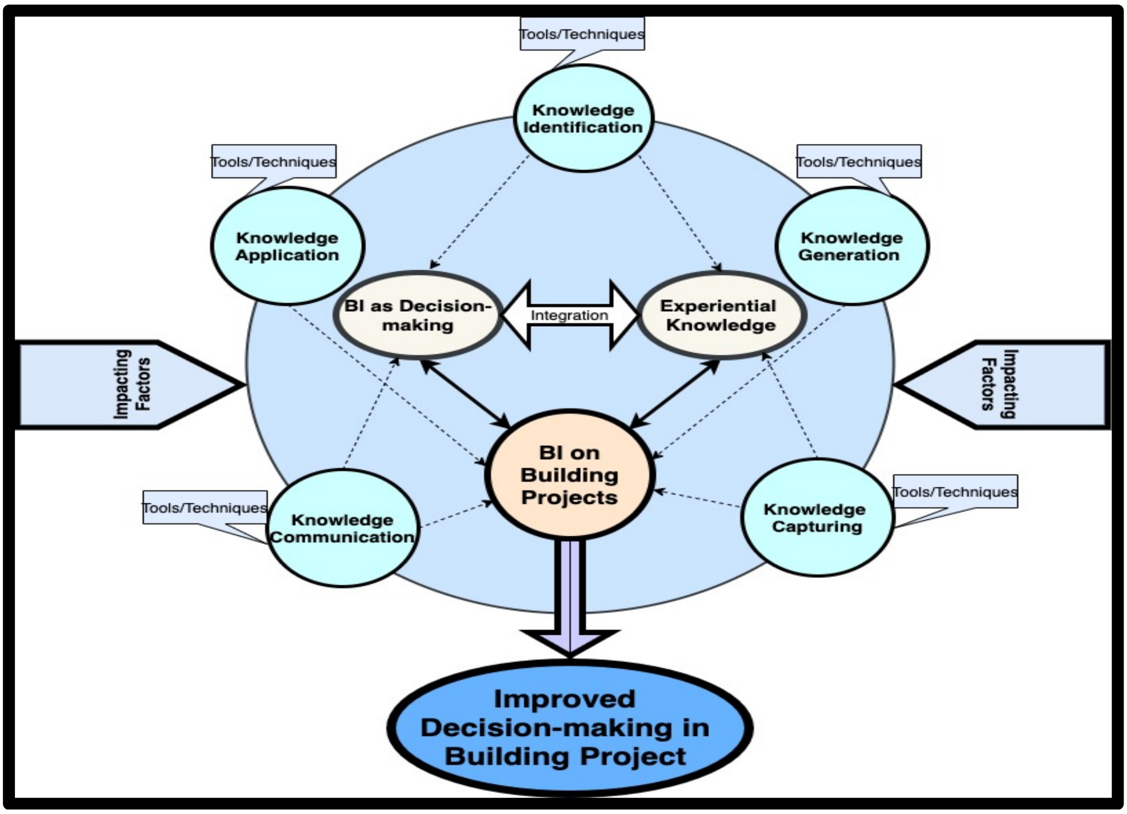


Figure 2. 20: Preliminary BIM-K framework for integrating EK and BI

BI as decision-making (section 2.3) refers to a path-dependant process whereby decisions made regarding series of tasks and activities undertaken at the early phase of building projects will have implications on tasks and activities in the remaining phases of the projects' lifecycle. Since decisions made at the early phase of a project will impact later phases, various tasks and activities requiring decision throughout the project lifecycle should be critically considered right from the beginning. BI as a decision-making process and the key tasks and activities for decision-making in BI were reviewed in sections 2.3.3 and 2.3.4, respectively. The required 'EK' for integration into BI can reside with individual or among a team or embedded in organisation routine. EK can be acquired through different means (such as introspection, perception, memory, and testimony) and various sources such as colleagues, personal experience, and company experience.

The integration of these two concepts occurs within a KM process and supported by appropriate KM methods and techniques. The KM processes for integrating 'EK' into 'BI' include knowledge identification, generation, capture, communication, and application (2.5.2). Each of the KM processes is supported by the appropriate KM tools and techniques (section 2.5.3).

2.9 Chapter Summary

This chapter reviewed the key concepts relevant to the study. These concepts include BIM and BI as decision-making, EK and knowledge management for integrating EK into BI. Section 2.2 discussed BIM and its adoption within the UK construction industry as well as main drivers, benefits, and challenges associated with its adoption, Section 2.3 presented BI as a complex, path-dependant decision-making process. To make sense of the complexity and challenges associated with BI, a rational decision-making process was adopted for this study. BI was described as a series of decision-making process whereby a decision made at one phase of the project could significantly impact on other phases. It documents the key tasks and activities for decision-making in BI.

A review of the concepts of EK is carried out in section 2.4, which provides various definitions and different classifications of knowledge. The section provided a theoretical understanding for the concept of EK and discusses the peculiar nature of EK, the values of EK and the challenges associated with it. It highlights the roles of EK as a critical resource for decision-making in BI. Section 2.5 reviews how KM as a discipline can help facilitate the integration EK into BI. Accordingly, KM processes and tools for integration EK into BI were reviewed and a 5-step process developed by European Committee for Standardisation was adopted for the study. Thereafter, factors impacting on the effective integration of the EK into BI were also discussed and the identified factors were grouped into three categories – individual, project-team and organisational-related factors. A review of previous studies on KM and BIM was undertaken with a view to identify the gap in knowledge in terms of integration of EK and BI.

In section 2.6, a comprehensive review of over 20 previous studies on KM and BIM revealed that previous studies have not adequately consider EK for integration into BI. The review showed that emphasis has always been placed on data and information at the detriment of EK, which serves as a valuable asset for aiding decision-making. In section 2.7, after a review of theories relevant to the study, knowledge-based theory (KBT) was adopted as the theoretical lens for the study, which provided the basis for the identification of the knowledge and skills important to the decision-makings in BI. The review of these concepts culminated in the formation of a preliminary BIM-Knowledge framework in section 2.8, which form the basis for the data collection and analyses for the study. The next chapter will focus on research methodology with a view choosing and justifying appropriate research method and strategy for collecting and analysis empirical data that answers the set research questions and fulfil the aim and objectives of the study.

CHAPTER 3. RESEARCH METHODOLOGY AND METHODS

3.1 Introduction

The essence of this study is to develop a framework for capturing and integrating EK into BI for improved decision-making in building construction projects. Following the concept of 'research onion' proposed by Saunders et al., (2016), this chapter presents a detailed discussion of the research methodology adopted to achieve the aim and objectives of the study. Saunders et al. (2016) presented an overall methodological framework for designing research in the form of an 'onion' (Figure 3.1) with several layers. The chapter started with the philosophical assumptions underpinning the study in terms of the ontological, epistemological and axiological assumptions. Possible approaches, methodological choices and strategies to the study were identified and evaluated to identify the most appropriate ones for the study given the nature of the research problem. The chapter addresses the issue of time horizon for the research.

The core of the 'research onion' which deals with techniques and procedures for data collection and data analysis forms the last section of this chapter. The different research approaches and strategies were assessed to develop a robust research design for this study. Available philosophical paradigms suitable for addressing research problems within the social science where construction management is situated were evaluated. Consequently, pragmatism was deemed the most suitable for addressing the research problem and answering the research questions. In line with the philosophical assumptions for the study, a combination of both qualitative and quantitative methods of data collection and data analysis is deemed most appropriate for the study. Hence, a concurrent mixed method was adopted and justified as the methodological choice for the study. The chapter ends with a summary of the adopted research methodology and method for the study.

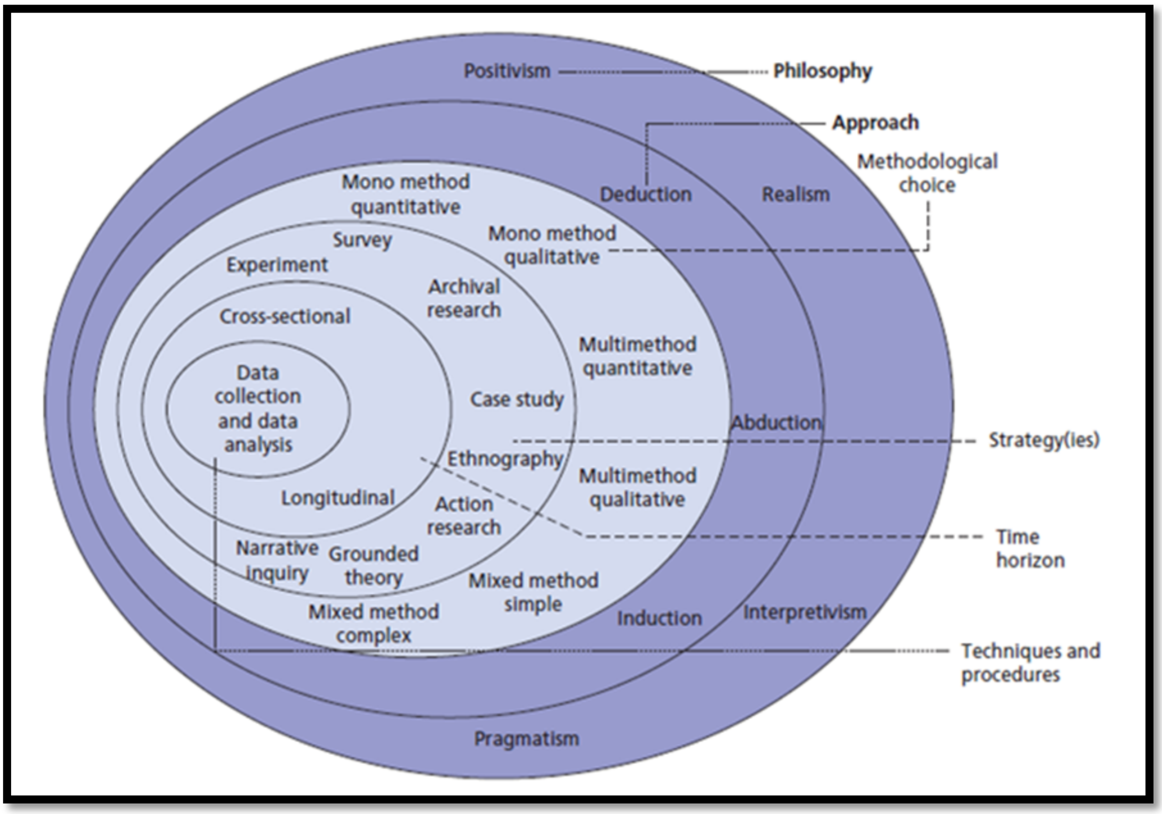


Figure 3.1: The 'Research Onion' as the Research Design Framework. Source: Saunders (2016).

Research paradigms determine how the world and its associated phenomena are viewed, understood, and interpreted. It refers to the theoretical perspective that shapes the way research is formulated and implemented (Mackenzie & Knipe, 2006). Saunders et al. (2019) describe it as the method for collecting and explaining the knowledge of a phenomenon. In social science field of study, where construction management belongs, paradigms are also referred to as theoretical perspectives (Crotty, 1998), research methodologies (Neuman, 2009), worldviews (Creswell, 2014), and a system of shared beliefs and practices (Morgan, 2007). Like the structural elements of buildings, Fellow and Liu (2008) argued that paradigm determines the integrity of any research activity. Hall (2012) submitted that a worldview consists of philosophical stances, comprising ontology, epistemology, axiology and methodology. Accordingly, paradigms are distinguished by their associated: philosophy – source, nature and knowledge development; ontology – beliefs regarding the nature of knowledge and reality; epistemology – the relationship between the researcher and the knowledge and reality; axiology – the roles of values; and methodologies – how knowledge is accessed (Haq, 2014; Williams, 2018). Hence, in a bid to view this study with right lenses, the remaining part of this sections will evaluate various aspects of research paradigm such as research philosophy, ontology, epistemology, axiology, methodology and methods (Scotland, 2012).

3.2 Research Philosophy

Research philosophy deals with the source, nature and development of knowledge (Bajpai, 2011; Saunders et al., 2016). The philosophical assumptions made by a researcher guide the process which influences the selection of methods used to investigate problems. In social research, these assumptions are underpinned by some considerations, such as the existing body of knowledge and the nature of the research problem (Yin, 2003). The philosophical position determines how knowledge is acquired and accepted within a particular field of enquiry. It is better to resolve the issue of research philosophy right from the beginning to establish an appropriate relationship between a researcher and the participants. The early resolution will also ensure that the right method of data sampling, data collection, and data analysis are adopted for the study. There are several models for understanding and classifying research philosophy in social and natural science literature (Guba & Lincoln 2005; Tashakkori & Teddlie, 2003; Hall, 2013). However, according to the 'research onion' model of Saunders et al. (2016), there are four research philosophies: positivism, realism, interpretivism and pragmatism. These research philosophies will be briefly reviewed, considering their strengths and weaknesses, and then choose the most appropriate philosophy for the study.

3.2.1 **Positivism**

Positivism, a dominant paradigm in social science inquiry (Morgan, 2013), posits that reality exists independent of the researcher (Guba & Lincoln, 1994). As such, a research underpinned purely by positivist paradigm is characterised by realism ontology, objective epistemology, theory or hypothesis testing, deductive research process, extensive use of quantitative data collection and analysis approach, systematic approach to data validity, extensive use of numbers and figure (Gage, 1989; Guba & Lincoln, 1994). The primary purpose of positivists' enquiry is to provide explanation, prediction and control (Krauss, 2005) by revealing, describing and measuring relevant factors, providing an explanation in terms of cause-and-effect relationships, and putting understanding to use in organisations (Burrell & Morgan, 1979). Since positivism involves the use of scientific and mathematical approach, it only allows researchers to employ quantitative research methods such as questionnaires, regression analysis, structural equation modelling and experimental designs (Iorio & Taylor, 2014; Ishii et al., 2014; Ding et al., 2014). Some of the major criticisms against positivist paradigm include its denial of the role of human agency which makes it incapable of investigating human action, its unnecessary restrains to the realm of inquiries, its failure to capture complexity and nuances, among others.

Despite positivism capability to ensure generalisation of research findings using the objective approach, the need for an intersubjective relationship between the research and practitioners cannot be ignored in a poorly understood, culturally complex and messy, and less explored research area such as the integration of EK and BI in the construction industry. The requirement of this study to explore in-depth the EK required for integration into BI is antithetical to positivist paradigmatic approach, which only seeks to explain, predict and control relationships between variables. Therefore, positivism is not adopted for addressing the research problem.

3.2.2 **Interpretivism/constructivism**

In contrast to positivists' claim to single truth and mind-independent reality, interpretivists, also known as constructivists (Creswell & Plano Clark, 2011), insisted that there are multiple realities. They posited that meaning is constructed through the active engagement of human beings, in social interaction with the phenomenon under study (Crotty, 1998). Hence, researches underpinned by interpretivism could be identified by their ontological relativism, subjective epistemology, focus on pattern and text, primary use of qualitative approach, value judgement based on individual and group consensus as well as common emphasis on understanding, inductive approach that focusses on theory generation, among others (Burrell & Morgan, 1979; Neuman, 2000). Researchers adopting constructivism as a philosophical paradigm often employ methodologies such as grounded theory and ethnography (Maier & Branzei, 2014; Musca et al., 2014); qualitative methods of data collection such as interviews, direct observation, and focus group discussion (Magnaye et al., 2014; Ahern et al., 2014). The main goal of interpretivism is to seek an in-depth understanding of a phenomenon by focussing on social construction and reproduction of meanings, symbols and languages through inductive reasoning (Myers, 2008; Burrell & Morgan, 1979).

Interpretivism paradigm has been criticised on the basis that its concept of truth is socially constructed and relative (Guba & Lincoln, 1994). Although interpretivism can help develop an in-depth understanding of complexities involved with decision-making using EK during BI, which could necessitate the adoption of a subjective epistemology.

However, it is also essential to investigate and examine practically testable and verifiable factors impacting on the effective integration of EK into BI. These factors should be devoid of individual biases and sentiments that are valued in interpretivism. Hence, interpretivism paradigm may be suitable for providing in-depth meanings to some of the research problems. However, it lacks the required objectivity to identify, examine and measure those factors that impact on the integration of EK into BI. Therefore, the research problems cannot be wholly solved through the adoption of interpretivist philosophy alone.

3.2.3 **Realism**

Realism as a philosophical assumption, relies on the idea of independence of reality from the human mind (Saunders et al., 2012). Realism queries what the presence of knowledge is and its relationship with our understanding (Saunders et al., 2012). There are two types of realism: direct realism and critical realism. While direct realism perceives the world through personal human senses, critical realism argues that human senses can be deceptive; hence, do not always portray the real world (Novikov & Novikov, 2013). The essential features of a study underpinned by critical realism include its interest in cause and effects, investigation of mechanism underlying an event or action, causal explanation, use of qualitative and quantitative approach – each at intensive and extensive scales respectively – as well as multiple perspectives to single reality (Sayer, 2000; Krauss, 2005). The purpose of critical realism is to uncover, understand and explain mechanisms that underlie a phenomenon (Bygastad & Munkvold, 2011).

Critical realism provides a perspective in which qualitative and quantitative methods and assumptions can be integrated while facilitating insights and strategies that can enable researchers to understand better the phenomena they study (William, 2018). As such, a mixture of methods such as case studies, interviews, surveys, and statistical analysis techniques are allowed. Critical realists may choose to combine interviews with questionnaire survey, experimental designs, structural equation modelling, or system dynamics (Yang et al., 2014; Cheng, 2014;). However, critical realism is not adopted as the most appropriate paradigm for this study, despite its ability to accommodate the use of both qualitative and quantitative methods, a method deemed relevant to the study. This is because the aim of the research is not to explain a causal relationship or investigate the mechanism underlying an event or action. The aim is to develop a BIM-Knowledge framework for the integration of EK into BI to improve decision-making in BIM projects.

3.2.4 **Pragmatism**

Pragmatism posits that knowledge can never be truly representative of reality. As far as pragmatism is concerned, the fundamental determinant of research philosophy is the research question (Patton, 1990). A defining feature of pragmatism is a shift away from focusing on the nature of reality and truth towards what works and using all available approaches to understand the problem (Morgan, 2007). However, some researchers have argued that pragmatism goes beyond "what works" and that the principles of pragmatism are equally fit for analysis of problem-solving as a human activity (Morgan, 2014). They posited that pragmatic paradigm offers an immediate and useful middle-position in terms of philosophy and methodology, using practical and outcome-oriented methods of inquiry that is action-based (Johnson & Onwuegbuzie, 2004) without undue argument regarding metaphysical assumptions about ontology and epistemology (Morgan, 2014). Pragmatism, therefore, offers an alternative approach to social research, free from the antagonistic dualism of positivism and interpretivism (Morgan, 2014; Hall, 2013).

The main principle of pragmatism is the emphasis on experience, which involves the continual interaction of beliefs and action. Pragmatism, therefore, focuses less on finding the truth, but rather on what is useful to believe (warranted assertions) as determined by competent enquiry (Dewey, 1941). Truth, according to the pragmatic paradigm, does not necessarily align with the representation of reality but exists in a relational theory of meaning that is continuously changing according to practical necessities of the present (Scotty, 2016). Dewey (1925) called for a philosophy that focuses on human experience rather than abstract metaphysics. Accordingly, pragmatism relies on more than one methodological approach to enquiry depending on the nature of the research question (Creswell, 2009). Though pragmatism has been criticised for emphasising action and experience instead of theory and opinion, Morgan (2007) argued that it is still the most suitable paradigm for social science researches as it removed the artificial dichotomy between positivism and constructivism and placed 'emphasis on an intersubjective approach' which captures the duality.

3.2.5 **Justification for the Adopted Philosophy for the Research**

After critical analyses of the available philosophical positions proposed by Saunders et al. (2016), this research adopts pragmatism as its philosophical stance for some reasons. This study aims to explore EK required for integration into BI as well as identify and measure the factors impacting on the effective integration of EK into BI.

According to Saunders et al. (2016) and Yin (2003), the choice of research philosophy should be informed by the nature of the research problem, the kind of research questions, existing knowledge within the research area, and available time to the researcher. The nature of this research problem involves the integration of EK, which is sticky and context-specific, into BI, and identifying factors which impacts on the effective integration. Pragmatism readily provides a pluralistic approach required to address the complex nature of these research problems.

Pragmatism examines the 'how' and 'what' of research problems based on the intended results. The research questions indicated the need to answer both the 'how' and 'what' question within this study. As stated in section 1.5, the three primary research questions this study intends to answer include:

i. What is EK, and how can it be integrated/validated in BIM environment to improve decision-making?
ii. What factors impact on the effective integration of EK into BI for improved decision-making in building construction projects?
iii. What are the skills and knowledge required by the key decision-makers in BI?

Providing satisfactory and holistic answers to these questions requires adopting a worldview that is not committed to only one system of philosophy and reality (Creswell, 2014). Pragmatism offers researchers the freedom of choice in choosing research methods, techniques and procedures that best serve their purpose since it embraces both positivism and interpretivism mode of enquiry (Parvaiz et al., 2016). Consequently, a pluralistic approach to inquiry, based on pragmatic research philosophy, which addresses research problems in the most appropriate ways that bring about positive consequences (Teddlie & Tashakkori, 2010) was justifiable for this study. The need to adopt pragmatism is further justified because the fundamental research questions are not interested in finding out what arguably constitutes the truth or reality, but rather to facilitate human problem solving – i.e., how can EK be used to facilitate human problems associated with decision-making in BI?

Though the construction management field has been dominated by positivist approach for long (Dainty, 2008), the need for a paradigmatic approach that allows for the adoption of mixed methods has been advocated by many researchers in the construction management (Abowitz & Toole, 2010; Mahamadu, 2017; Williams, 2018).

Pragmatism is particularly appropriate where research questions are best addressed using more than one approach. Therefore, the philosophy underpinning this research is pragmatism. Same philosophy had been adopted by some researchers who conducted similar research, such as Mahamadu (2017) who developed a decision support framework to aid selection of construction supply chain organisations for BIM-enabled projects.

3.2.6 Ontological Assumption of the Study

Ontology explains the nature of reality (Saunders et al., 2019). It is a study of being, and it reflects how researchers interpret a phenomenon. It is the philosophical position about the nature of reality and the existence of the entities (Easterby-Smith et al., 2012; Saunders et al., 2019). As such, ontology helps to know what exists, the nature of what exists, the constituents of what exists, and the interactions amongst the constituents (Blaikie, 2007). This knowledge helps individuals to ascertain whether an entity is real or relative in a social setting. Saunders et al. (2019) divide ontology into two: objectivism and subjectivism. Objectivism posits that social entities exist outside the social actor while subjectivism views social entities from the perceptions and result of the actions of social actors. Based on the adopted pragmatic philosophical adopted for this study, the ontological position for the research could be positivism, subjectivism or both, depending on what best answers the particular research question. This is because the study seeks to combine both exploratory interpretation and quantitative explanation in a single research.

3.2.7 Epistemological Assumption of the Study

The epistemological stance of a study depicts the ways through which knowledge could be apprehended (Neuman, 2009). It focuses on what constitutes valid knowledge in a field of study (Saunders et al., 2019) and how to obtain such knowledge. It is about the most appropriate ways of enquiring into the nature of the world (Easterby-Smith et al., 2012). According to Oppong (2014), knowledge can be seen from three perspectives: objectivism, subjectivism, and relativism. Objectivism aligns with the positivist position, which viewed knowledge as independent of the social actor or observer. Subjectivism, however, advocates adequate interaction between the researcher and the phenomenon under study. However, relativism argues that knowledge is context-, concept-, and activity-dependent (Archer et al., 2016). Knowledge must be situated within a social-context or historical-perspective to know the reality. Relative epistemology allows for the combination of both subjective and objective ways of knowing in a study.

Based on the pragmatic philosophy adopted for the study and the need to address the research questions from more than one perspective, both subjective and objective epistemologies are deemed relevant to the study. On the one hand, subjective epistemology is employed to explore the personal experience of selected BIM experts from the UK construction industry, how KM can help capture and integrate EK during BI. Based on their individual experiences with BIM-enabled projects, sources of EK required for BI in building construction projects will also be explored using qualitative research method. It will further provide insights into the list of factors which can impact on the effective integration of EK into BI. On the other hand, the study employs objective epistemology to seek and test the opinions of BIM professionals across the UK construction industry regarding the constructs extracted from the literature. These constructs include sources and tasks relating to EK, KM tools and techniques for integrating EK into BI, factors impacting on the effective integration of EK into BI, and skills/knowledge essential to key decision-makers. These constructs will be investigated using a questionnaire survey as the research instrument. Therefore, this research adopts relativism as its epistemological position. Relativism allows for the combination of both subjective and objective methods in one study, depending on the research question. The combination allows for the weakness of one method to be compensated with the strength of the other method through triangulation, and the findings can be used to corroborate and strengthen one another.

3.2.8 **Axiological Position of the Study**

Axiology refers to the aspect of research philosophy that focuses on a judgment about the value in the research process (Saunders et al., 2019). Oppong (2014) identified three positions associated with axiology; thus: (i). Science must be value-free, (ii). It is not possible to eliminate value from any part of science, and (iii). Value is not only inevitable but a desirable aspect of the research process. Oppong (2014) submitted that social inquiries should always adopt an axiological position, arguing that values have always influenced social science researches. Hence, researchers in social science should not only admit but also deliberately include their cultural orientation in the research process. In line with pragmatic philosophy, the axiological position of this research is that value plays a major role in the interpretation of the results. Table 3. 1 presents a comparison of the research philosophy discussed with emphasis on pragmatism as the adopted philosophical position for the study.

Table 3. 1: Comparison of the Four Research Philosophies

Philosophy	Ontology – nature of reality	Epistemology – what constitutes acceptable knowledge	Axiology – role of value
Positivism	External, objective and independent of social actors	Focus on causality and law like generalisation, reducing phenomenon to simplest elements	Research is value-free. Researcher independent of the data and maintain objective stance.
Interpretivism	Subjectivism: socially constructed reality with multiple changes	Focus on details of situation, realities behind these details, subjective meanings motivating actions	Research is value-bound. Researcher cannot be separated from the research, hence, subjective.
Realism	Objectivism: reality exist independent of human thought and belief but interpreted through social conditioning	Focus on explaining within context or contexts.	Research is value laden. Researcher is biased by world views, cultural experiences and upbringing.
Pragmatism	External, multiple, view chosen that best answers research question	Relativism: combining different perspectives to help interpret the data.	Values play a large role in interpreting results, researcher adopting both objective and subjective points of view.

Source: Adapted from Saunders et al. (2016)

3.3 Research Approach for this Study

Regardless of the research area, it is imperative to discuss the research approach and situate one's research within one of the available approaches as well as provide a valid justification for the adopted approach. The research approach forms the second layer of the 'research onion' model. According to Saunders et al. (2016), there are three research approaches found in the literature. These are: Deductive research approach, Inductive research approach, and Abductive research approach. The next subsections will review these research approaches in order to adopt the most suitable one for the study.

3.3.1 **Deductive Research Approach**

According to Wilson (2010), a deductive approach is concerned with the development of a set of hypotheses, based on existing theory, upon which a research strategy is designed to test the hypotheses. A set of hypotheses are formulated for confirmation or rejection using the deductive approach. It involves reasoning from the general to the particular (Pelissier, 2008). It explores a known theory or phenomenon and test if it is valid, given a particular circumstance. Following the path of logic, the deduction starts with a theory and leads to a new hypothesis, which is tested through observation to confirm or reject the hypothesis (Snieder & Larner, 2009). It is usually associated with positivism, using quantitative methods of data collection and data analysis (Tribe, 2001).

According to Robson (2002), a deductive approach follows these processes: 1. Deduce hypotheses from theory, 2. formulate a set of hypotheses in operational terms and propose relationships between two specific variables, 3. Make observations or test the hypotheses using appropriate methods, 4. Examine the outcome of the test and confirm or reject the hypotheses, 5. Modify the theory, if hypotheses are not confirmed. Since this study is not aimed at formulating and testing hypotheses, the deductive approach alone is not adopted as the primary approach for this study. However, the study acknowledged that some research questions might tend towards a positivist view (Hislop, 2009), which is compatible with a deductive approach. Similarly, the fact that 'EK' is intended to be 'captured and reused' also align with the deductive approach.

3.3.2 **Inductive Research Approach**

Contrary to the deductive approach, the inductive approach does not require the formulation of hypotheses. It begins with observations, and theories are formulated at the end of the research process based on the observation (Goddard & Melville, 2004). This approach aims to generate meanings from the collected data to identify patterns and relationship in order to build a theory. However, Saunders et al. (2012) explained that the researcher is free to use existing theory to formulate the research question(s) to be explored. The approach is based on learning from experience and generally associated with interpretivism, using qualitative methods of data collection and data analysis.

The processes involved in the inductive approach are 1. Generate some research questions from the aim and objectives of the research or existing theory; 2. Make detailed observations or conduct some tests; 3. Look for the pattern and; 4. Develop a theory. Based on the aim of the research, inductive approach alone will not be able to provide a sufficient approach to answer all the research questions for the study. However, exploration of the experiences of stakeholders on BI through in-depth interviews, which is closely related to interpretivism and generally associate with inductive approach (Imenda, 2014), is a cardinal part of this research. Therefore, the study might also adopt an inductive approach to answer some of the research questions.

3.3.3 **Abductive Research Approach**

Also known as the retroductive approach, abduction sets out to make up for the weaknesses associated with deductive and inductive approaches by adopting a pragmatist perspective. According to Saunders et al. (2012), deductive approach lacks the clarity on how to select theory to be tested via formulating hypotheses while the inductive approach is criticized because no amount of empirical data will allow for theory-building. As the third alternative reasoning, abductive approach overcomes these weaknesses by adopting a pragmatic perspective to research.

The abductive research process is devoted to the explanation of 'incomplete observation', 'surprising facts' or 'puzzles' that were specified at the beginning of the study using qualitative and quantitative research methods of data collection and data analysis in an integrated manner (Bryman & Bell, 2015). Based on this research aim which seeks to develop a conceptual BIM-Knowledge framework for integrating EK into BI for improved decision-making in BIM projects, the abductive approach is adopted for this research. Consequently, the study will involve both deductive and inductive approaches iteratively to provide comprehensive answers to the research questions. Table 3.2 shows a comparison among the three research approaches.

Table 3.2: Comparison of the Three Research Approaches

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

3.3.4 **Justification for the Choice of Research Approach**

After critical analyses of the available philosophical positions proposed by Saunders et al. (2016), this research adopts pragmatism as its philosophical stance for some reasons. This study aims to explore EK required for integration into BI and identify and measure the factors impacting the effective integration of EK into BI. According to Saunders et al. (2016) and Yin (2003), the choice of research philosophy should be informed by the nature of the research problem, the kind of research questions, existing knowledge within the research area, and available time to the researcher. The nature of this research problem involves integrating EK, which is sticky and context-specific, into BI, and identifying factors that impact the effective integration. Pragmatism readily provides a pluralistic approach required to address the complex nature of these RQs stated above. This research adopts the abductive research approach because it best addresses the research aim and objectives and it is in accord with the research paradigm and philosophical stance already adopted. It also allows for the development of the framework to integrate EK into BI through the exploration and explanation of the research constructs and variables.

Accordingly, the study started with a review of extant literature to enable the researcher to develop a preliminary conceptual framework (deductive approach) which will then be explored based on real-life experiences of BIM experts within the UK construction industry using semi-structured interviews (inductive approach). The interviews' essence is to explore the perceptions of these experts on the need and means to integrate EK into BI for improved decision-making in building construction projects. The findings from the literature review and the interviews would be guided by the inductive approach as it seeks to investigate what is obtainable among the construction stakeholders in the field. This approach will be heavily relied on to provide answers to the first research question.

However, data from the literature also form the basis for the questionnaire design to corroborate the interview results and test the generalisability of the literature's findings using the deductive approach. Findings from the two approaches will be used to refine the preliminary conceptual framework for the integration. Hence, the adoption of the abductive approach allows the combination of both inductive and deductive approaches and allows the moving forth and back between the two approaches for the development the framework, where appropriate, to answer the research questions in line with the research aim and objectives. Furthermore, abductive reasoning process which allows for back-and-forth movement between an inductive and a deductive reasoning process, as obtainable in this study, typically aligns with pragmatism already adopted for this study (Parvaiz et al., 2016; Morgan, 2007).

3.4 Research Methodological Choice

Research methodological choice forms the third layer of the 'research onion' model. It refers to the plan of action, approach or design behind the preference and application techniques in the research (Crotty, 2003). It describes the philosophy underpinning the research methods, including the choice and justification for using either qualitative or quantitative methods, or a mixture of both. Saunders et al. (2016) identify three main categories of research methods: mono methods: qualitative and quantitative; multi-method: qualitative and quantitative; and mixed methods: simple and complex (see Figure 3. 2). The mono methods refer to techniques which rely solely on the use of either qualitative or quantitative method of inquiry for research. Multi-methods and mixed methods rely on the combination of both qualitative and quantitative methods for investigating one research inquiry.

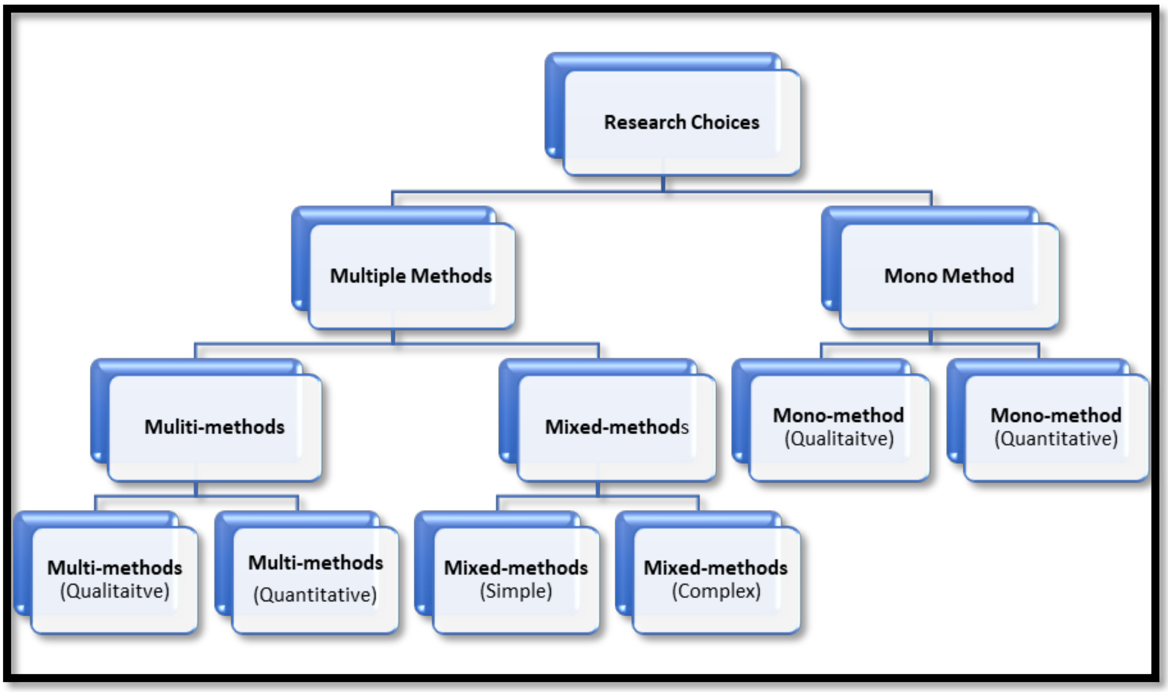


Figure 3. 2: Research methodological choices. Source: Adapted from Saunders et al. (2009)

3.4.1 **Mono-method (Qualitative and Qualitative) Research Methodology**

Mono-method research methodological choice refers to a situation where a researcher seeks to explore the understanding of particular social or human phenomenon using a single method. The method can either be a single qualitative data collection (e.g. unstructured interview) with qualitative data analysis procedures; or a single quantitative data collection technique (e.g. questionnaire) with quantitative data analysis procedures (Saunders et al., 2019) as represented in Figure 3. 2. The first scenario is known as 'mono-method qualitative' while the scenario is referred to as 'mono-method quantitative' methodological choice.

3.4.2 **Multi-method (Qualitative and Quantitative) Research Methodology**

Multi-method refers to a situation where a researcher combines more than one data collection techniques with associated analytical techniques within either a qualitative or quantitative research method (Tashakkori & Teddlie, 2003). There are two possible scenarios for this methodology: 'multi-method qualitative' or 'multi-method quantitative' methodological choices (Figure 3. 2). Multi-method qualitative applies to a situation where textual (qualitative) data is collected using more than one technique (e.g., semi-structured interviews and diary accounts) and analyse the data using qualitative procedure (e.g. content analysis). On the other hand, multi-method quantitative methodology refers to a situation where a researcher chooses to collect numeric (quantitative) data using two or more quantitative techniques such as questionnaire and experiment, and then analyse the data using statistical procedures (Saunders et al., 2012). Hence, in a multi-methods, qualitative and quantitative techniques and procedures are not mixed.

3.4.3 **Mixed Methods (Simple and Complex) Research methodology**

Mixed-methods research involves a mixture of qualitative and quantitative data collection techniques and analysis procedures in a single study (Figure 3. 2). There are two possibilities here also: ‘mixed-methods simple; and ‘mixed-methods complex’ (Saunders et al., 2016). The mixed-methods simple methodology involves the use of qualitative and quantitative data collection techniques and analysis procedures either at the same time (concurrent/parallel) or one after the other (sequential) without combining them. In this case, qualitative data are analysed qualitatively, and quantitative data are analysed quantitatively. However, the mixed-methods complex combines quantitative and qualitative data collection techniques and analysis procedures as well as combining the two approaches at other phases of the research. In this case, qualitative data might be transformed and ‘quantitised’; while quantitative data might be converted and ‘qualitised’ (Saunders et al., 2009).

Depending on how the methods are mixed, Creswell (2014) identified four basic classifications of the mixed methods approach. These include 1. Convergent Parallel Mixed Methods wherein both quantitative and qualitative data collection and analysis are conducted concurrently or in parallel; 2. Explanatory Sequential Mixed Methods which started with the collection and analysis of quantitative data and followed by collection and analysis of qualitative data; 3. Exploratory Sequential Mixed Methods wherein qualitative data is collected and analysed first and followed by quantitative data collection and analysis; and 4. Transformative Designs which seeks to use any of either method, but encased the design within a transformative framework or lens.

According to Bryman (2006), mixed methods can be used for triangulation, facilitation, complementarity, generality, aid interpretation, study different aspects of the study, or solving a puzzle (Table 3. 3). The use of mixed methods in single research is more effective than mono-method research (Brannen, 2005). The combination of both qualitative and quantitative approaches allows for in-depth exploration of the research problem and broader generalisation of its findings. Given that this research seeks to develop a framework that will integrate EK into BI to improve decision-making and the adopted research philosophical assumptions, this study, therefore, adopts convergent parallel mixed methods. This method allows for data collection from two or more sources to corroborate research findings within a single study through triangulation. The next sub-section justifies the choice of convergent mixed methods as the methodological choice for the study.

Table 3. 3: Reasons for Using Mixed Methods Designs in Research

Reason	Explanation
Triangulation	Using two or more independent data sources or data collection methods to corroborate research findings within a single study
Facilitation	Using one data collection method or research strategy to aid research using another data collection method or research strategy within a single study
Complementarity	Using two or more research strategies in order that different aspects of an investigation can be dovetailed
Generality	Using independent source of data to contextualise main study or use quantitative analysis to provide sense of relative importance
Aid interpretation	Using qualitative data to help explain relationships between quantitative variables
Study different aspects of research	Using quantitative method for investigation at macro level and qualitative method at micro level (or vis-versa)

Solving a puzzle	Using an alternative data collection method when the initial method reveals unexplainable results or insufficient data

Source: Adapted from Saunders et al., 2016.

3.4.4 **Justification for Mixed-Methods as the Research Methodological Choice for the Study**

As stated in section 3.4.3, the research method adopted for this study is convergent parallel (concurrent) mixed methods research. This is to achieve the aim and objectives of the study and to provide answers to the research questions which seeks to explore how EK can be integrated into BI in one hand, and investigate the factors influencing the integration on the other hand. Mixed methods are very useful in exploring new or poorly researched areas (Robson, 1993), such as integrating EK into BI to provide a comprehensive understanding that may be difficult using a single method (Love et al., 2002). Using mixed methods will also reduce the deficiencies and bias that may arise from using any single method. The findings from both qualitative and quantitative can be used to corroborate each other using the strengths of one method to overcome the other's weakness as a means of improving the reliability and validity of the research findings. A general weakness of the questionnaire is the absence of context which reduces social phenomenon (like EK) to numerical figures. This weakness can be compensated for using the qualitative research method to corroborate and explain the reasons for the facts from the quantitative method.

Mixed methods have also been proposed as the most appropriate research methodology for construction management and building construction because of the nature of construction as a social system (Love et al., 2002) involving complex and dynamic interaction of various stakeholders from multidisciplinary backgrounds (Holt & Goulding, 2014). Accordingly, this study adopts mixed methods since the study's fundamental objective is to understand the complex and dynamic interaction among stakeholders as they integrate their experiences into BI to improve decision-making. Furthermore, mixed methods allow the use of different lenses to look at different aspects of the study to give a holistic view of the phenomena under investigation. This method will provide a more complete and comprehensive perspective on the phenomena and generate new insights into concepts under investigation.

Although mixed methods were adopted in answering all the research questions, it is important to point out that the weight on each of the methods (qualitative and quantitative) varies from question to question (Santos et al., 2017). This variation is reflected in how the data from each of the methods were analysed and presented in the report. For example, the emphasis for the research RQ1 is on the qualitative method (QUAL + quant) while RQ2 is essentially dominated by the quantitative method (QUANT + qual). Accordingly, the qualitative findings are first presented in chapters 4 and 5, where answers are provided to RQ1. Conversely, in chapters 6 and 7, the quantitative method analyses are presented first while findings from interviews are only used to corroborate the results from the questionnaire. Questionnaires have been employed for RQ1, in addition to the interview, because of its usefulness for investigating broader data about people, their experience, attitudes, opinions and awareness of event (McGuirk & O'Neil, 2016). Since this study also seeks to gather original data about experts' experience with BI and their awareness of what and how EK can be integrated into BI, it was deemed necessary to use a questionnaire to corroborate the interview data. The justification for this approach is to ensure that all relevant data is collected and analysed. It also allows to validation and corroboration of findings.

While many researchers (e.g., Robson, 1993; Holt & Goulding, 2014; Shokri-Ghasabeh & Chileshe, 2014) have advocated the use of mixed methods in construction management as a means of gaining a complete understanding of social phenomena, it is vital to note that some 'purists' (such as Blaikie, 1991) have condemned the use of mixed methods. Some of the disadvantages of mixed methods are that it may be time-consuming and expensive. Despite these challenges, mixed methods are still preferred due to its relevance to this study and numerous benefits. These benefits include: it provides an opportunity to answer a broader and more complete range of research questions; it allows for the integration of both qualitative and quantitative approaches; it permits the application of triangulation approach to improving exploration and understanding of the phenomena under study, which will be difficult using a single approach. Other benefits are: it provides strong evidence for the conclusion using an integration of qualitative and quantitative data; it allows innovative perspectives on the research topic; and it increases the validity of the results and the conclusion through triangulation of data from different methods (Johnson & Christensen, 2004; Shokri-Ghasabeh & Chileshe, 2014). The next section will provide further details on the research strategies adopted for the study.

3.5 Research Strategies

The next layer of the ‘research onion’ is the strategy layer. Research strategy refers to the ways or methods of conducting an inquiry. According to Saunders et al.

(2012), research strategy is a plan and set of action(s) for achieving a goal. There are several research strategies in the literature (Creswell, 2014; Neuman, 2009), each with its strengths and weaknesses. Despite some overlaps and interrelationships among the research strategies (Yin, 2003), the following different types of research strategies can be identified from the literature: experiment, survey, archival research, case study, action research, ethnography, grounded theory, narrative inquiry and phenomenology (Saunders et al., 2016; Collis & Hussey, 2009).

The summary of the characteristics of each strategy is presented in Table 3. 4. Experiment and survey strategies are primarily linked to quantitative research method; archival research and case study strategies are suitable for either qualitative or quantitative method while the rest are solely linked to qualitative research methods (Saunders et al., 2012). Depending on the nature of the research, two or more research strategies can be combined in mixed-methods research. Consequently, this research will adopt a combination of phenomenology and survey as the two major research strategies, using semi-structured interviews and questionnaires as data collection instruments, respectively. These two strategies will be discussed further, and their choice justified in the next sub-sections.

Table 3. 4: Research Strategies and their Characteristics (Saunders et al., 2016)

Research Strategy	Characteristics
Experiment	• Suitable for laboratory research rather than the field • Unlikely to be related to the real world of organisation
Survey	• Used for exploratory and descriptive research • Most frequently used to answer ‘what’, ‘who’, ‘where’, ‘how much’, and ‘how many’ questions • Easy to explain and to understand research strategy
Archival research	• Make use of administrative records and documents as the principal source of data • Allows research questions which focus upon past and changes over time to be answered
Case study	• Suitable for research which wishes to gain rich understanding of the research context and processes • Able to generate answers to the research questions ‘why’, ‘what’, and ‘how’ • Not suitable for collecting that data for generalisation
Action research	• Provides an in-depth understanding to specific phenomena, however, literature advices using it the education context
Ethnography	• Used to study groups of people • Requires a longer term of fieldwork study
Grounded theory	• Data collection process might several field visitations

	• Criticised for its confusing process and time required for completion
Narrative inquiry	• Suitable for small, purposive samples • Intensive and time consuming
Phenomenology	• Suitable for investigating participants' worldview and experiences with respect to a phenomenon • Concerned with individual's perception of phenomenon under investigation

3.5.1 **Phenomenology**

Phenomenology is a research strategy involving the study of human experience and the way things present themselves to us and through such experience (Sokolowski, 2000). It is the study of structures of consciousness as experienced from the first-person point of view (Smith, 2008). Therefore, this strategy is most suitable for studies where individual personal experiences of respondents about the phenomenon are essential to answer research questions (Creswell, 2009). Phenomenological research aims to provide insights that contribute to thoughtfulness and practical tact, using the methods of 'openness to experience' and 'reduction'- meaning of phenomenon as appear to experience/consciousness. In essence, phenomenology gathers lived experience, using interviews or observation, rather than opinions, views, beliefs (Moustakas, 1994). It is most appropriate for exploring personal experiences of BIM professionals regarding the integration of EK into BI on projects they have been directly involved. It is also useful in understanding their 'lived experience' in terms of making decisions during BI. Consequently, interviewees were asked to respond to questions based on their personal (lived) experiences with BI.

3.5.2 **Survey**

Survey research is a form of research strategy involving the collection of quantifiable data from a sizeable population using structured method like questionnaire (Sapsford, 2007). This strategy allows researchers to obtain data about practices, situations or views at one point in time through questionnaires and structured interviews. It enables researchers to study more variables at one time while collecting data about the real-world environment. It is appropriate in scenarios where contemporary data is required within geographically dispersed contexts (Bryman, 2004). It is suitable when the research questions start with 'who', 'what', 'where' 'how many' and 'how much'. It is, therefore, suitable for explanatory and descriptive research. Some of the weaknesses of survey research are the difficulty in getting insight into the causes or processes involved in the phenomena measured and the possibility of several sources of bias.

3.5.3 **Justification for Strategies Adopted for the Research**

As stated earlier, the two main research strategies adopted to fulfil this study's aim and objectives are phenomenology and survey. The strategies align with the pragmatic philosophical stance and the concurrent (parallel) mixed methods already adopted for the study. Phenomenology, a research strategy that involves an investigation into participants' worldview and experience, is employed to fulfil the qualitative aspect of the study's requirements. The use of phenomenology was based on the need to explore the personal experiences and perspectives of the BIM stakeholders on the EK required for BI and how this can help improve decision-making process during BI in building construction projects. Many previous researchers have used this same strategy (such as Manu, 2013; Ajayi et al., 2017; Mahamadu, 2017) at the exploratory phase of the mixed methods.

Integration of EK presumes that experiences can be captured. This assumption lends itself to a positivist philosophy and quantitative methodology. Consequently, a survey research strategy is adopted to investigate and understand the phenomena from broader groups of respondents involved with BI using questionnaires. Questionnaire surveys have been widely used for the quantitative aspect of mixed methods research involving BI by many previous researchers such as Amuda-Yusuf, 2018; Muhammadu, 2017; Akinade, 2017; Smith et al., 2016. The next section explains the time horizon of the study.

3.6 Time Horizon of the Study

The fifth layer of the 'research onion' represents the time horizon. Time horizon describes the duration within which the research is conducted in order to answer the research question (Saunders et al., 2012). There are two types of time horizon in designing research (Saunders et al., 2016), namely: cross-sectional and longitudinal time horizons. Cross-sectional researches, also known as one-shot researches, are limited to a specific time frame while longitudinal researches are repeated over an extended period. In cross-sectional studies, data is collected once, over a short period – days, weeks or a few months. It is used when there is a constraint on time or resource.

Longitudinal studies aim at researching the dynamics of a problem by investigating the phenomenon continuously over a long period. The nature of the research questions, which seeks to answer the "how knowledge can be integrated into BI" and "what factors impact on the effectiveness of this integration" may not require any observation over a long period. As such, data were collected over a short period. Both qualitative and quantitative data for this study were collected almost simultaneously between July 2018 and June 2019. The next section will be devoted to the specific application of the adopted research strategies regarding the research techniques and procedures, given the convergent parallel mixed methods adopted already]

3.7 Research Techniques and Procedures for the Study

Research techniques and procedures are the innermost core of the 'research onion'. They refer to the methods of data collection and data analyses. Data can be collected using qualitative or/and quantitative data collection techniques and analysed using qualitative or/and quantitative data analyses procedures. As discussed earlier, the convergent parallel mixed methodological choice was adopted to fulfil the research aim and objectives of this study using qualitative (semi-structured interview) and quantitative (survey questionnaire) methods of data collection and data analyses in parallel. Detailed discussions of the adopted research techniques and procedures for this study are discussed in the following sub-sections.

3.7.1 **Qualitative Data Techniques and Procedure**

The overall aim of this study is to develop a BIM-Knowledge framework for the integration of EK BI for improved decision in BIM projects. The overall sampling technique design adopted for the research is convergent parallel mixed methods sampling, which involves selecting units of analysis for both qualitative and quantitative methods using both non-probabilistic and probabilistic sampling techniques simultaneously (Teddlie & Yu, 2007). This section and the following subsections present the research techniques and procedures adopted for the qualitative method of the study.

3.7.2 **Sampling Techniques**

The interview phase of the research adopted a non-probability sampling method, using both purposive/judgmental sampling and snowball techniques (Atkinson & Flint, 2001). These sampling techniques allow a researcher to deliberately choose experienced and information-rich participants for in-depth exploration of the phenomenon under investigation (Palinkas et al., 2016), and therefore, suitable for qualitative research (Patton, 1990). The primary source of contacting the research participants was LinkedIn. An invitation letter to participate in a research interview on BIM-Knowledge framework was written and uploaded on various BIM groups such as BIM Experts, BIM and the AEC

Profession, BIM4SME. The invitation letter (a copy attached in the appendix) provides a brief background to the study, the purpose of the research and the requirements for participation. Interested participants were contacted and sent a consent form. Subsequently, suitable date, time and interview mode (online, phone call or face-to-face) were mutually agreed for the interview.

After each interview, participants were asked to identify and recommend people from their contacts who can also participate in the research interview, based on their experience and knowledge of the subject matter. This technique is known as snowballing. The technique is particularly useful for explorative, qualitative and descriptive research (Atkinson & Flint, 2001). It seeks to leverage the social networks of the initial participants to avail a researcher with an increasing set of possible participants (Thomson, 1997). Through this technique, thirty stakeholders in BI with a good understanding of KM within the UK construction organisations were identified for the semi-structured interviews. The sample size was considered adequate based on the recommendation of Saunders et al. (2012), who suggested a minimum 5 – 25 participants for semi-structured, in-depth interviews. The participants were selected across various organisation sizes (see Figure 3. 3), different job titles (see Figure 3. 4), years of experience (see Figure 3. 5), including the duration and mode of the interview (see Figure 3. 6). Detailed profiles of the participants in the interviews are summarised in Table 3. 5.

Table 3. 5: Profile of the Interviewees and Interview Summary

Job Title	Code	Organisation Size	Year of Experience	Interview Mode	Interview Duration
BIM Director	BD1	Large	10 years	WebEx Video	31 mins
	BD2	Small	5 years	WebEx Video	32 mins
	BD3	Large	10 years	Phone call	44 mins
	BD4	Large	10 years	Phone call	64 mins
BIM Manager	BM1	Large	12 years	WebEx Video	34 mins
	BM2	Medium	4 years	Face-to-face	54 mins
	BM3	Large	5 years	Face-to-face	45 mins
	BM4	Large	7 years	Phone call	94 mins
	BM5	Medium	9 years	Phone call	44 mins
	BM6	Small	5 years	Face-to-face	41 mins
	BM7	Large	4 years	Phone call	69 mins
	BM8	Large	12 years	Phone call	62 mins
	BM9	Large	5 years	Phone call	56 mins
	BM10	Medium	6 years	Face-to-face	81 mins
	BM11	Small	10 years	Phone call	30 mins
	BM12	Large	4 years	Phone call	77 mins
BIM Coord	BC1	Medium	10 years	WebEx Video	106 mins
	BC2	Large	8 years	Phone call	73 mins
	BC3	Small	7 years	Phone call	60 mins

	BC4	Large	4 years	Face-to-face	47 mins
	BC5	Large	10 years	Phone call	47 mins
Inform. Manager	IM1	Large	10 years	WebEx Video	32 mins
	IM2	Large	5 years	Face-to-face	56 mins
	IM3	Small	6 years	Phone call	82 mins
	IM4	Medium	10 years	Face-to-face	41 mins
	IM5	Small	5 years	Phone call	55 mins
Client Rep.	CR1	Small	7 years	Phone call	79 mins
	CR2	Large	10 years	Face-to-face	30 mins
Cost Est.	CE1	Small	7 years	Skype	36 mins
	CE2	Medium	4 years	Phone call	42 mins

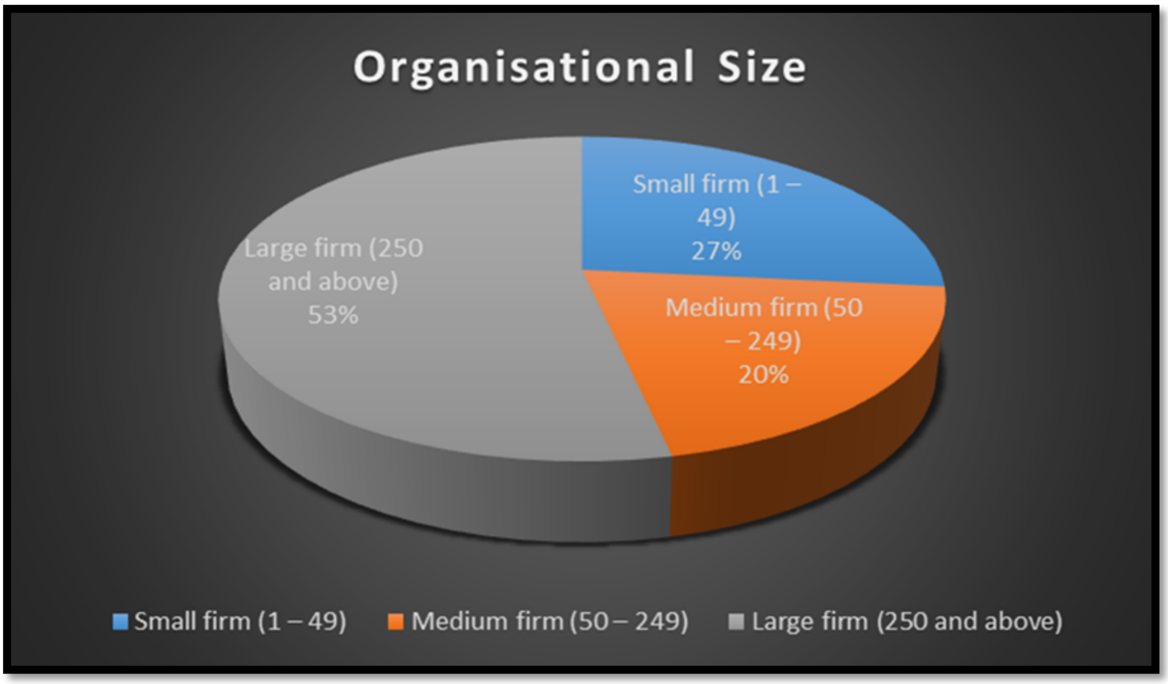


Figure 3. 3: Organisational size distribution of participants in the interview

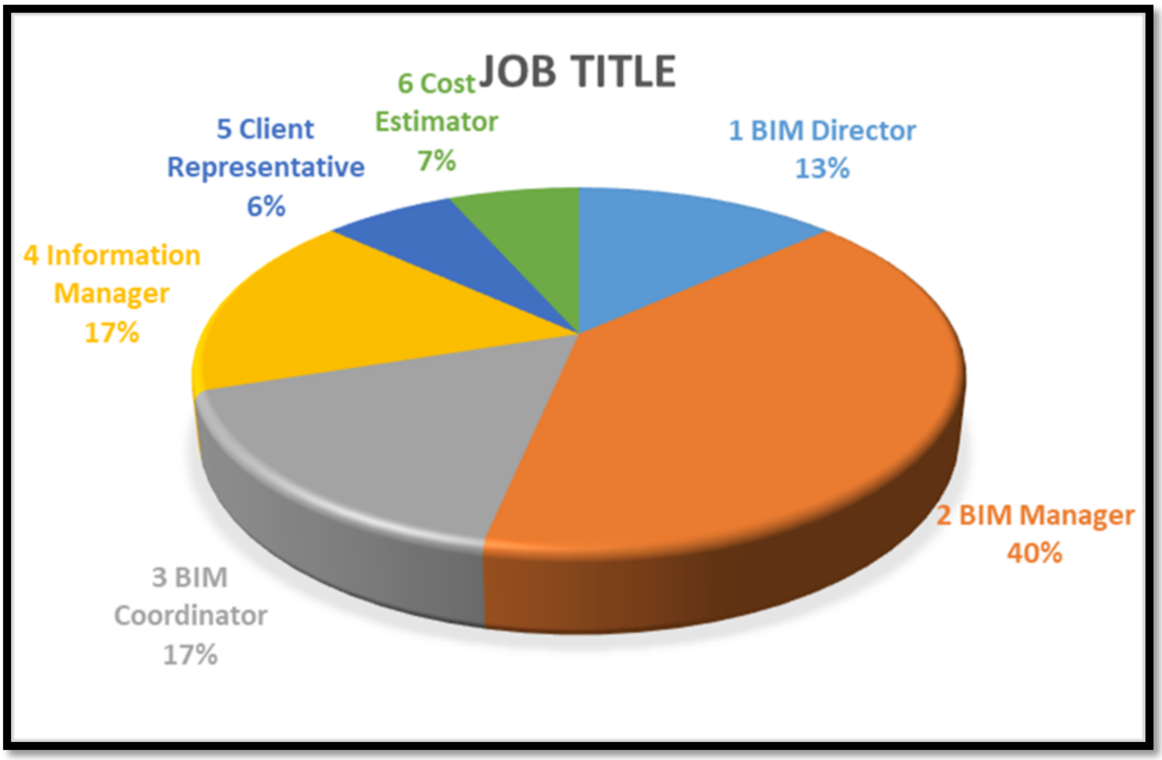


Figure 3. 4: Job title distribution of participants in the interview

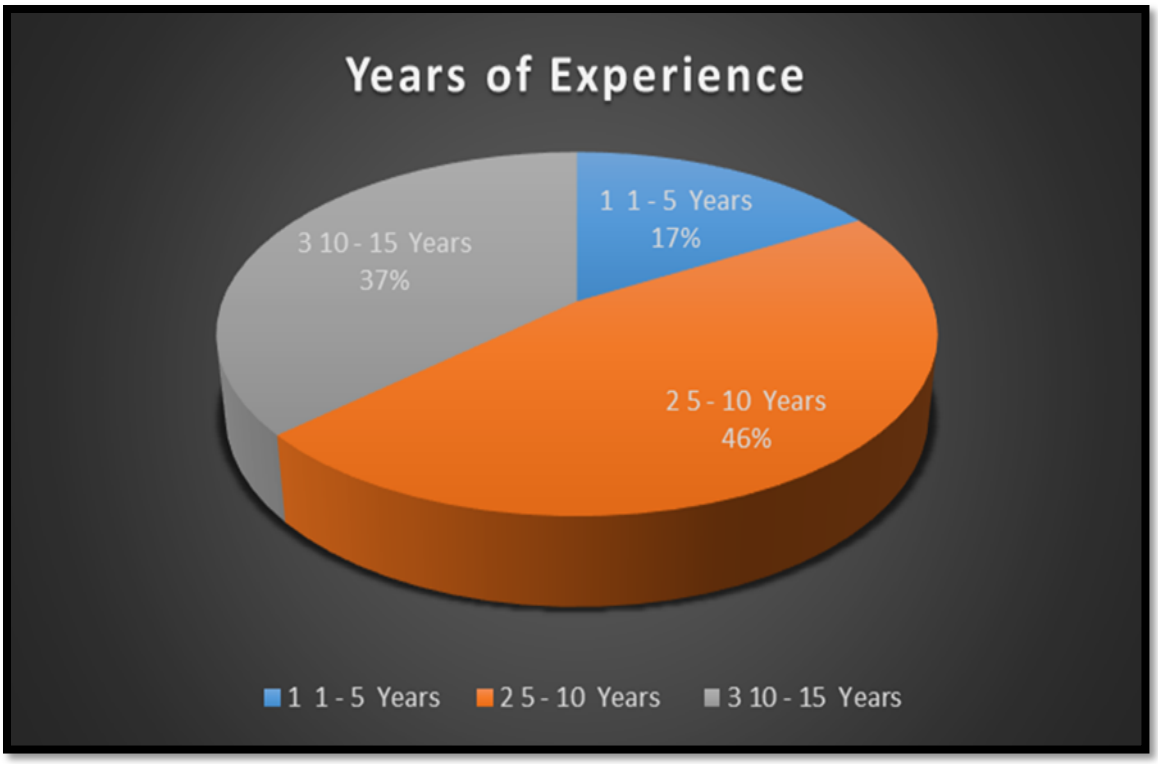


Figure 3. 5: Years of experience distribution of participants in the interview

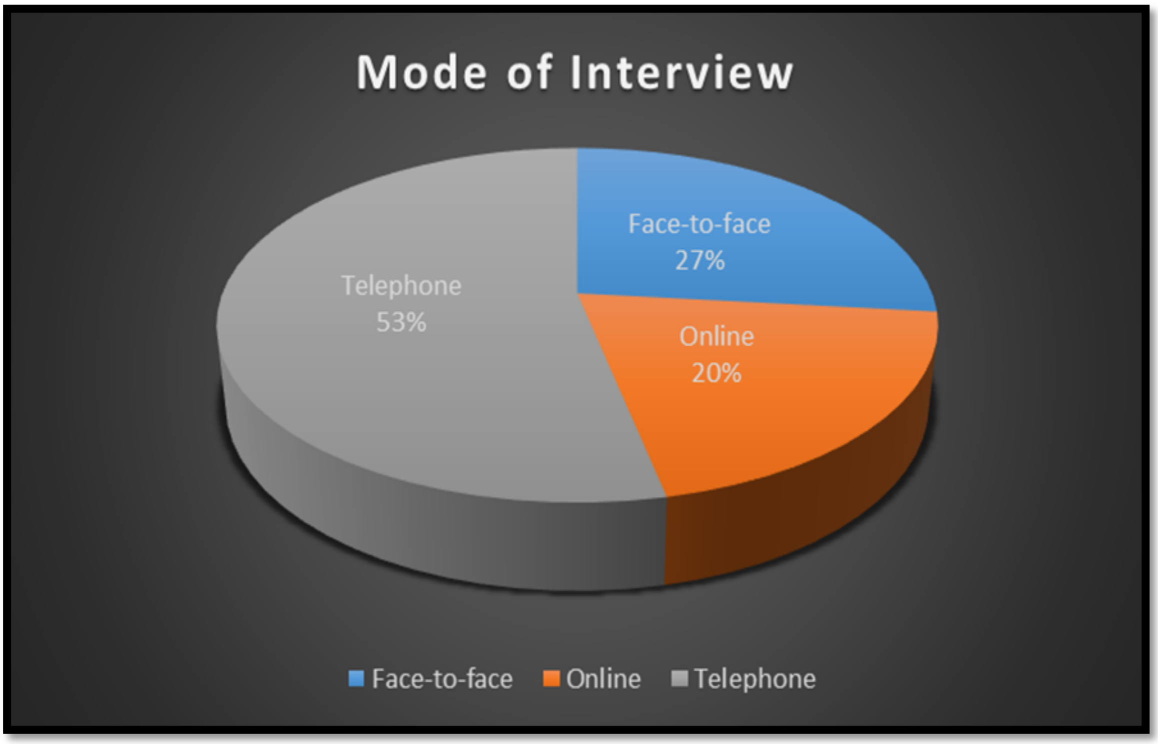


Figure 3. 6: Modes of interview

3.7.2.1 Data Collection Method

The data collection mode was very flexible, as participants were given a choice to select the most convenient method for them. They had the option of choosing between 1. Face-to-face interview, 2. Telephone calls, or 3. Online interview using WebEx or Skype (Figure 3. 6). All the interview sessions were conducted using a semi-structured interview schedule (a copy of the interview questions is attached in the thesis's appendix). Before the interviews, permissions were obtained to record the session, using either a digital recorder for face-to-face interviews or telephone calls. The online platforms (WebEx and Skype) also have provisions for video recording. The video recordings were later converted to MP3 audio for transcription and analysis.

Participants were encouraged to discuss their personal experience with BI; EK required for BI; decision-making processes within BIM-enable projects; KM processes; tools and techniques used for managing knowledge; factors impacting knowledge integration; and the essential skills and knowledge required by key decision-makers in BI. The interview duration varies with time available to the interviewee and his wealth of experience with the subject matters. However, the interviews' average duration was about an hour that ranged between 30 and 106 minutes. A few of the interviewees spent about 30 minutes because of their tight schedule or other engagements. However, most of them have requested a copy of the interview questions helped in maximising the available time.

3.7.2.2 Transcription of the Interview

The audios of the interviews were uploaded into Otter Transcribe, an online transcription software, for transcription. The transcribed documents were reviewed and edited by carefully listening to the original audios and going through the manuscript for accurate representation. Typographical errors due to the different accents of the researcher and the participants were corrected.

3.7.2.3 Data Analysis

Analyses of qualitative data follow structured methods, starting with reading and rereading the transcripts to gain adequate familiarisation with the data (Braun and Clarke, 2006). This stage was followed by coding and describing the data. The coded data were then aggregated and classified into themes according to the research objectives (RO). These themes are then reviewed and connected to explain or meanings (Maguire & Delahunt, 2017). Following this process, the semi-structured interviews' manuscripts were analysed using NVivo 11 to identify units of meaning from the significant statement and classify them into recurring themes.

3.7.2.4 Coding Scheme

Coding scheme starts by organising data from all the transcripts in a systematic and meaningful way. Coding reduces the extensive data to only relevant codes by capturing only segments of the transcripts relevant to the research questions and objectives (Maguire & Delahunt, 2017). The coding scheme was used to identify the sources of EK required for BI, KM tools, and techniques for generating, capturing, and sharing EK for integration into BI and factors that impact the effective integration of the EK into BI. Furthermore, the coding scheme was also used to identify the key decision-makers in BI, and the skills and knowledge required by these critical decision-makers. All relevant and related data were gathered around a common theme to create a meaningful story around the research objectives. To illustrate how the themes emerged from the codes, Table 3. 6 shows examples of coded data segments from the interview.

Table 3. 6: Examples of Coded Data Segment from the Interview

Theme	Codes	Source	Examples of Quotations
Methods and tools for identifying people with the required knowledge for BI	Certification and Qualification	BM12, BM3, BM4, BM5, CE1, CE2,	"I will look for certificate and experience and also memberships or something related that proves that they are just capable to do BIM." BM12
	Practical demonstration	BM4, BM5, CE2, CR1, CR2, IM2	"The second one is to practically demonstrate the basic understanding of the BIM process and guidelines." BM5

	Skill matrix	BC2, BC4, BM10, CR2	"You need to get the gauge of what is their previous experience in projects. You use the matrix-base kind of, how good are you at Revit?" BM10

3.7.3 **Quantitative Research Method**

This section presents the overall processes for the quantitative method of the study. The research population and sampling techniques were explained, followed by the questionnaire design processes. After that, various sections and the scale of measurement of the questionnaire were discussed. The research instrument was tested through a pilot study, and the implications of the pilot study highlighted. The last sub-section explains the approach to data collection and analysis.

3.7.3.1 Research Population and Sampling Technique

This study's research population includes various stakeholders and professionals within the UK construction industry who have been involved with BI. Since there are no directories of BIM stakeholders and professionals in the UK yet, LinkedIn platform, which is the largest professional online network, was used to get the BIM professionals' population in the UK construction industry (Mirabeau et al., 2013). The search for "BIM professionals in the construction industry" with "United Kingdom" as location yielded a total number of 1,046, which constituted the universal or general population for the research. The universal population represents the largest group of potential participants in research with some similar basic attributes (Asiamah et al., 2017). In this case, they represent all BIM professionals in the UK construction industry known and targeted by the researcher.

A probabilistic sampling technique was used for the quantitative method of the research. 'Invitation to Connect' was randomly sent to the general population on LinkedIn. The invitation included a short note about the research and the reason for the invitation. Only 611 people accepted the invitation, out of which 584 contact details (emails and telephone numbers) can be accessed from their home page. The list of 584 participants randomly selected from the list of "BIM professionals in the construction industry in the UK" generated from LinkedIn constitute the study population or accessible population for the study. Using a 95% confidence level, 7.5 confidence interval, and population size of 584, the study's required sample size was calculated, using an online sample calculator to be 132 respondents for the study. A total number of 584 questionnaires were sent out in two batches, based on the time they accept the invitation.

3.7.3.2 Questionnaire Design

The questionnaire consists of eight sections. Section 1 (Introduction) explained the study's aim and solicited for the respondents' support in filling the questionnaire. It stated the purpose of the research findings and assured respondents that their responses would remain confidential. Section 2 contains general information about respondents. The section consists of the type of firm, size of the firm, job title, and years of experience with BI.

In section 3, respondents were asked to indicate how effective they find the identified KM tools and techniques for capturing EK relating to BI. The question contains 15 variables and respondents were asked to rank their degree of effectiveness on a 4-point Likert scale, ranging from 1 - not effective to 4 - highly effective. Lozano et al. (2008) posited that the optimum number of alternatives for Likert scales range between four and seven. They argued that fewer alternative would return results with reduced reliability and validity. Similarly, a higher number of alternatives does not yield any significant value. The 4-Likert scale chosen was to prevent a response from sitting on the fence by picking the middle value arising from indecision. The section's focus was to identify the most effective KM tools and techniques that BIM professionals employ in capturing EK related to BI for future reuse and continuous improvement.

Section 4 relates to the EK required for BI. The section seeks to investigate the EK required for improving decision-making during BI in building construction projects. Accordingly, the section is divided into three subsections:1. Importance of sources and activities relating to EK to improve decision-making during BI; 2. The usefulness of EK for improving decision-making regarding BI tasks and activities during the pre-design phase; 3. Importance of capturing and integrating EK relating to tasks and activities at subsequent phases (design, construction and post-construction) for improving decision-making during BI. Subsection 1 contains seven variables; subsection 2 contains fifteen variables, while subsection 3 contains a total of thirty-one variables. These variables were placed on a 4-point Likert scale, and respondents were to rank them.

Section 5 is a matrix question relating to the decision-making processes and different phases of the building lifecycle. The section seeks to investigate respondents' experience regarding the extent to which they usually consider different building lifecycle phases when engaging in the various decision-making activities regarding BI. Ten decision-making process activities adopted from the literature were tabulated against four phases of the building lifecycle. Respondents were asked to rank the extent to which they consider each decision-making activity on a 4-point Likert scale ranging from 1 - never considered to 4 - always considered.

Section 6 aims to investigate the factors impacting on the effective integration of EK into BI. These factors were categorised into three: 1. Individual-related factors, which contains eight variables; 2. Project team-related factor, which comprises ten factors; and 3. Organisation-related factors, which contains eight factors. In all, 26 factors identified from the literature were investigated. Respondents were asked to rank the extent to which these factors impact on the effective integration of EK into BI based on their personal experience. The variables were ranked on a 4-point Likert scale ranging from 1 - not impactful to 4 - highly impactful.

Section 7 contains a list of skills and knowledge considered important to key decision-makers in BI. Like section 5, this question is a matrix question and respondents were asked to rank the degree of importance of the itemised skills and knowledge now and in the next five years. They were also asked to indicate the degree of training needed (now) to attain the skills and knowledge considered important in the next five years on a 4-point Likert scale. There are 20 variables listed as skills and knowledge considered important for key decision-makers based on the literature review findings..

3.7.3.3 Pilot Study and its Implications

The research instrument was tested through a pilot study. A pilot study's essence is to evaluate the content validity, predictive or concurrent validity, and construct validity of the instrument (Ismail et al., 2017; Creswell, 2014). The pilot study was aimed to validate the research instrument. It will produce valuable feedback which can be used to test the clarity of the language, flow of the layout, and logic of the questions in the research instrument before full launching of the survey. Twenty respondents were chosen for the pilot based on Isaac and Michael (1995) recommendation that a sample size of 10 – 30 people could be enough. The respondents cut across practitioners and academics. Eleven out of the twenty questions, representing a 55% response rate, were returned while five people submitted valuable written comments on improving the questionnaire.

The feedback from the pilot study helped in improving the language of the questions. For instance, one of the respondents observed that some of the questions were negatively worded and suggested writing consistently. Other valuable comments include the need to write abbreviations such as KM in full and to provide contextual definitions of the major concepts (such as KM, EK and BI) at the beginning of the questionnaire. However, some of the respondents complained about the questionnaire's size and the time it takes to complete it. They suggested a downward review of the questionnaire, provided it will not affect the study's quality..

3.7.3.4 Data Collection Method

The final draft of the questionnaire was designed and launched online using the Bristol Online Survey (BOS) platform recommended by the University for researchers. BOS is a free online platform for designing, distributing and analysing survey questionnaires. The key advantages of using online survey include accessibility to remote individuals, save time and cost efficiency (Wright, 2005). Other advantages include the fact that it is more accurate, quick to analyse, and very convenient. Using the contacts of BIM professionals in the UK construction industry obtained from the LinkedIn, a total number of 584 questionnaires were sent out in two batches.

3.7.3.5 Response Rate

The first batch consists of 396 participants, while the second batch consists of 188 participants. Out of the total number of 584 questionnaires sent out, eight failed delivery; fifteen sent auto-replies that they are out of the office; nine people replied that they would not have time to complete any questionnaire and pleaded to be excused. After several email reminders, 89 and 33 responses were received from the first and second batch respectively, making a total number of 112 responses. The sample size for the study is 132 people (section 3.7.2.2). Therefore, the 112 responses received represent 84.85% of the expected sample size. Out of these, five failed preliminary analysis due to gross incomplete information and were removed from further analysis. Hence, only 107 questionnaires were subjected to statistical analysis using the SPSS Statistics 21 version.

3.7.3.6 Statistical Analysis Techniques

The essence of statistical analysis is to establish the suitability of the collected data and understand the responses' pattern. The statistical analysis results will be combined with the findings from the interviews, through triangulation to develop a conceptual framework for capturing and integrating EK into BI. Therefore, data description and validation were carried out using different statistical analysis techniques.

Descriptive analysis of the respondents' information was performed to determine their distributions according to firm type, firm size, job title and years of experience with BI. All the variables in the questionnaire were subjected to descriptive analysis using SPSS. The mean values from the descriptive analyses were used to rank the level of importance, degree of usefulness, and level of the variables' impacts.

It is vital to ensure that a reliable set of data is used for statistical analyses in research. Accordingly, Cronbach's alpha was used to test the research instrument's reliability and check if the factors in the questionnaire measure the constructs of the study (Field, 2009). A high-reliability coefficient (α) confirms the collected data's internal consistency as a statistical measure of research constructs.

Factors analysis is a statistical technique for data reduction or structure detection through which correlated factors are identified from smaller variables (Meredith, 1993). A set of uncorrelated factors can be unravelled from the reduced data using factor analysis. The Kaiser-Meyer-Olkin (KMO) and Bartlett test of sphericity was used to confirm the data's adequacy and appropriateness for factor analysis.

Kruskal-Wallis H coefficient (P), a non-parametric test, was also performed to check if there are variances in the response pattern based on organisation size, job title and years of experience with BI. The respondents' perceptions will be considered statistically different when the Kruskal-Wallis coefficient is less than 0.05 at 95% confidence level.

3.7.3.7 Preliminary Data Analysis

A preliminary analysis of the respondents' information in section 2 of the questionnaire was carried out. Table 3. 7 presents the results of the respondents' analysis in terms of the types of respondents' firm, size of their firm, their job title and years of their experience with BI. Figure 3. 7 to Figure 3. 10 shows the bar charts of the respondents' information. The preliminary analysis reveals that majority of the respondents, representing 38%, were from contracting firms. 53% of the respondents work with large companies with over 250 employees. The reason may be because large companies handle most of the BIM projects. In terms of job title, majority of the respondents answer the title of a BIM manager (36%) while information managers account for only 2%. About 45% of the respondents have spent less than five years implementing BIM, and only 10% of them have spent over 15 years implementing BIM within the UK construction industry. This reason may be due to the recent mandate from the UK Government on BI on all publicly procured projects by 2016.

Table 3. 7: General Information about the Research Respondents

Items	Variables	Frequency	Percentage (%)
Firm type	Architectural or Planning Firm	21	19.6
	BIM Consultancy Firm	20	18.7
	Construction/Contracting Firm	41	38.3
	Engineering Consultancy Firm	19	17.8
	Project/Facility Management Firm	6	5.6
Firm size	Micro Firm (1 - 9 employees)	16	15.0
	Small Firm (10 - 49 employees)	18	16.8
	Medium Firm (50– 249 employees)	16	15.0
	Large Firm (over 250 employees)	57	53.3
Job title	Architect/Design Manager	11	10.3
	BIM Manager/Director	38	35.5
	BIM Adviser/Consultant	14	13.1
	BIM Technician/Coordinator	17	15.9
	Information/Knowledge Manager	2	1.9
	Project/Construction Manager	9	8.4
	M&E/Civil Engineer	7	6.5
	Quantity Surveyor/Cost Estimator	9	8.4
Years of experience	1 to 5 Years	48	44.9
	5 to 10 Years	34	31.8
	10 to 15 Years	14	13.1
	Above 15 Years	11	10.3

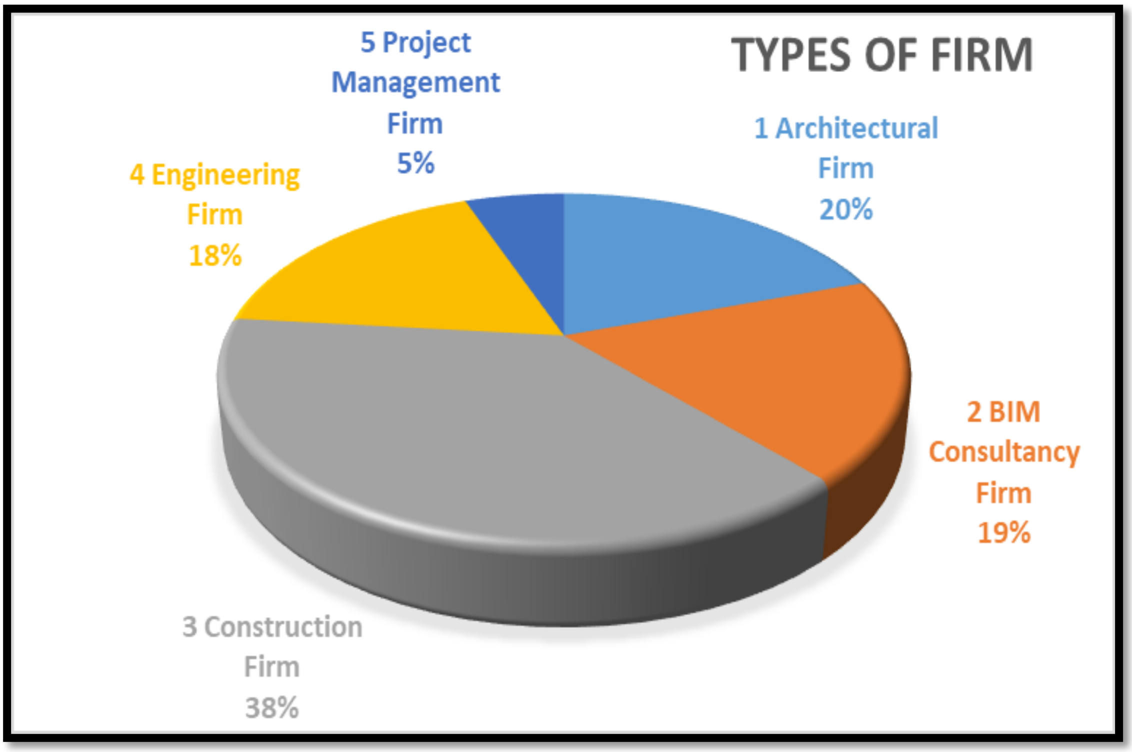


Figure 3. 7: Types of firm distribution of participants in the survey

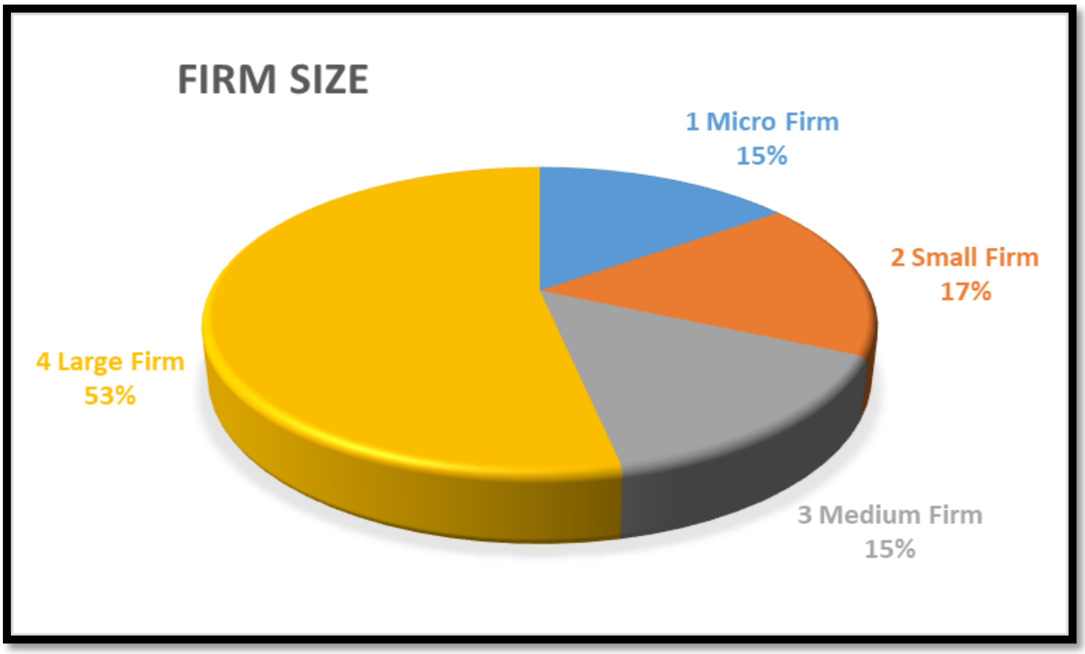


Figure 3. 8: Firm size distribution of participants in the survey

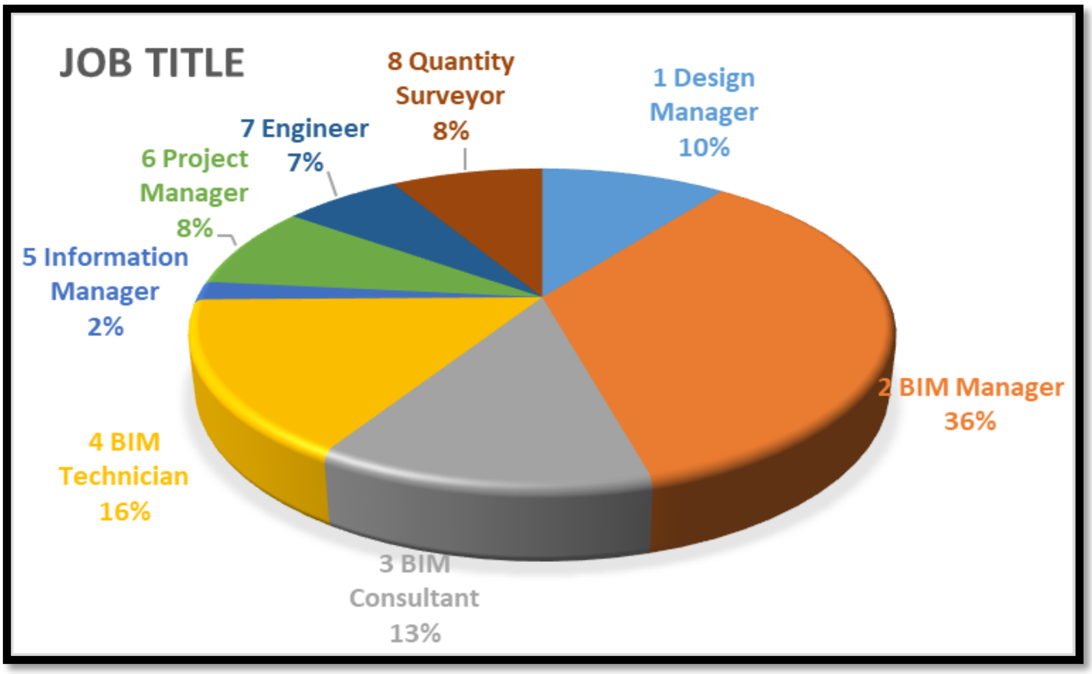


Figure 3. 9: Firm size distribution of participants in the survey

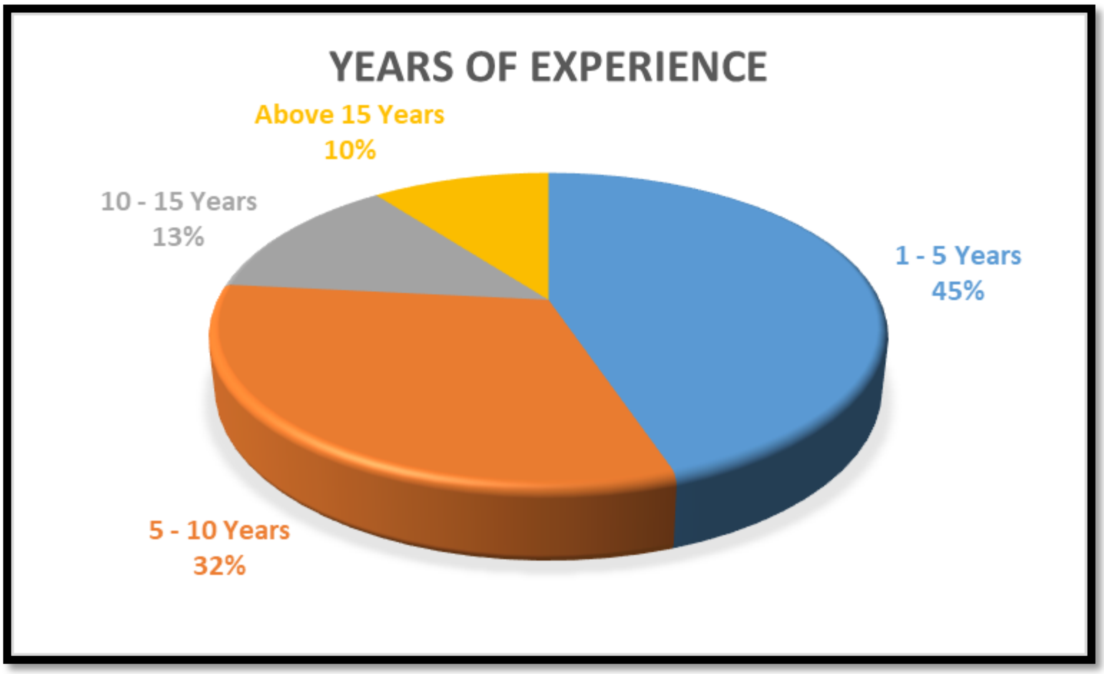


Figure 3. 10: Firm size distribution of participants in the survey

3.7.3.8 Data Validity and Reliability

Reliability test was carried out to test the internal consistency of the variables in the questionnaire and the suitability of the data for analysis using Cronbach's Alpha. Field (2009) recommends determining the Cronbach's alpha coefficient of variables when using a Likert scale in a survey questionnaire. Cronbach's alpha value ranges from 0 to 1, and the higher the value of alpha, the more reliable the variables. A value of 0.7 is considered acceptable, 0.8 shows good internal consistency, and 0.9 represents an excellent internal consistency of the data (Tavakol & Dennick, 2011). Furthermore, 'Cronbach' alpha if item deleted' were also calculated for each of the variables. Any variable with 'Cronbach' alpha if item deleted' above the overall group value should be removed (Field, 2009). Such a factor is regarded as a bad construct that does not contribute to the factors' overall reliability. The results of Cronbach's alpha tests are presented and discussed at the appropriate chapter.

3.8 Ethical Considerations for the Research

The issue of ethical consideration is critical in protecting the privacy, dignity and confidentiality of all participants in every research (Knight & Ruddock, 2008; Merriam, 1998). Although this study does not involve any vulnerable group such as under-aged and disabled, efforts were still made to inform and protect all participants' privacy and confidentiality in the interview. Several steps were taken to achieve this. The research was designed and conducted in compliance with the ethical requirements for postgraduate research in the London South Bank University (LSBU) and the Economic and Social Research Council (ESRC). Ethical approval was sought and obtained from the Faculty Ethical Committee before the commencement of the data collection.

Participants were provided with consent forms, which clearly explained the aim and objectives of the study, their role in the research including the right to withdraw at any time or not to answer any question they are not comfortable with, how the data will be protected, and the purposes for which the data will be used. The analysis of the interview transcripts adopts a coding scheme that protects the identity of the participants. Similarly, the introductory section of the questionnaire survey also provides the respondents with information about the purpose of the research and how the data will be used, stored and disposed in line with ethical guidelines of the university. A copy of the research information sheet, letter of ethical approval, the consent form and the research instrument are attached in the appendix of this thesis.

3.9 Chapter Summary

This chapter highlighted the research methodology and process adopted for conducting this research, following the 'research onion' model (Saunders et al., 2016). Various concepts relating to the research methodology were discussed and evaluated for relevance to the study. After a critical evaluation of the available philosophical position, the study adopted pragmatism as the study's research philosophy. Accordingly, the abductive research approach was adopted, using phenomenology and survey as research strategies in convergent (triangulation) parallel mixed methods research design. Semi-structured interview and questionnaire survey were the two data collection techniques, and the data from these sources were subjected to content analysis and statistical data analysis respectively for triangulation. Table 3. 8 presents the summary of the research methodology and the justifications for the choices made. The next four chapters, chapters 4 to 7, will the discussing analyses of the collected based on the research methodology presented in this chapter.

Table 3. 8: Summary and Justification of the Adopted Research Methodology for the Research.

Areas of Choices	Available Choices	Choice Made	Justifications for the Choice Made
Research Philosophy	Positivism, Constructivism, Realism,	• Pragmatism	Pragmatism focuses attention on the research problem in social science research and use pluralistic approaches to derive

	Transformative, Pragmatism		knowledge about the problem (Tashakkori & Teddlie, 2010).
Research Approach	• Deduction, • Induction, • Abduction	• Abduction	Abduction allows a researcher to move forth and back between theories and data, and offers great opportunity to triangulate inferences developed from qualitative and quantitative research (Feilzer, 2010)
Research Strategy	• Experiment • Survey, • Archival Research, • Case Study, • Action Research, • Ethnography, • Grounded Theory, • Narrative Inquiry, • Phenomenology	• Phenomenology • Survey	Phenomenology is suitable for exploring BIM experts' lived experience with BI as described by them on one hand while survey allows for the investigation and understanding of the phenomenon from wider BIM practitioners on the other hand.
Method of Enquiry	• Mono Methods, • Multi-methods, • Mixed Methods	• Mixed Methods	The study adopts both qualitative and quantitative methods of data collection and analysis at the same stage of the research.
Types of Mixed Methods Design	• Convergent Parallel Mixed Methods, • Explanatory Sequential Mixed Methods, • Exploratory Sequential Mixed Methods, • Transformative Methods	• Convergent Parallel Mixed Methods Design	Both qualitative and quantitative methods of inquiry are used at roughly the same time in order to provide comprehensive analysis of the research problem and integrate the information in the interpretation of the overall findings (Creswell, 2014).
Types of Convergent Parallel (Concurrent) Mixed Design	• Concurrent Triangulation Design, • Concurrent Nested (Embedded) Design, • Concurrent Transformation Design	• Concurrent Triangulation Design	Both qualitative and quantitative methods are used simultaneously to seek convergence and corroboration of findings from different methods and designs within a study of same phenomenon to provide a comprehensive analysis of the research problem (Creswell, 2014). Both methods are used to confirm, cross-validate, or corroborate findings in a single project.
Data Collection Instrument	• Archival Records • Documentation, • Focus Group Discussion,	• Literature • Interviews • Questionnaire	Literature review and semi-structured interviews were used for the collection of qualitative data at the early stage of the

	• Literature, • Questionnaire, • Interview, • Artefacts, • Observation		research while questionnaires were used to elicit the opinions regarding the earlier findings from a larger sample size
Sampling Designs	• Concurrent design (parallel, nested, or Multilevel sample) Sequential design (identical, parallel, nested or multilevel samples)	• Concurrent Design using Parallel samples	Samples for the qualitative and quantitative components of the research are different but drawn from the same population of interest (Onwuegbuzie & Collins, 2007).
Data Analysis Methods	• Statistical Analysis, Case Description • Reliability Analysis, • Factor Analysis. • Thematic Analysis, • Content Analysis,	• Content Analysis • Statistical Analysis • Reliability Analysis	Analysis of both qualitative and quantitative data is conducted separately using content analysis and statistical analysis respectively. The results are then compared, interpreted and integrated.

CHAPTER 4: EK REQUIRED FOR IMPROVING DECISION-MAKING DURING BI.

4.1 Introduction

This chapter and the subsequent three chapters present findings of the analyses and discussions of the data collected from both qualitative and quantitative methods which serve as the basis for the conceptual BIM-Knowledge framework proposed in chapter 8. The research questions and objectives informed the division of the chapters. In addition to the literature review, chapters 4 and 5 provide answers to the first research question – "what is EK and how can it be integrated/validated in a BIM environment to improve decision-making in BIM projects?" This is the most important research question, considering the aim of the research. Accordingly, three research objectives (objectives 1 – 3), were formulated to explore and provide answers to the RQ1.

This chapter presents the results of the findings from the analyses of both qualitative and quantitative data for the first research objective – "to explore the knowledge required for implementing BIM projects through investigation of the decision-making process in BI". It starts with the presentation of the findings from the interviews in section 4.2. After this, the results from the survey questionnaires on "sources and activities relating to EK during BI" and the "degree of usefulness of EK for improving decision-making regarding various BI tasks and activities" were presented in section 4.3. Section 4.4 presents and discusses the findings from both qualitative and quantitative regarding the decision-making process in BI. Finally, a summary of the findings from the analyses in this chapter is presented in section 4.5.

4.2 Findings from the Interview

As stated in chapter 3, the qualitative data was collected using a semi-structured interview and analysed through content analysis, using NVivo Pro 11. Details of the data collection methods were presented in section 3.7.2.1, along with the experts' profiles in Table 3. 5 and Figure 3. 3 to Figure 3. 6. The interviews' findings are presented in three sections based on the questions asked in line with the RQ1. Findings regarding knowledge identification of EK required for BI are presented in section 4.2.1 and critical phase for decision-making in BI in section 4.2.2.

The coding scheme and final categorisation of the identified factors were based on the dominant codes that emanated from the individual interview analysis. The coding scheme was used to identify the knowledge required, methods and tools for identifying people with the required BI experience based on a thorough reading of the transcribed data. The main themes were based on the research objectives and the interview questions, while the emergence of codes employed a data-driven coding technique (Braun & Clarke, 2006).

Based on Gu and London (2010) recommendation, coding system and identification of themes were created through the use of labelling. For the sake of analysis of this study, the labels used are theme, codes, sources and quotations. "Theme" refers to the main issue relating to developing the framework for the integration of EK into BI as appeared in the research objectives, research questions, or the interview questions. "Codes" are the summation or grouping of the respondents' most recurring ideas based on the interview analysis. "Sources" refer to those respondents who expressed similar idea relating to a particular code. "Quotations" are typical examples of respondents' verbatim statements that are associated with the code. This coding scheme was adopted to present all the findings from the semi-structured interviews as presented in the subsequent sections.

4.2.1 Knowledge Identification - EK Required for BI

After asking the interviewees to share some of their experiences on BI within the UK construction industry, they were asked to explain the kinds of knowledge required to implement BIM in other to improve decision-making in building construction projects. This question is in fulfilment of the research object 1 of the study. The summary of the findings is presented in Table 4. 1. The coding scheme and final categorisation for the experience-based knowledge required for BI were based on the dominant codes that emanated from the analysis of the individual interview conducted with the stakeholders as stated above (section 4.2). The central theme for this section, the knowledge required for BI (BI), is based on the objective of the study. However, the emergent codes evolved from the analysis of the individual response to the question regarding the EK required for BI. Five dominant codes emerged from the analysis; these are 1. Lesson learned from past mistakes and best practices; 2. Practical experience with BI; 3. Experience using BIM technology and software; 4. Knowledge of BIM standards and policies; and 5. Domain knowledge of Construction. Figure 4. 1 shows a screenshot of the analysis of the responses in NVivo.

Table 4. 1: What kinds of Experience-based Knowledge are Required to Implement BIM in other to Improve Decision-making in Building Construction Projects?

Theme	Codes	Sources	Examples of Quotations
Knowledge required for BI	Lesson learned from past mistakes and best practices	BC1, BC4, BC5, BD1, BM10, BM2, BM7, BM7, BM8, CE1, CR1, IM3, IM4	*"…for me, it will be documenting why things always go wrong, and then it proves to people why you should be doing it a different way." CE1* *"There are different types of knowledge that are required. On the basic level, what we need is knowledge assets in terms of best practices..." IM5*
	Practical experience with BI	BC3, BM1, BM5, CR2	*"…we will ask them to provide evidence of their experience in BIM projects. So, the architects will have to, as part of their tender return, demonstrate that they've done BIM level 2 projects." CR2* *"Experience is practical knowledge. So, practical knowledge includes tacit knowledge as well as the explicit knowledge, right? So, this is what we need…" BM1*
	Experience using BIM technology and software	BD3, BD4, BM10, BM12, BM7	*"You need that software knowledge, but you do need that technical knowledge as well." BM10* *"…we need to get hands on experience using the various different BIM platforms. We need to be comfortable using quickly adopting new technologies, quickly adopting new software programs." BM7*
	Knowledge of BIM standards and policies	BC3, BM10, BM12	*"I think it's just making sure you've got a knowledge of all the standards." BM4* *"First of all, they have to know all the standards. Otherwise, how can you understand BIM if you don't know what BIM is?" BM12*
	Domain knowledge of Construction	BD4, BM8, CE1, IM5	*"you need the knowledge of the domain itself, what it is you're an expert in, whether it be building services or structures or water or railways or whatever, you have to have that knowledge" BD4* *"it's always better to have a construction related degree, whether vocational or higher education." BM8*

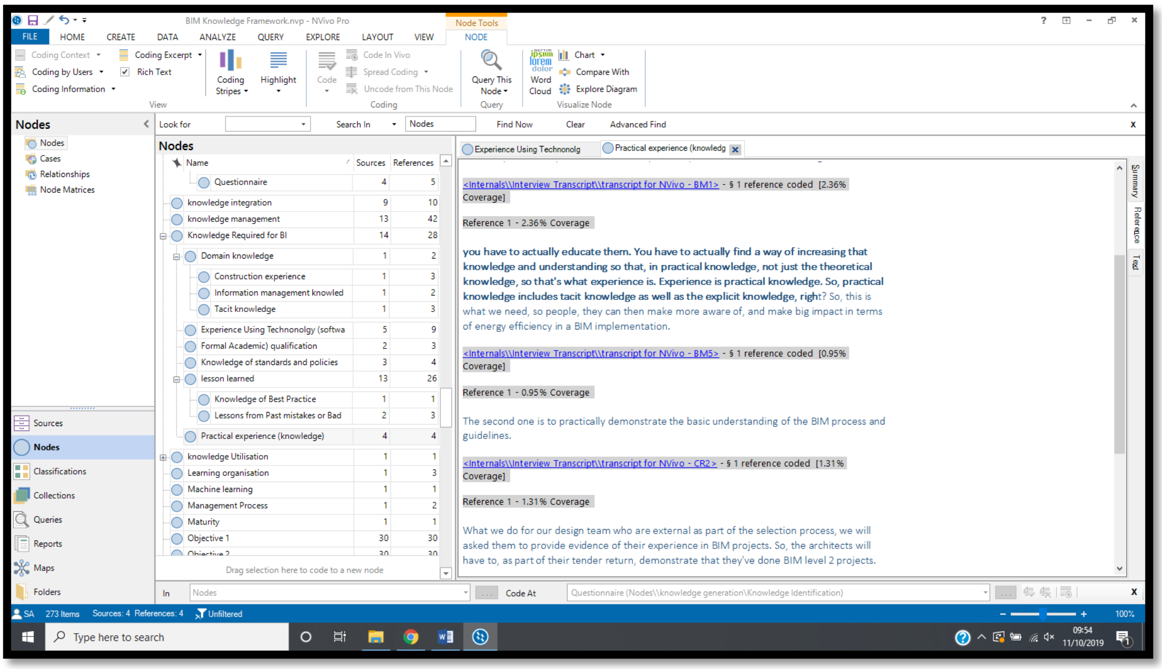


Figure 4. 1: Identification of the Required EK for BI

This section presents the summary of the experts' responses on methods and tools used to identify people with the required EK for BI. Table 4. 2 presents the summary of the findings. The central theme for this section is: "methods and tools for identifying people with the required knowledge for BI". The theme was based on the interview question to enrich the RQ1 of the study. The dominant codes emerged from the analysis of data collected from the interviews, as presented in Figure 4. 2. The analysis of the responses to the methods and tools for identifying people with the required knowledge to implement BIM revealed seven dominant codes. Majority of the respondents relied on academic qualifications and BIM certification for identifying people with required EK for BI. Other methods and tools identified are the ability to demonstrate BIM understanding practically, use of skill matrix, filling questionnaires, curriculum vitae, regular, and innovation. Figure 4. 2 shows a screenshot of the analysis on NVivo.

Table 4. 2: How do you identify those people with the required knowledge to implement BIM on building construction projects?

Theme	Codes	Source	Examples of Quotations
Methods and tools for identifying people with the required knowledge for **BI**	Certification and Qualification	BM12, BM3, BM4, BM5, CE1, CE2, BC3, CR1, BC1, BD4, CR2	*"I will look for certificate and experience and also memberships or something related that proves that they are just capable to do BIM." BM12* *"The first one is through certification. They want to know what certificate and what training I have done and what evidence I have got to show for that." BM5*

	Practical demonstration	BM4, BM5, CE2, CR1, CR2, IM2	*"The second one is to practically demonstrate the basic understanding of the BIM process and guidelines." BM5* *"I think they should have evidence that they have done it in the past." CR1*
	Skill matrix	BC2, BC4, BM10, CR2	*"You need to get the gauge of what is their previous experience in projects. You use the matrix-base kind of, how good are you at Revit?" BM10* *"the skills matrix picks like traditional skills that people get and then we score them on a zero to three. zero may be used for novice; three for expert." BC2*
	Questionnaire	BM6, BM7, BM8, CR2, IM4	*"Well, normally we have competency questionnaire, okay, that you share. This is normally developed within a construction company by the BIM lead. So, almost like a questionnaire of the key skills that are require" BM8*
	Curriculum vitae	BC2, BM11, BM3, BM4	*"Check their experience on the CV, try and associate each one with a certain category of architectural, engineering or mechanical, electrical" BM3*
	Regular assessment	BD2, BD4, BM10, BC1, BM12, BM7	*"I can know that they're knowledgeable if, for example, they can start a project on their own, doing BIM"* *"You've also got individuals annual performance reviews" BC1*
	Innovation	BC1, BC2, BC3, BC4, BD2, BD4, CE1, CR1, IM4, IM5	*"At the moment, I think only innovation comes to mind." CR1* *"Where innovation is identified, we work with our local business and university partners to identify solutions." BD2*

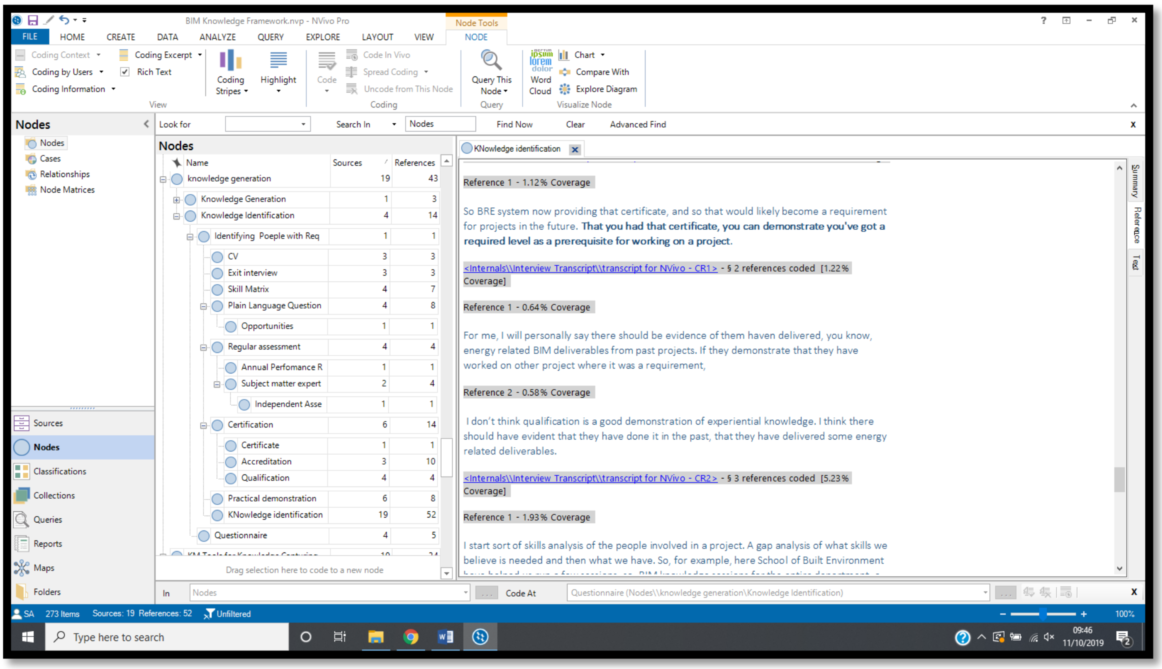


Figure 4. 2: Screenshot of NVivo of theme and codes on identification of people with required knowledge for BI

4.2.2 Critical Phase for Decision-making and Decision-Making Process in BI

This section seeks to explore the experiences of respondents with the decision-making process in BI in line with various phases of building project lifecycle discussed in section 2.3.4. Given the various phases in a project lifecycle, it is essential to identify and justify the project phase where the integration of EK into BI will be most impactful on decision-making. Based on their experiences with BI, respondents were asked to identify the most critical phase for decision-making and justify their choice. Besides, they were asked to describe a decision-making process they have been involved with while implementing BIM. The summary of responses to the questions is tabulated and presented in the appendix.

Analysis of the interview scripts shows that respondents expressed divergent views regarding the critical phase for decision-making in BI. This divergent may not be unconnected with the complex nature of decision-making and difference in the professional background of respondents. According to the respondents, deciding on the most critical phase will depend on many factors, such as the project type and nature, the client's goals for BI, the types of question to be answered, among others. Some of the respondents submitted that:

"I think it really depends on the project and the goals of the employer and what type of building is involved. So, the likes of something HS2, large highways projects, it's kind of a different stage to a school or hospital." BC3

"The crucial decision-making stage depends on what the questions are,
such as points of procurement. I think the main thing is the questions,
being able to formulate them and frame the questions well" BD1

While many of the interviewees aligned with a particular project phase as the most critical phase for decision-making, some denied preference for any specific stage. To them, all the stages are equally important. This was the opinion of BM10 and BM11.

"There is no one. They're all the same. ...
But really, they're all is important" BM11
"I don't think any stage should be more important" BM10

An example of those who supported the design phase is a BIM manager, who happens to be an architect. He posited that the design stage is the most critical:

"the most crucial stage is actually the concept stage, and at the end,
the following stages will actually take shape basically based on the
decisions that are made in the concept stage because it has to
be in a collaborative manner." BM1

Supporting his choice, he argued that:

"Early stage, the concept stage is the very important stage. This is
where the architect actually communicates with almost all the
stakeholders in terms of energy efficiency, in terms of cost, in terms of,
you know, the performance or targets, and also, the clash detection
aspects as well, with the contractor and things like that." BM1

Despite the divergence of opinions, majority of the respondents were unanimous that the early stages of the building process are the most critical phase for decision-making. Accordingly, experiences from previous projects should be integrated as early as possible at this phase to improve decision-making. One of the BIM Directors expressed his view thus:

"I think there are different decisions at different stages. So, a lot of the
decision-making is around what is the best concept solution for the problem,
if it is a building or infrastructure investment is intending to meet some
demand or another, and so, making the decisions around what is the best solution
to meet the reason, the demand, why the building or the infrastructure is
going to be developed, should take place at a very early stage." BD4

Another BIM manager stressed that the most critical phase is the brief stage:

"The beginning. Right from the beginning. So, the most critical is the brief.
So, for me, the brief is definitely the first and most important part, and then
it's the development of that brief into data first, and then to information.
Those are critical because your decisions that creates your footprint
for what the project is going to be, and you can't go… if you miss that step,
and you do it wrong, the rest of the project is doomed to fail." BM2

Speaking from a contractor point of view, another BIM manager said:

"For me, it's the first stage because this is where you set up all of your program, all of your project guidelines, and exactly what you require from everyone. This is the most important stage, the first stage and contract. So, you must be very careful with the contract and the requirements. The words that connect to make it. You may be liable by the words, the wording in the contract that may look like there's something that is missing. So, if you see something which is not correct, or see something you should never probably do, something which is too vague or something that you don't agree with in the contract, in the first part, you must bring it up straight away. Otherwise, it is going to affect your whole project." BM3

Justifying reason for their choice of the early stage, some of them said:

"Because that's where your clients, the assets owner, decides reasons for that kind of project. If they want it to be energy efficient, then they will be able to have the key stakeholders to draft design brief that will be suitable to achieve those goals." BM8

"The initial stage, which is the strategic/inception, is when you're originally deciding on the project, and you're deciding either to deliver it, I think you need to embed BIM into that process at the very, very start." CE1

"because the earliest stages of BIM, it's where you decide whether you need a building or not. That's the most critical question, because that can be the biggest waste. If you don't sit down, in the earlier stage, with a client; if you build a building that isn't required, it doesn't satisfy your business objectives, and then that's wastage. The biggest waste of all is a building that isn't required by the clients. You have to be very carefully at the feasibility stages, I think, that's it. The key question is: do we need a building or not? As stupid as that question sounds, it's actually a very difficult question to answer from a client point of view." IM3

While the critical phase for BI may depend on various factors, it can be deduced from the above that majority of the respondents believed that the early stages (pre-design phase) is the most critical, followed by design and construction phases. This opinion was succinctly summarised by one of the BIM managers when he said:

> *"well, to me, there are three stages: one is the beginning, is development, when we are starting the project. The second one, when we are doing the design, all these pre-construction processes, and the last one, and not the least, is the construction and the close-out of the project… So, three phases to me, are: development and documentation, design and pre-construction, and then construction and close out" BM12*

The conclusion drawn from this analysis is that the pre-design phase, which consists of the strategic definition and brief stages, is the most critical phase where EK needs to be integrated into BI to improve decision-making. This position is in line with the findings of Sinclair (2019), who submitted that achieving the overall project goal depends on successful BI at the pre-design phase. It is, therefore, crucial to improve the quality of the decisions made at the phase through the integration of experience-based knowledge from the BIM experts.

4.3 Findings from the Questionnaire Survey

As indicated in section 3.4.4, a questionnaire survey was designed and analysed to corroborate the findings from the interviews. Accordingly, the questionnaire survey seeks to investigate various sources and activities relating to EK that is important to improve decision-making during BI (section 4.3.1). The survey further seeks to investigate the level of usefulness of EK regarding BI tasks and activities at the pre-design phase (section 4.3.2). The essence is to determine how useful the respondents find EK for improving decision-making regarding BI tasks and activities.

Furthermore, respondents were asked to indicate how important they find capturing and integrating EK from various tasks and activities relating to other phases of building projects to improving decision-making during BI (section 4.3.3 – 4.3.5). This question is to help identify tasks and activities from which EK can be captured for integration while implementing BIM. Decisions taking during BI can significantly impact on the whole project lifecycle, hence the need to capture and integrate knowledge from other phases to the pre-design phase. Respondents were required to rank their opinions on a 4-point Likert scale. The results of the analyses of the questionnaire are presented in the following sub-sections.

4.3.1 Sources of EK Required for BI

A descriptive analysis was carried out on the sources and activities relating to EK in BI. The essence is to help identify sources from which EK required for BI can be acquired. Knowledge from these sources and activities can be easily identified, acquired and internalised (Nonaka & Takeuchi, 1995) as EK for reuse to improve decision-making in BI. These EK sources were presented as variable and respondents were asked to rank them. The mean and standard deviation values of the variables were computed. Table 4. 3 presents the result of the analysis of the variables. Base on the 4-Likert scale of importance, the result shows that all the variables are highly important sources and activities relating to EK for BI. However, the five highest ranked variables are listed below:

1. Knowledge from documented best practices in BI
2. Knowledge from the lessons learned from past mistakes during BI
3. Knowledge from research, training and skill acquisition in BI

4. Knowledge from creative ideas arising during BI
5. Knowledge from brainstorming and group discussion on BI.

Table 4. 3 shows the results of the calculated mean, standard deviation, ranking of the variables, Cronbach alpha, and Kruskal-Wallis coefficient values. The mean values of the variables should be fairly close together to show that all the variables are testing the same concept (Tavakol & Dennick, 2011). The mean value can be used to identify variables for possible removal in order to increase the internal consistency or reliability of the variables. Any variable with a mean value that is too high or too low may be flagged for removal. The descriptive statistical analysis in Table 4.3 shows that the difference between the highest and the lowest mean value is 0.4, which show a high degree of closeness.

Additional statistical analysis was conducted to test the internal consistency and reliability of the variables. Table 4.4 presents the result of "total-item statistics" for all the seven variables. To determine if any item should be removed, two columns on the table should be examined: "Corrected item-total correlation" and "Cronbach's alpha if item deleted". "Corrected item-total correlation" helps determine how much the item correlates with the overall score. Any correlation score (r) less than 0.30 shows that the item may not belong to the scale and maybe deleted. More importantly, the "Cronbach's alpha if item deleted" gives the Cronbach alpha of the item if it is removed from the questionnaire. The current Cronbach alpha coefficient (α) value of the seven variables is 0.747. Any item with "Cronbach's alpha if item deleted" score higher than the current Cronbach' alpha value may be considered for removal. Table 4. 4 shows that item SA4 has a value of 0.291 and 0.752 for "Corrected item-total correlation" and "Cronbach's alpha if item deleted" respectively. These values indicate that the item may not be contributing to the group reliability and internal consistency of the questionnaire.

However, the researcher chose to keep this item for two reasons. One, the differences in the item's scores and the benchmarks are too small and not significant to warrant the removal of the item that was ranked highly important by all the respondents. Two, the result of the interviews (section 4.2.1) further strengthens the importance of the variable for inclusion in the analysis.

Kruskal-Wallis coefficient test was used to determine if there is any significant difference in the opinion expressed by the respondents regarding the variables, as shown in Table 4. 3. Analysis of the result indicates that there is no divergent in the respondents' perception across organisation size and years of experience with regards to sources and activities relating to EK.

Table 4. 3: Descriptive and Non-Parametric Analysis of Sources and Activities relating to EK

Label	Sources and Activities relating to EK	Mean	SD	Rank	Cronb. Alpha	Kruskal-Wallis Coef. (Org. Size)	Kruskal-Wallis Coef. (Year Exp.)
SA1	Knowledge from creative ideas arising during BI	3.30	.662	4	0.747	0.428	0.243
SA2	Knowledge from documented best practices in BI	3.48	.744	1		0.254	0.134
SA3	Knowledge from research, training and skill acquisition in BI	3.41	.658	3		0.759	0.301
SA4	**Knowledge from the lessons learned from past mistakes during BI*	*3.47*	*.663*	*2*		*0.263*	*0.357*
SA5	Knowledge from mentoring and mentorship by experts on BI	3.15	.711	5		0.081	0.317
SA6	Knowledge from brainstorming and group discussion on BI	3.14	.852	6		0.696	0.821
SA7	Knowledge from Communities of Practice on BI	3.08	.851	7		0.070	0.271

Note to Table: *denotes factors that have 'Cronbach's Alpha if item deleted' above the group's Cronbach's Alpha, which suggest that the factor could be removed to enhance the group's reliability.

Table 4. 4: Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Knowledge from creative ideas arising during BI	19.75	8.130	.547	.376	.702
Knowledge from documented best practices in BI	19.56	8.441	.389	.238	.734
Knowledge from research, training and skill acquisition in BI	19.64	8.387	.475	.286	.717
**Knowledge from the lessons learned from past mistakes during BI*	19.58	9.034	.291	.168	.752
Knowledge from mentoring and mentorship by experts on BI	19.90	8.229	.461	.241	.719
Knowledge from brainstorming and group discussion on BI	19.89	7.545	.514	.440	.707
Knowledge from Communities of Practice on BI	19.97	7.259	.579	.503	.689

Note to Table: *denotes factors that have 'Cronbach's Alpha if item deleted' above the group's Cronbach's Alpha, which suggest that the factor could be removed to enhance the group's reliability.

4.3.2 EK regarding BI Tasks and Activities at Pre-design Phase

A list of key tasks and activities expected to be carried out at different phases of building project lifecycle was compiled from RIBA PoW (2013) in section 2.3.4. The list forms the basis for the variables used in this section. Based on their personal experience in practice, respondents are to indicate how useful they find EK for making decisions regarding BI tasks and activities at the pre-design phase. They were required to rank the degree of usefulness on a scale of 1 = not useful to 4 = very useful. Table 4. 5 presents the results of statistical analysis, indicating the mean values, the standard deviation, mean rank, Cronbach alpha, and Kruskal-Wallis coefficient. The results of the analyses show that the respondents find EK very useful for decision-making regarding all the BI tasks and activities at the pre-design phase. However, the five highest-ranked variables with a minimum mean value of 3.45 are listed below:

1. Establishing project scope and BIM deliverables
2. Determining BIM competencies of project teams
3. Developing project goals and objectives
4. Identifying client business case
5. Defining the roles and responsibilities of various stakeholders.

The difference between the highest and lowest mean values is 0.41, indicating a high level of closeness among the variables. Also, Cronbach's alpha value was computed to determine the internal consistency and reliability of the variables. The result shows a high level of reliability with a Cronbach's alpha value of 0.848. The "Cronbach's alpha if item deleted" for each variable indicated that all the items contributed to the overall internal consistency of the questionnaire since none of the items has a score higher than 0.848. Table 4. 6 shows that the scores on the "Corrected item-total correlation" are more above 0.30, which indicates there is no need to delete of the items.

Kruskal-Wallis test was carried out to determine whether there is a statistically significant difference in the pattern of responses along organisation size and years of experience. The results show differences of opinion regarding four items based on the size of the organisation (Table 4. 5). The items were BTA4, BTA6, BTA7 and BTA15. However, respondents only differ on one item, BTA4, based on their years of experience

Table 4. 5: Descriptive and Non-Parametric Analysis of BI Tasks and Activities (Pre-design Phase)

Label	BI Tasks and Activities (Pre-design Phase)	Mean	SD	Rank	Cronb. Alpha	Kruskal-Wallis Coef. (Org. Size)	Kruskal-Wallis Coef. (Year Exp.)
BTA1	Identifying client business case	3.45	.692	5	0.848	0.494	0.927
BTA2	Developing project goals and objectives	3.48	.664	3		0.673	0.626
BTA3	Preparing a strategic brief	3.35	.728	10		0.324	0.518
BTA4	Undertaking feasibility studies	3.13	.802	15		**0.020*** **	**0.050**
BTA5	Reviewing Site information	3.17	.807	13		0.733	**0.179**
BTA6	Deciding the project budget	3.15	.888	14		**0.017*** **	0.456
BTA7	Assembling the project teams	3.35	.778	11		**0.049*** **	0.998
BTA8	Determining BIM competencies of project teams	3.50	.705	2		0.771	0.895
BTA9	Defining the roles and responsibilities of various stakeholders	3.41	.726	6		0.777	0.430
BTA10	Agreeing on software tools and their interoperability issues	3.38	.760	8		0.895	0.612
BTA11	Establishing project scope and BIM deliverables	3.54	.634	1		0.989	0.468
BTA12	Establishing workflow and communication strategies	3.47	.663	4		0.512	0.785
BTA13	Deciding on a common data environment (CDE) for data operations	3.30	.767	12		0.857	0.908
BTA14	Defining the BIM tools and their interoperability	3.39	.670	7		0.606	0.713
BTA15	Preparing handover strategy and risk assessments	3.36	.732	9		**0.004*** **	**0.199**

Note to Table: ***denotes factor that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their organisation size.

**denotes factor that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their years of experience.

Table 4. 6: Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Identifying client business case	46.95	35.512	.400	.402	.843
Developing project goals and objectives	46.92	36.280	.321	.375	.847
Preparing a strategic brief	47.06	36.016	.312	.351	.848
Undertaking feasibility studies	47.27	33.515	.550	.483	.834
Reviewing Site information	47.25	33.749	.522	.555	.836
Deciding the project budget	47.25	33.430	.491	.513	.839
Assembling the project teams	47.06	34.073	.505	.424	.837
Determining BIM competencies of project teams	46.91	33.858	.600	.526	.832
Defining the roles and responsibilities of various stakeholders	47.00	33.219	.661	.533	.828
Agreeing on software tools and their interoperability issues	47.03	34.218	.504	.473	.837
Establishing project scope and BIM deliverables	46.87	35.278	.479	.531	.839
Establishing workflow and communication strategies	46.94	34.168	.603	.601	.833
Deciding on a common data environment (CDE) for data operations	47.10	34.570	.456	.493	.840
Defining the BIM tools and their interoperability	47.02	35.790	.381	.492	.844
Preparing handover strategy and risk assessments	47.05	35.303	.396	.255	.843

4.3.3 EK regarding BI Tasks and Activities at Design Phase

In an attempt to understand the importance of capturing EK relating to the project lifecycle for integration into BI, descriptive analysis was carried out on various BIM tasks and activities associated with different phases (design, construction and operation) of the building project as presented in Table 4. 7. The difference between the highest and the lowest mean value is 0.41, which indicates proximity among the variables. The top five highest-ranked tasks and activities for the design phase are:

1. TA14 - Reviewing handover strategies and risk assessment
2. TA1 - Preparing Concept, Developed and Technical Designs
3. TA3 - Finalising project brief and design alterations
4. TA8 - Preparing constructability analysis
5. TA10 - Reviewing and updating the Project Execution Plan

Table 4. 7 presents the results of the statistical analysis for the design phase, showing the mean value, standard deviation, group ranking, and Kruskal-Wallis. Additionally, Table 4. 7 also shows the overall ranking of all the variables for tasks and activities from the design phase to operation phase. Cronbach's alpha coefficient of the design phase is 0.847. The "Cronbach's alpha if item deleted" revealed that one item, TA3, should be removed because its alpha coefficient value of 0.850 is more than the group Cronbach's alpha coefficient. The Cronbach's alpha coefficient based on standardised items dropped to 0.846 upon removing the item. Consequently, the item was left since its removal reduces the internal consistency of the scale.

The analysis of the Kruskal-Wallis Coefficient indicated that there was variation in the opinion of the respondents regarding two items based on their organisation size. The two items are TA1 and TA7. However, there is no variation among respondents' perception based on years of experience and job title.

4.3.4 EK regarding BI Tasks and Activities at Construction Phase

The same set of statistical analyses conducted for the design phase was repeated for the tasks and activities at the construction phase. The results of the analyses are included in Table 4. 7. The difference in the mean values of the variables indicated a high level of closeness. The top five highest-ranked construction tasks and activities are listed below:

1. TA18 - Resolving design queries from site
2. TA23 - Preparing the 'As-built model' for handover

3. TA17 - Prefabricating building components
4. TA19 - Preparing onsite and offsite construction programme
5. TA22 - Implementing the handover strategy.
6. TA21 - Inspecting site and reviewing work progress

Cronbach's alpha coefficient of the construction group was 0.824. However, "Cronbach's alpha if item deleted" value of 0.832 for item TA23 indicates that it is not contributing to the internal reliability of the group and should be removed. After removing the item, the group standardised Cronbach's alpha coefficient rose to 0.833, which indicated a good internal consistency of the scale.

One item, TA15, returned a P value of 0.011, which is less than 0.05 threshold for Kruskal-Wallis coefficient, based on the organisation size of the respondent. There was unanimous agreement among the respondents regarding all the items based on years of experience and job title.

4.3.5 EK regarding BI Tasks and Activities at Post-construction Phase

The statistical analyses for the operation phase involving mean, standard deviation, group ranking, overall ranking, Cronbach alpha, and Kruskal-Wallis were carried out and presented in Table 4. 6. The range of the mean value revealed that the variables are very close. The following items were ranked as very important by the respondents:

1. TA31 - Updating 'As-built' model with feedback information as required.
2. TA27 - Handing over the building to the client.
3. TA29 - Maintaining and repairing the building as scheduled.
4. TA30 - Evaluating performance and providing feedback for future use.
5. TA28 - Carrying out activities listed in the handover strategy.

The Cronbach's alpha coefficient of the variables under the operation phase was 0.789 and none of the "Cronbach's alpha if item deleted" was up to that value implying that all the items are contributing to the internal consistency of the scale of measurement. Only item TA26 has its P coefficient below 0.05 based on the respondents' organisation size, as highlighted in Table 4. 7. The Kruskal-Wallis coefficient values based on years of experience and job title show unanimity among all the respondents.

In addition to the group ranking, Table 4. 7 also shows the overall ranking of the most important items for the building life cycle. The overall ranking indicates that it is very important to capture and integrate EK relating to the following tasks and activities for improving decision-making during BI. The overall topmost ranked variables, with a minimum mean value of 3.30, are ranked and listed below:

1. TA31 - Updating 'As-built' model with feedback information as required.
2. TA18 - Resolving design queries from site.
3. TA27 - Handing over the building to the client.
4. TA29 - Maintaining and repairing the building as scheduled.
5. TA17 - Prefabricating building components.
6. TA16 - Preparing onsite and offsite construction programme.
7. TA14 - Reviewing handover strategies and risk assessment.
8. TA30 - Evaluating performance and providing feedback for future use.
9. TA1 - Preparing Concept, Developed and Technical Designs.

Table 4. 7: Descriptive and Non-Parametric Analysis of BI Tasks and Activities (Project Lifecycle)

Label	BI Tasks and Activities	Mean	SD	Group Ranking	Overall Ranking	Cronb. Alpha	Kruskal-Wallis Coef. (Org. Size)	Kruskal-Wallis Coef. (Year Exp.)
A	**Tasks and Activities at Design Phase**							
TA1	Preparing Concept, Developed and Technical Designs	3.30	.717	2	10	0.847	**0.043*****	0.197
TA2	Developing the 3D model (Visualisation model)	3.21	.736	7	19		0.874	0.601
TA3	*Finalising project brief and design alterations*	*3.26*	*.734*	*3*	*13*		*0.736*	*0.933*
TA4	Integrating time schedule into the 3D model (4D)	3.05	.851	12	28		0.155	0.830
TA5	Integrating costs into the 3D model (5D)	2.94	.822	13	30		0.177	0.692
TA6	Preparing materials and components specifications	3.12	.798	9	24		0.086	0.517
TA7	Preparing sustainability analysis	2.91	.889	14	31		**0.006*****	0.507
TA8	Preparing constructability analysis	3.25	.757	4	14		0.291	0.501
TA9	Submitting drawings for building permits	3.07	.898	11	26		0.911	0.101
TA10	Reviewing and updating the Project Execution Plan	3.25	.802	5	15		0.893	0.297
TA11	Discussing and agreeing on the model update	3.21	.753	6	17		0.736	0.477
TA12	Preparing and reviewing construction strategies	3.19	.766	8	22		0.998	0.714
TA13	Developing health and safety strategy	3.11	.865	10	25		0.605	0.586
TA14	Reviewing handover strategies and risk assessment	3.32	.760	1	8		0.324	0.298
B	**Tasks and Activities at Construction Phase**							
TA15	Contract administration	2.95	.851	11	29	0.824	**0.011*****	0.510
TA16	Preparing onsite and offsite construction programme	3.32	.672	4	7		0.272	0.860
TA17	Prefabricating building components	3.33	.727	3	6		0.338	0.524
TA18	Resolving design queries from site	3.46	.663	1	2		0.129	0.834
TA19	Inspecting site and reviewing work progress	3.26	.708	5	11		0.470	0.129
TA20	Construction quality control	3.20	.782	9	20		0.862	0.653
TA21	Resource planning and procurement method	3.21	.786	7	18		0.171	0.717
TA22	Implementing the handover strategy	3.26	.680	5	12		0.225	0.850
TA23	**Preparing the 'As-built model' for handover*	*3.38*	*.722*	*2*	*4*		*0.576*	*0.919*
TA24	Implementing and updating construction strategies	3.20	.679	8	21		0.095	0.166
TA25	Updating health and safety strategies	3.17	.830	10	23		0.055	0.523
C	**Tasks and Activities at Post-construction Phase**							
TA26	Concluding the contract administration	3.07	.908	6	27		**0.030**	0.675
TA27	Handing over the building to the client	3.43	.715	2	3		0.221	0.914
TA28	Carrying out activities listed in the handover strategy	3.23	.747	5	16		0.273	0.263

TA29	Maintaining and repairing the building as scheduled	3.34	.729	3	5	0.789	0.281	0.676
TA30	Evaluating performance and providing feedback for future use	3.31	.840	4	9		0.797	0.936
TA31	Updating 'As-built' model with feedback information as required	3.47	.663	1	1		0.392	0.760

Note to Table: *denotes factors that have 'Cronbach's Alpha if item deleted' above the group's Cronbach's Alpha, which suggest that the factor should be removed to enhance the group's reliability.

**denotes factor that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their years of experience.

***denotes factor that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their organisation size.

4.4 Decision-making Process for BI and Different Phases of Building Lifecycle

Based on the adopted rational decision-making process in section 2.3.2, respondents were asked to indicate the extent to which they consider experiences from different phases of building lifecycle when engaging in decision-making activities regarding BI. The essence is to identify the patterns in which the phases are considered regarding the adopted rational decision-making process. Table 4. 8 presents the summary of findings from the analysis of respondents.

Table 4. 8: Summary of Decision-making process and Phases considered during BI

No	Decision-making Process	Always considered	Sometimes considered	Rarely considered	Never considered
1	Identify the problem	Construction	Design	Pre-design	Operation
2	Establish goals and objectives	Pre-design	Design	Construction	Operation
3	Gather relevant data and information	Design	Construction	Pre-design	Operation
4	Determine criteria for evaluation	Pre-design	Construction	Design	Operation
5	Develop possible alternative solutions	Construction	Pre-design	Design	Operation
6	Analyse possible alternative solutions	Pre-design	Construction	Design	Operation
7	Select the most suitable solution	Pre-design	Construction	Design	Operation
8	Implement selected solution	Design	Pre-design	Construction	Operation
9	Review effectiveness of selected solution	Construction	Design	Pre-design	Operation
10	Capturing lessons learned	Operation	Construction	Design	Pre-design

Table 4. 8 shows that experience from the pre-design phase is the most frequently considered (40%), followed by construction phase (30%) and design phase (20%). Respondents indicated that they always consider EK from the pre-design phase when establishing the goals and objectives for implementing BIM, determining the criteria for evaluating alternative BIM solutions, analysing alternative BIM solutions to the problem, and selection of the most suitable solution. Findings from the interviews confirmed the pre-design phase as the most critical for decision-making. Interview results supported the view to establish the goals and objectives for BI at the early phase of the project in a structured and sequential way:

"a lot of the decision-making around what is the best concept solution for the problem, if it is a building or infrastructure investment is intended to meet some demand or another, and so, making the decisions around

what is the best solution to meet the reason, the demand, why the building or the infrastructure is going to be developed should take place at a very early stage. So, I think there is the need to make better strategic decisions early by using early-stage modelling of solutions to get that decision made in kind of a sequence. So, there is an increased need to focus on the early stages and make better decisions at early stage through better information" BD4

Three of the BI tasks and activities requiring EK at the pre-design stage (section 4.3.2) align with the establishment of goals and objectives for BI. These tasks and activities are: establishing project scope and BIM deliverables; developing project goals and objectives; and identifying client business case. This fact indicates synergy between the BI tasks and activities requiring EK at the pre-design phase and EK that is always considered for the establishment of goals and objectives for BI.

Establishing realistic goals and objectives requires that relevant EK (such as knowledge of OIR, AIR and EIR) should be readily available at this stage. One of the BIM managers argued that it is requisite to set up requirements from the start. However, he lamented that this practice is still far from reality in practice:

"But, critical for me is organization information requirements (OIR) The OIR has to be set up by the client, by the investor, from the very beginning, as well as the asset information requirements (AIR) and the employer information requirements (EIR). Those three must be put in place right from the beginning. Yeah. You implement it from stage one, that is the best thing. But unfortunately, it doesn't happen in reality." BM9

In addition to phases where EK is always required, Table 4. 7 also shows that EK from the pre-design phase is "sometimes considered" at the pre-design phase while developing possible alternative BIM solutions and implementation of the selected solution.

A holistic overview of Table 4. 7 revealed that EK from all the phases (pre-design, design and construction) is, at least, "somehow considered" during processes of decision-making in BI. Only EK from the operational phase is "never considered", except when capturing lessons learned from BI. The reason might be because not many projects have implemented BIM up to the operational phase. Evidence from the literature (e.g. Eadie et al., 2013; Julie, 2013; Hoseini et al., 2017) supports that BIM activities are still primarily focussed on design and construction stages, with no empirical case study on operational phase.

The pattern of response, as coded in colour, shows some revelations. For example, process 1 and 9 (shaded in green) follow the same pattern. The problem to be addressed is identified in process 1, while the effectiveness of the selected solution to the problem is in process 9. This pattern probably implies that errors committed during BI are often manifested and identified as problems during construction and design phases. A review of the effectiveness of any selected solution to the problem should equally take into consideration knowledge from these phases in a similar pattern. As mentioned before, knowledge from the operation phase is "never considered" because most people are yet to empirically see the benefit of BIM at the operation phase, let alone considering EK at the phase. Another interviewee buttresses the point by saying:

"The experience and knowledge come from early stages, which is difficult to show to the supply chain because they want to see the benefits within their own sector of the industry. They haven't seen any evidence of that yet. Whereas all of our experiential evidence is coming from designers, coming from construction." IM3

Similarly, processes 4, 6 and 7 also follow a similar pattern (coded in yellow colour). These processes involve determining criteria for evaluating possible BIM solutions; analysing possible alternative solutions; and selecting the most suitable solution. All these processes are requisite to the implementation of the selected solution. It is, therefore, surprising that process 5, development of the possible alternative solution, does not follow the same pattern. EK in these processes is "always considered" during pre-design, "sometimes considered" during construction and "rarely considered" during the design phase.

It is not entirely clear why process 3, 5 and 8 did not follow the same pattern with other processes. However, the reason may be attributed to the complex nature of the decision-making process itself or differences in the level of importance attached to knowledge at different phases. The difference in the level of importance may be influenced by the professional background of respondents or the type of companies they are working. It is not impossible for architects to "always consider" EK from the design phase while construction engineers will "always consider" construction above the design phase.

Another interesting pattern is the one between process 2 (establishment of goals and objectives for BI) and process 10 (capturing of lessons learned and best practices for future reuse). Consideration of EK in process 2 follows the typical project lifecycle (pre-design, design, construction and operation). This flow aligns with the conclusion drawn from respondents' answers to the critical phase for integrating EK to BI to improve decision-making (section 4.3.2). However, the process of capturing lessons learned from best practices and past mistakes, identified as the most required EK for BI (sections 4.2.1 and 4.3.1) follows a reverse order (operation, construction, design and pre-design phases). Figure 4. 3 shows the inverse relationship between the processes of capturing and integrating EK for improved decision-making throughout a project lifecycle.

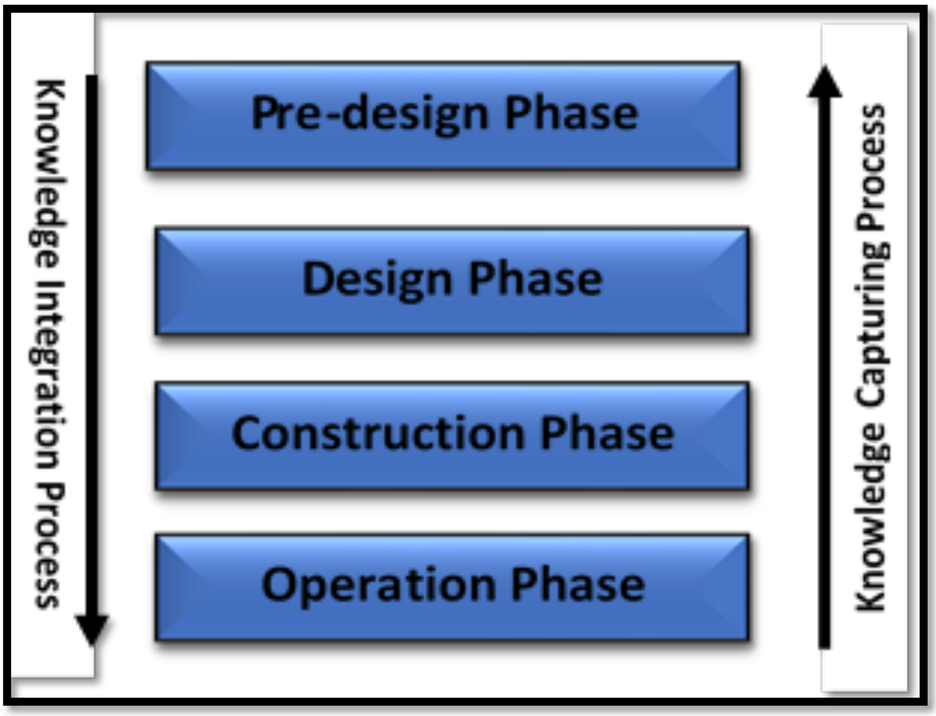


Figure 4. 3: Relationship between phases of project lifecycle and knowledge capturing and integration during decision-making processes

4.5 Chapter Summary

The purpose of this chapter is to partly provide answers to RQ1 by addressing the first research objective of this study using empirical data collected from both interviewees and questionnaire surveys. It concludes that EK for integration into BI can be identified and sourced from lessons learned from past mistakes, knowledge of best practices, and practical experience with BI and its related technologies and policies. The methods and tools for identifying people with this required knowledge in BI in the UK include certification/qualification, practical demonstration of BIM competencies, regular assessment, and questionnaire survey use. This conclusion aligns with the findings of Bigliardi et al. (2014) who identified similar tools within construction industry in Italy. While respondents expressed divergent views on the critical phase for integrating EK into decision-making in BI, it was deduced that the phases' criticality flows from pre-design through design and construction to operation phase.

Furthermore, the extent to which respondents find EK useful regarding BI tasks and activities at the pre-design phase was assessed. The analysis revealed that EK is regarded as very useful for establishing project scope and deliverables, determining BIM competencies of project teams, developing project goals and objectives, identifying client business case, and defining the role and responsibilities of stakeholders. Similarly, the chapter evaluated how important it is to capture and integrate EK relating to tasks and activities from other phases of the project life cycle to improve decision-making during BI. The result showed that it is very important to consider EK acquired from BIM tasks and activities at various project phases while implementing BIM. Doing this will ensure that informed decisions are made since the whole project lifecycle is considered right from the start.

The chapter ended by analysing how respondents consider EK from different phases of project lifecycle while engaging in decision-making activities regarding BI. The result revealed that EK from operation phase is "never considered" for any decision-making processes except while capturing lesson learned. The reason adduced for this was that most respondents had not implemented BIM projects up to the operational phase. The next chapter will complement the findings from this chapter by developing a KM process map for integrating EK into BI as well as identify the methods and tools to facilitate the integration.

CHAPTER 5: KNOWLEDGE MANAGEMENT PROCESS FOR INTEGRATION OF EK INTO BI

5.1 Introduction

The previous chapter explored the knowledge identification process by identifying the EK sources required for BI and investigated the decision-making processes for BI. The chapter also investigated the project phase that is most critical for the integration of EK to improve decision-making. In furtherance of these findings, this chapter presents the findings of the interviews and questionnaires about the remaining KM processes for integrating EK into BI. Appropriate KM methods and tools for the integration, based on the proposed KM processes identified in section 2.5.2 will be analysed. The KM methods and tools/techniques (see section 2.5.3) are meant to facilitate organisational KM processes and support the process of integrating knowledge into BI.

The chapter starts with the analyses and findings from the experts' interviews using NVivo. It presents the KM methods and tools for generating the required EK for integration into BI (section 5.2.1). After that, the analysis and findings on methods and tools for capturing the generated knowledge are documented (section 5.2.2). Sections 5.2.3presents the methods and tools used by interviewees for communicating the EK among their project team members. The methods and tools for applying EK were presented in section 5.2.4.

Section 5.3 presents the survey analysis results regarding the tools and techniques for capturing and integrating EK into BI. Section 5.4 presents a KM process map incorporating methods and tools suggested by the respondents in sections 5.2 and 5.3. The chapter ends by summarising the findings on the appropriate methods and tools for integrating EK into BI.

The chapter contributes to the central research question RQ1 – "in what ways can EK be integrated into BI for improved decision-making?". The integration requires a KM process supported by appropriate tools and techniques. Based on the adopted pragmatic paradigm, this chapter presents empirical data from the interviewees' lived experiences on tools and methods used for each of the processes. As early discussed in section 2.5.2, the proposed KM processes adopted for integrating EK into BI are knowledge identification, knowledge generation, knowledge capturing, knowledge communication, and knowledge application. Since knowledge identification process and its tools have been discussed already in the previous chapter (section 4.2.1; Table 4. 2), only details of the findings of the remaining processes are presented and discussed in the subsequent sections.

5.2 Findings from the Experts Interviews

5.2.1 KM Methods and Tools for Generating EK during BI

As discussed in section 2.5.2, knowledge generation refers to the process of creating new knowledge or acquiring existing knowledge to improve decision-making or solve existing problems within the organisation boundaries (Semertzaki, 2011). The idea is to generate a 'new knowledge' that can improve decision-making during BI. The KM methods and tools for generating EK supports the process of knowledge creation and acquisition to improve decision-making during BI. Based on their experiences with BI, interviewees were asked to identify the methods and tools they are using to generate EK required on BIM projects. The analysis of the experts' responses revealed five dominant codes: social media, technology, education and training, brainstorming and discussion, and collaboration. The coding scheme of the findings is presented in Table 5. 1, while Figure 5. 1 shows the screenshot of the analysis in NVivo.

Table 5. 1: Methods and Tools for Generating EK Required for BI

Theme	Codes	Sources	Examples of Quotations
Methods and tools for generating EK required for BI	Social media	BC1, BC4, BM9, IM2, IM4	*"when we think about decentralisation of organizations which still make up of your project team, we've got social media and various applications that can be used." BC1* *"And I guess finally it comes down to the kind of social media platforms like search, LinkedIn and Twitter is a big one as well." BC3*
	Technology	BC1, BD1, BD3, BD4, CR1, IM2, IM4,	*"I think a knowledge of technology and being competent when it comes to technology is another really important one, particularly for the construction sector" IM2*
	Education and Training	BC1, BM3, BM9, CE1, BM10, CE2, BM4, BM5, BC2, BD4, CR2, BM11, IM3, BM12	*"Generally speaking, the knowledge generation would be through, I will suggest two forms: it will be through education and training." BC1* *"they have to attend courses, webinars, and they have to do in-house training from, of course, the company has to provide these; otherwise, it is impossible" BM12*

	Brainstorming and Discussion	CR1, BM9, BC2, BD2, BD3,	*"I am going to prioritise these things. Open meeting first, brainstorming second, then the use of technology-related data storage like the common date environment, then collaborative cloud-based." CR1*
	Collaboration	BC3, BC4, BC5, BD1, BD2, BD3, BD4, BM1, BM2, BM5, BM11, IM1, IM12, CR1, CR2, CE1, IM2, IM5	*"I found collaborative agreements several successful. Really, in terms of collaboration, you got as much you can get out with. The whole point of collaboration is that it should be transparent." BM5* *"And if I could build a team in a collaborative way, where contractors will build a relationship with clients – early contractor engagement, and that we have to go up with the architectural team which you know can deliver." IM1*

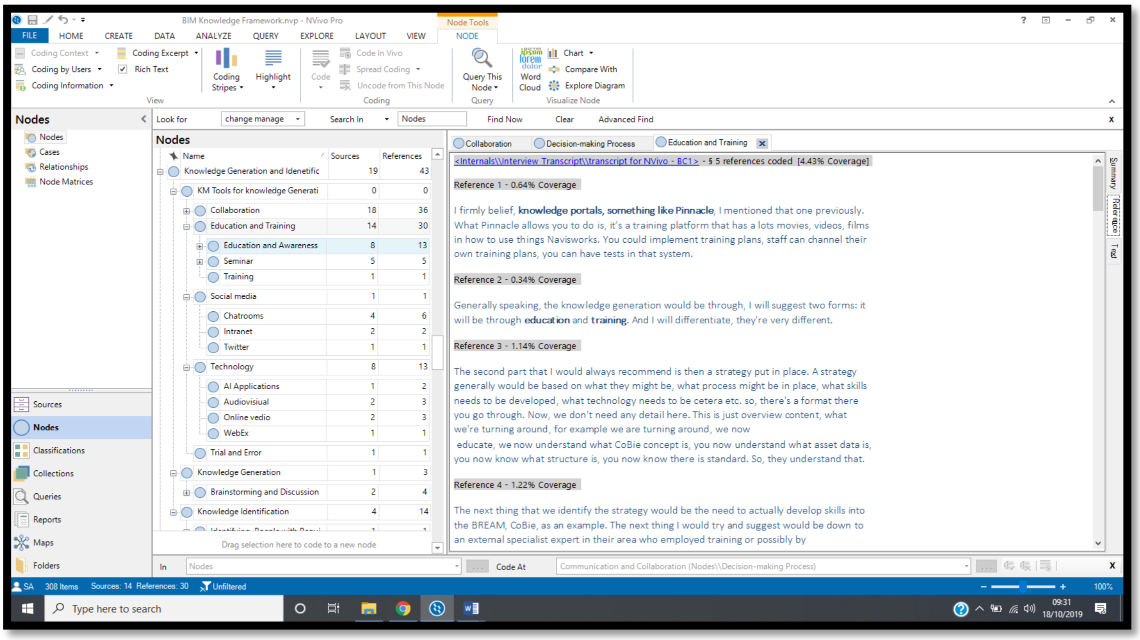


Figure 5. 1: Screenshot of NVivo of Methods and Tools for Generating EK required for BI

5.2.2 KM Methods and Tools for Capturing and Storing EK during BI

Knowledge codification involves the process of capturing and storing valuable experience-based knowledge for possible future reuse (section 2.5.2). Capturing knowledge, especially in the construction industry, where knowledge is usually tacit and experience-based knowledge, is very tedious and challenging. There is, therefore, the need to identify tools and methods that are commonly used for this process in BIM-enabled projects. Hence, the respondents were asked to identify the KM methods and tools commonly used on their organisations to capture and storing knowledge during BI. The responses from the interviews were coded under six major categories, as shown in Table 5. 2 and Figure 5. 2. These codes are BIM Execution Plan (BEP), conferences and seminars, informal face-to-face meetings, mentoring, multimedia platforms, and post-project evaluation meetings.

Table 5. 2: Methods and Tools for Capturing EK Required for BI

Theme	Codes	Sources	Examples of Quotations
Methods and tools for capturing EK required for BI	BIM Execution Plan	BC3, BC4, BD2, BD3, BM11, BM2, BM3, BM8, IM1, BC1, BC2, BD1, BD4, CE1	*"We capture that in the BIM execution plan actually. It is the only logical place to capture this because if don't separate BIM responsibilities in the main responsibility, …" BD2* *"That may change in time, but now you have to capture those responsibilities, you have to capture those authorities within the BIM execution plan." IM1*
	Conferences and seminars	BC2, BC3, BC4, BM10, IM3,	*"a lot of it the way we capture our experiences and share our experiences across the industry, within BIM technologies, we organise our own conference once a year in revenue moments every year in Newcastle." IM3*
	Informal face-to-face Meeting	BM6, BM8, BM9, IM4, IM5, BD1, BD3,	*"the mouth-to-mouth was very good. So, if I know something new or something positive, the first thing I do is, I sit down for 10 to 15 minutes with my colleagues, I explained to them the new discovery, and then they will remember." BM9*
	Mentoring	BC2, BC3, BC4, BM10, BM2, BM3, BM4, BM7, BM8, IM3, IM4, BD3	*"what we've been trying to do, we do again this mentoring system where you put the experienced person who has got like 20 years in the industry actually putting buildings together next to someone who is good with the software and they teach each other how to put building together." BM2* *"You need someone to work with experienced individuals, and hopefully you can capture as much as you can before they retire and just hope for the best." BM8*
	Multi-media Platforms	BC1, BD1, BC2, BC3, BM10	*"because people actually learn and want to actually understand in different ways and formats. Many prefer multimedia formats these days." BC1* *"And I guess finally it comes down to the kind of social media platforms like search, LinkedIn and Twitter is a big one as well." BC3*
	Post-project Evaluation	BD1, BD2, BM4, BM8, CE1, CR1, CR2, IM3	*"what tends to happen is you'll do a post-project review and that document, so, we'll have a detailed review done on the project that identifies what went right, what went wrong, and we would retain that information/experience." CR2*

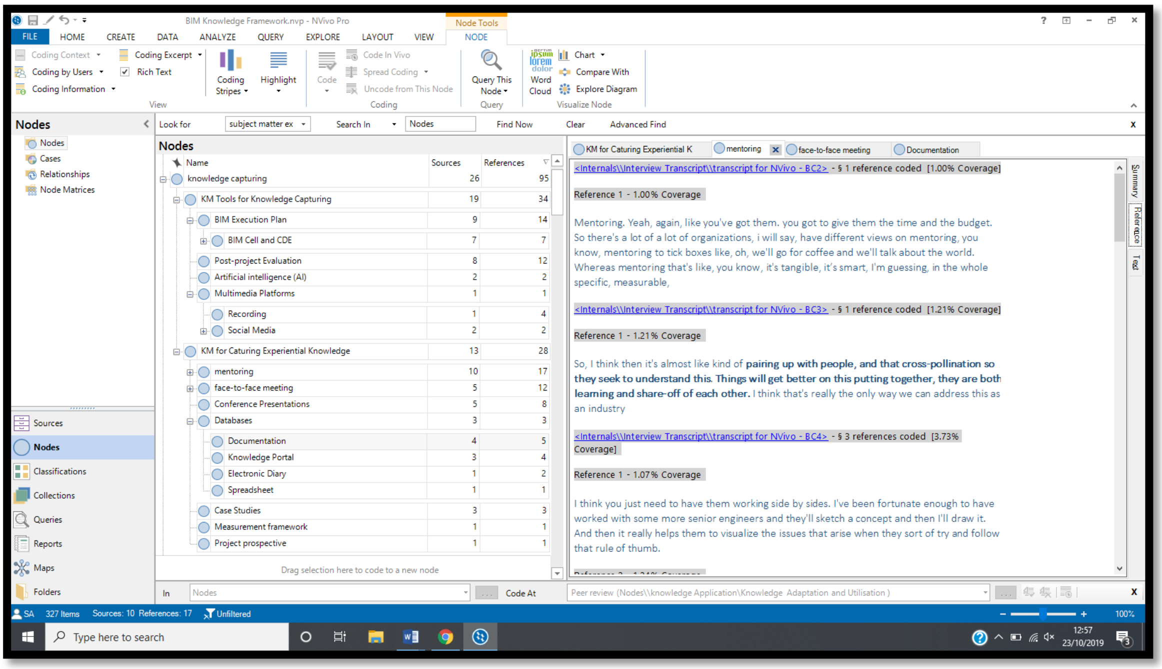


Figure 5. 2: Screenshot of NVivo of Methods and Tools for Capturing EK required for BI

5.2.3 KM Methods and Tools for Communicating EK during BI

The process of exchanging knowledge between two or more people is referred to as knowledge communication. As argued in section 2.5.2, it can be broadly divided into two: knowledge sharing and knowledge transfer. Accordingly, respondents were asked to identify the methods and tools they use for sharing and transferring knowledge on BIM-enabled projects within their firms. As shown in Table 5. 3, the methods and tools for knowledge sharing are broadly categorised into components: technology (IT-based) and non-technology. The technology component includes the use of Common Data Environment (CDE), computer network (e.g., internets and intranets), knowledge portals, organisation networking platforms (e.g. Yammer). The methods and tools for transferring knowledge were coded under headings: job rotation, mentoring program, shadowing, training program, and written documents.

Table 5. 3: Methods and Tools for Communicating EK Required for BI

Theme	Codes	Sources	Examples of Quotations
Methods and tools for communicating EK required for BI	**Knowledge Sharing**		
	Technology Components (e. g. Common Data Environment, Computer network, Knowledge portals, Organisational networking platform)	IM1, IM2, IM4, IM5, BC1, BC2, BC4, BC5, BD1, BD2, BD3, BD4, BM6, BM8,	*"You will agree with me that knowledge sharing has two components; there is a technological component; there is also a cultural component." IM5* *"the only way I see about sharing knowledge sensibly,*

		BM9, CR1, CR2, CE2,	*Ok, would be through a knowledge solution system to actually share that knowledge." BC1*
	Non-Technology Components (e. g. Formal recording, Community of Practice, Mentoring, Open plan studio, Team meeting, Visibility of knowledge experts, Workshops and Seminar)	IM4, IM5, BC1, BC2, BC3, BD4, BD2, CR1, BC1, BC4, BD2, BD3, CR1, BC2, BC4, BC3, BD4, BM2,	*"But for me, communities of practice are key factor to know the experts, to learn from the experts. And yes, each one, there is a personal knowledge mastery." IM5* *"Project scrum boards, weekly stand-ups, an open plan studio and a commitment to learning allows us to identify knowledge gaps, ... and how best to share that knowledge across the studio." BD2*
	Knowledge Transfer		
	Job rotation	BC1, BC2, BM4	*"knowledge is transferred normally only when individuals transfer from projects rather than actual formalized systems in terms of taking what worked well on." BC2*
	Mentoring program	BM8, BM9	*"And the best way, for me, is to sit in a one-to-one face with somebody, and then transfer the knowledge to someone else." BM9*
	Shadowing	BC4, 1M2, BC1	*"You can shadow people and follow them around, so you're able to transfer those skill sets to the younger people from the older, those who have more experience." IM2*
	Training Program	BM4, BM9, BM7	*"What we do as many businesses do is, we have a graduate training program." BM4*
	Written document	BM4	*"The other way we can transfer knowledge as well is; you could write documentation. So again, another thing that you could do is; you could write course notes…" BM4*

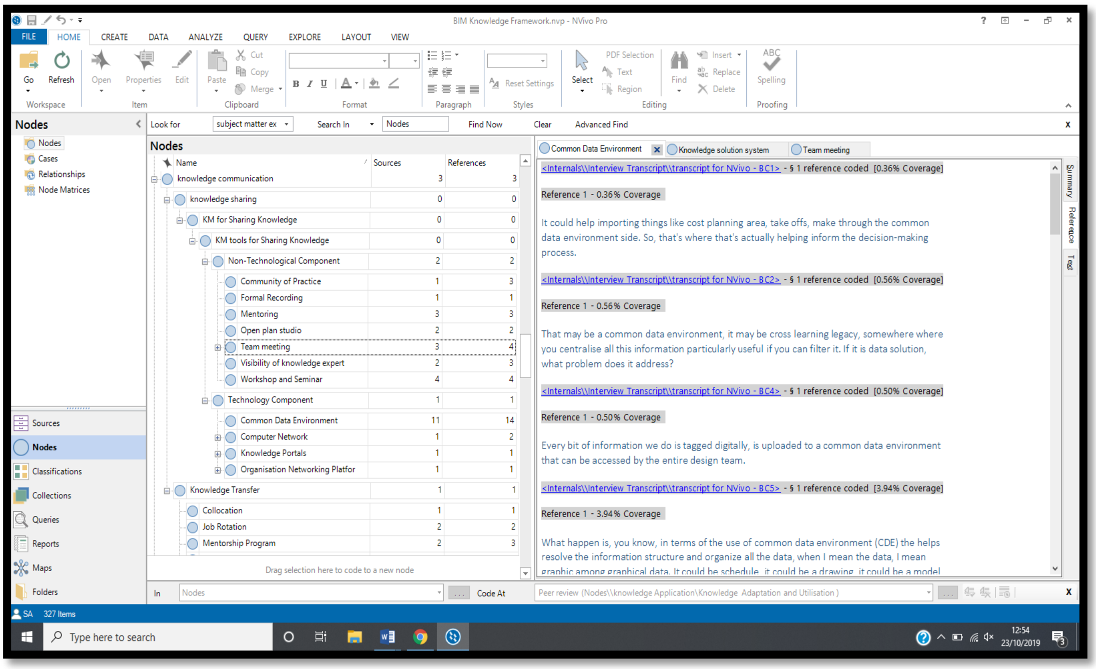


Figure 5. 3: Screenshot of NVivo of Methods and Tools for Communicating EK required for BI

5.2.4 KM Methods and Tools for Applying EK during BI

The communicated knowledge must be correctly applied, to complete the process of knowledge integration, through proper adaptation and utilisation of the knowledge within the organisation. The essence is to ensure that only relevant and useful knowledge is reused to inform decisions during BI. The identified methods and tools from the respondents for this process were coded under five headings: continuity, embedded process, quality assurance check, online assessment, panel review and personal feedback as shown in Table 5. 4.

Table 5. 4: Methods and Tools for Applying EK Required for BI

Theme	Codes	Sources	Examples of Quotations
Methods and tools for applying EK required for BI	Continuity	CR1, IM1, IM4	*"the continuity base is, when people work on a project, you need to keep the teams to work on subsequent projects. So, they carry the knowledge from this project onto the new project." CR1*
	Lessons learned report	BM2, CR1, IM4	*"I would say the main platform for us is continuous lessons learned platforms and quality assurance checks." BM2*
	Online Assessment	BM2, BM3, BM4, BM6	*"you can access web-based quizzes or questionnaires of checking sides on something which is basically assessments, online assessment, which is in term of BIM." BM6*
	Subject matter expert	BD1, BD2, BM2, BD1,	*"We have a committee of subject matter experts who review any idea or any*

		BD2, BM2, BM6, IM4	*proposal before anything is standardized." BD1*
	Personal Feedback	BC1, BM6, IM4	*"in my previous place, it was basically every year each employee was expected to provide some kind of personal feedback on things related not particularly with the job they worked on..." BM6*

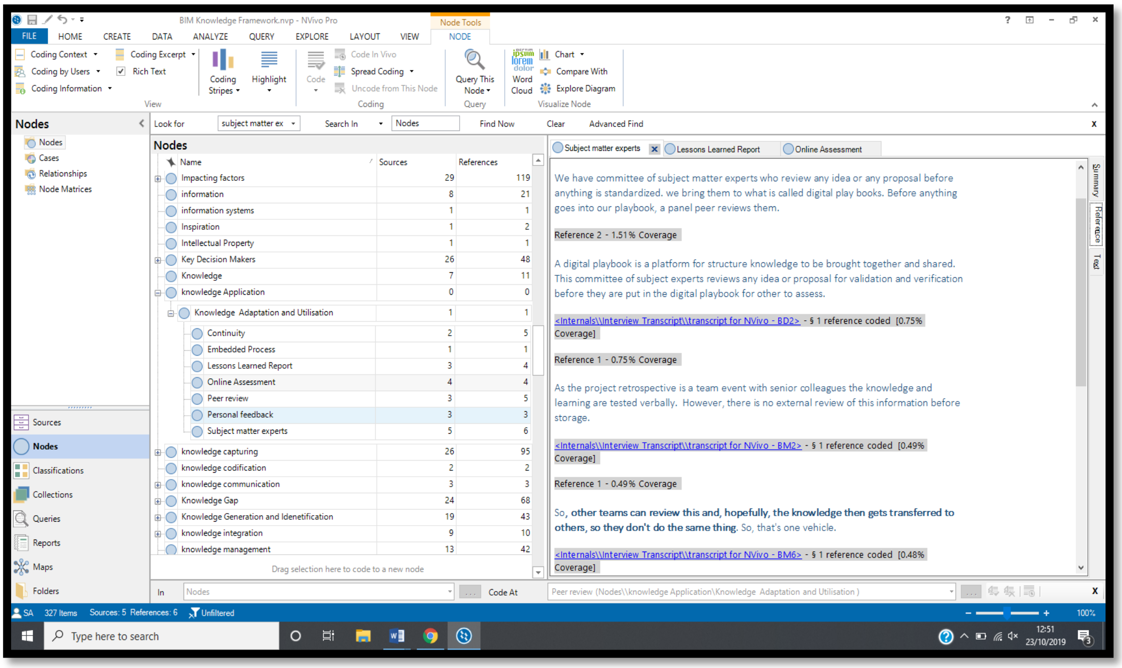


Figure 5. 4: Screenshot of NVivo of Methods and Tools for Applying EK required for BI

5.3 Findings from the Questionnaire Survey

In line with the mixed method research adopted for the study in section 3. 4, a list of KM tools and techniques was extracted from the review of the extant literature (section 2.5.3). In all, fifteen (15) tools and techniques that were considered suitable for knowledge integration in the literature were compiled into a list as shown in Table 2. 9. The list was turned into a survey questionnaire, and BIM experts from the construction industry were asked to indicate how effective they find the tools in capturing and integrating EK related to BI. This section presents the analysis of the survey questionnaire, using SPSS 21.

5.3.1 KM Tools and Techniques for Capturing and Integrating EK into BI

Statistical analyses, using SPSS, were carried out to determine the most effective KM tools and techniques for capturing and integrating experimental knowledge into BI. The result of the analyses (Table 5. 6) shows that the difference between the highest and the lowest mean values (3.38 and 2.07) is high. This requires that further test must be conducted to unravel the cause. Accordingly, Cronbach's Alpha was carried out to identify variables that are not contributing to the overall consistency. The mean values indicate that all the factors are moderately effective with a minimum value of 2.07 on a 4-points Likert scale. However, five of the factors were ranked highly effective for capturing EK for integration into BI. They are as listed below:

TT4 Mentoring/Apprenticeship/Training on BIM

TT15 Post Project Evaluation of BIM-enabled Project

TT3 Job Rotation/Experience Swapping/Secondment of BIM Experts

TT2 Conferences and Seminars on BIM

TT5 Collaborative Workspace containing BIM Experts.

Table 5. 6 presents a detailed statistical analysis of KM tools and techniques for capturing and integrating EK, including the mean value, standard deviation, mean ranking, Cronbach Alpha, and Kruskal-Wallis. Analysis of the result shows that there are statistically significant variations in the opinion of the respondents regarding communities of practice and social networking as tools for capturing and integrating EK.

The overall Cronbach's alpha coefficient for all the factors was 0.805. Besides, the 'Cronbach's alpha if item deleted' was computed, and the results suggested that two items have their Cronbach's alpha value greater than the overall value. These items are TT4 and TT5 with 'Cronbach's alpha if item deleted' of 0.806 and 0.809, respectively (see the sixth column of Table 5. 6). However, further analysis showed that the difference in the overall Cronbach alpha coefficient and the 'Cronbach's alpha if item deleted' for item TT4 is very insignificant (0.001); hence the item was retained. This position is further strengthened by the result of the interview, which revealed that mentoring is one of the major tools and techniques for capturing and integrating EK required for BI. Item TT5 was, however, removed from further analysis. After removing the item, the overall Cronbach's alpha coefficient moved from 0.805 to 0.809, which indicates a good internal consistency of the scale, as shown in Table 5. 5. The revised ranking of the remaining variables is as shown in Table 5. 7.

Table 5. 5: Reliability Statistics: Tools and Techniques for Capturing and Integrating EK

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	No of Items
.805	.802	15

Reliability Statistics: Revised Cronbach Alpha for Tools and Techniques

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	No of Items
.809	.804	14

Kruskal-Wallis test was conducted to determine if there is any statistically significant difference in the pattern of response along organisation size and years of experience. The results of the analysis revealed that there is a statistically significant difference in the pattern of response along years of experience regarding item TT1 - Communities of Practice. Similarly, item TT12 indicated a significant difference in respondents' answers regarding organisation size.

Table 5. 6: Descriptive and Non-Parametric Analysis of Tools and Techniques for Capturing and Integrating EK

Label	KM Tools and Techniques	Mean	SD	Rank	Cronb. Alpha if Item Deleted	Overall Cronb. Alpha	Kruskal-Wallis Coef. (Org. Size)	Kruskal-Wallis Coef. (Year Exp.)
TT1	Communities of Practice (e.g. BIM Hub)	2.92	.772	7	.794	0.805	0.64	**0.024****
TT2	Conferences and Seminars on BIM	3.12	.851	4	.790		0.41	0.055
TT3	Job Rotation/Experience Swapping/Secondment of BIM Experts	3.24	.853	3	.802		0.68	0.120
TT4	**Mentoring/Apprenticeship/Training on BIM*	*3.38*	*.656*	*1*	.806		*0.486*	*0.768*
TT5	**Collaborative Workspace containing BIM Experts*	*3.02*	*.859*	*5*	.809		*0.424*	*0.721*
TT6	Brainstorming/Group Discussion regarding BIM	2.93	.792	6	.795		0.215	0.906
TT7	Storytelling/Oral Narrations about BIM Projects	2.63	.860	10	.788		0.315	0.655
TT8	Intranet/Internet/Website on BIM-enabled Projects (e.g. IMRB)	2.37	.848	14	.796		0.484	0.124
TT9	Video Conferencing/Audio Conferencing among BIM Experts	2.45	.774	13	.794		0.553	0.811
TT10	Expertise Locators of BIM Experts (e.g. Yellow pages)	2.07	.906	15	.790		0.203	0.454
TT11	Electronic Chatroom for BIM Expert (e.g. Yammer)	2.45	.880	12	.785		0.375	0.345
TT12	Social Networking Tools for BIM Experts (e.g. LinkedIn)	2.55	.974	11	.783		**0.045*****	0.058
TT13	Interviews of BIM Experts	2.90	.887	8	.789		0.216	0.339
TT14	Questionnaire Surveys of BIM Experts	2.75	.867	9	.794		0.329	0.415
TT15	Post Project Evaluation of BIM-enabled Project	3.29	.832	2	.790		0.389	0.230

Note to Table: *denotes factors that have 'Cronbach's Alpha if item deleted' above the group's Cronbach's Alpha, which suggest that the factor should be removed to enhance the group's reliability.

**denotes factors that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their years of experience.

***denotes factors that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factor differ based on their organisation size

Table 5. 7: Revised Ranked Tools and Techniques for Capturing and Integrating EK into BI

Label	Variables	Mean	Rank
TT4	Mentoring/Apprenticeship/Training on BIM	3.38	1
TT15	Post Project Evaluation of BIM-enabled Project	3.27	2
TT3	Job Rotation/Experience Swapping/Secondment of BIM Experts	3.24	3
TT2	Conferences and Seminars on BIM	3.12	4
TT1	Communities of Practice (e.g. BIM Hub)	2.93	5
TT6	Brainstorming/Group Discussion regarding BIM	2.93	6
TT13	Interviews of BIM Experts	2.91	7
TT14	Questionnaire Surveys of BIM Experts	2.75	8
TT7	Storytelling/Oral Narrations about BIM Projects	2.64	9
TT12	Social Networking Tools for BIM Experts (e.g. LinkedIn)	2.56	10
TT11	Electronic Chatroom for BIM Expert (e.g. Yammer)	2.47	11
TT9	Video Conferencing/Audio Conferencing among BIM Experts	2.44	12
TT8	Intranet/Internet/Website on BIM-enabled Projects (e.g. IMRB)	2.37	13
TT10	Expertise Locators of BIM Experts (e.g. Yellow pages)	2.07	14

5.4 KM Process Map

The essence of this chapter is to map out a KMP that could enhance the integration of EK into BI for decision-making. This section presents the KMP map and KMP cycle for the integration along with tools and techniques for each of the process, as shown in Figure 5. 5 and Figure 5. 6, respectively. To improve decision-making in BI, the process starts by identifying EK required for integration into BI to improve decision-making and those with the required knowledge. Analysis of findings from the study (see sections 4.2.1 and 4.3.1) revealed that the most important sources of EK required for integration are knowledge of best practices and lesson learned from past mistakes. The tools and methods for identifying those with the required knowledge include certification/qualification, questionnaire, CV, among others (see section 4.2.2). The required EK can be created from within or acquired from outside the organisation using appropriate KM tools and methods such as brainstorming and discussion, collaboration, education and training.

The next process is to capture the generated EK for future use and reuse. Knowledge capturing is a complex process and very challenging. During BI, EK can be captured using appropriate tools and techniques such as mentoring, post-project evaluation, face-to-face meeting, use of BIM Execution Plan. The captured knowledge is then communicated among the stakeholders through knowledge sharing or knowledge transfer across the teams. EK is usually communication at BIM workshops and seminars, Communities of Practice meetings, during project meetings, or through mentoring, job rotation and training programmes. The use of Common Data Environment, knowledge portals, intranet and internet, are other methods of communicating EK. The essence of communicating knowledge is to make it readily available to those who may need to apply it to improve decision-making.

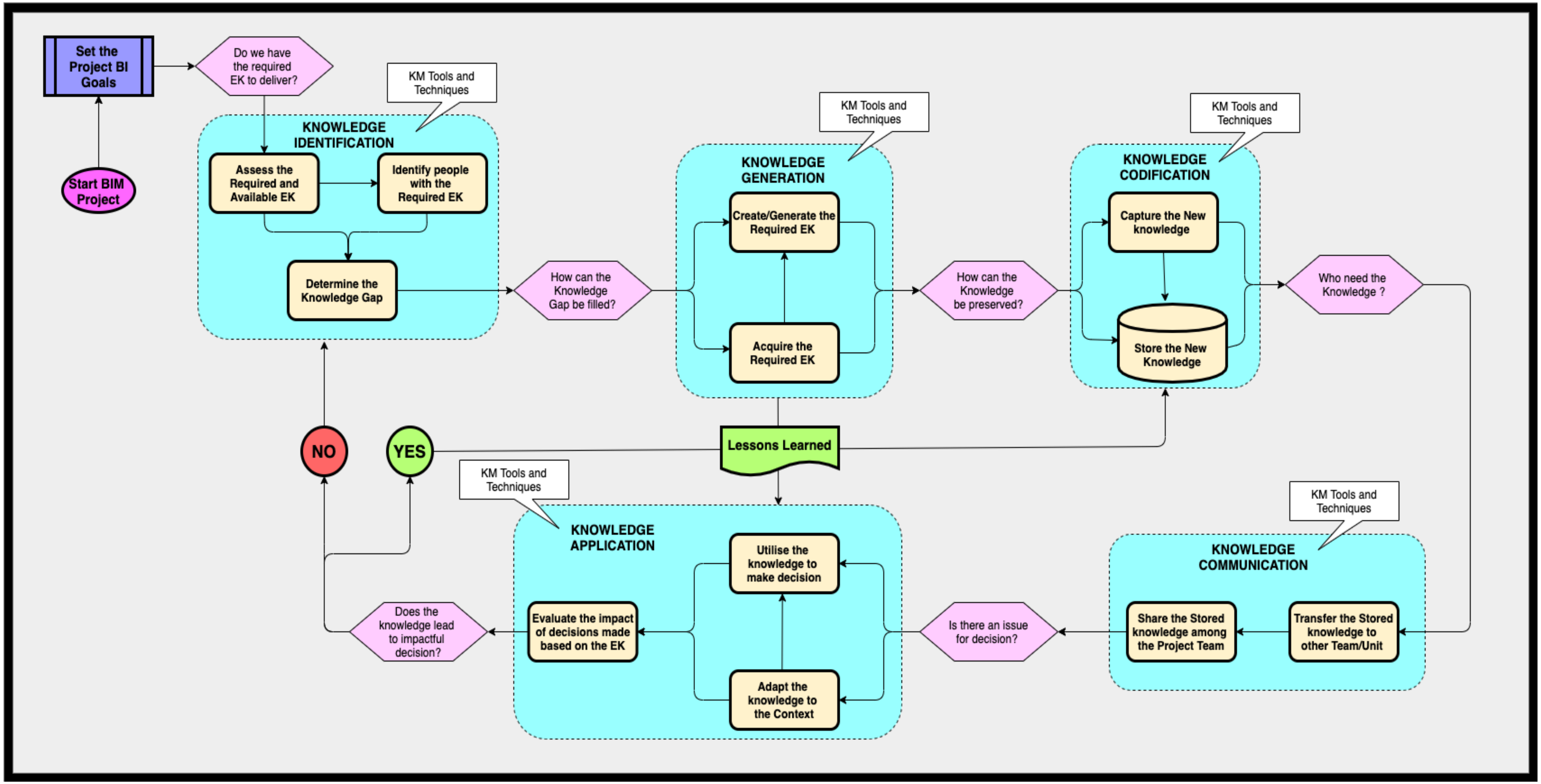


Figure 5. 5: KMP Map for Integrating EK into BI

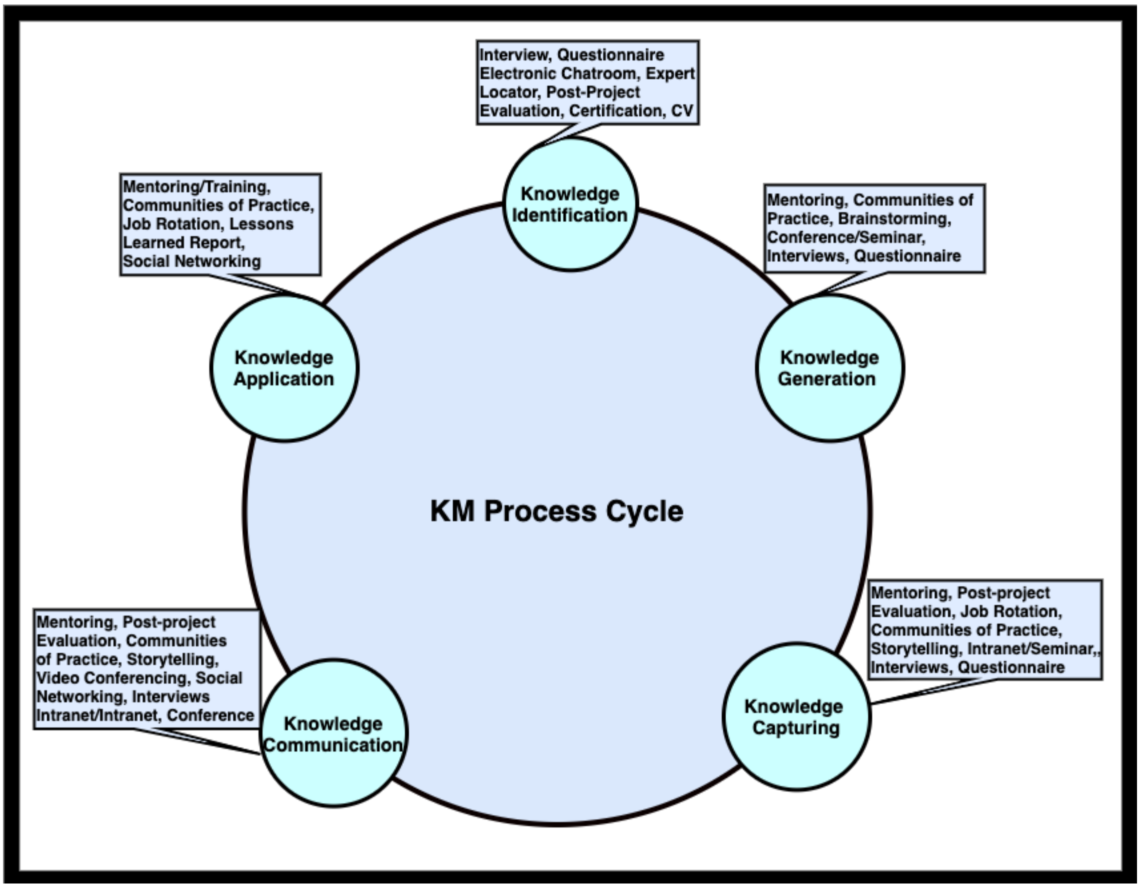


Figure 5. 6: KMP Cycle for integrating EK into BI.

The knowledge will then be reviewed and evaluated for adaptation and application using appropriate KM tools and methods. Such tools and techniques include subject matter experts, quality assurance check, personal feedback, online assessment. In order to improve decision-making, the communicated knowledge could be adapted and applied (used and reused) in different contexts, forming a basis for constructive feedback to identifying new EK required for BI. These KM processes need to be performed in a cycle to enable continuous improvement in decision-making while implementing BIM-enabled projects.

5.5 Chapter Summary

This chapter builds on findings from the previous chapter by mapping out the KM process for integrating EK into BI to provide a comprehensive answer to the first research question. The proposed KM map has five basic cyclical processes and appropriate KM methods and tools, as shown in Figure 5. 5 and Figure 5. 6. The KM process map depicts a continuous process that involves continuously capturing and integrating experience-based knowledge into BI for improved decision-making. Selection of appropriate KM methods and tools for each of the process is critically important to successful integration.

Apart from selecting appropriate KM methods and tools, some other factors can impact EK's successful integration into BI. These factors can either facilitate or inhibit the integration process's effectiveness by serving as either drivers or barriers. The next chapter shall be dedicated to identifying those factors and the extent of their impacts to ensure a smooth and effective integration.

CHAPTER 6: FACTORS IMPACTING ON EFFECTIVE INTEGRATION OF EK INTO BI

6.1 Introduction

Apart from mapping out a KM process for integrating EK into BI, some factors can influence the effectiveness of that integration. Effectiveness refers to the ability or power to making the integration successful or to achieve the desired outcome. A factor is a circumstance or fact that contributes to the result or outcome of something. The contribution can either be positive or negative. When a factor positively contributes to the outcome of somethings, it is referred to as a driver. Whereas, when it negatively influences the outcome, it is called a barrier or inhibitor. This chapter, therefore, seeks to provide an answer to the second research question (RQ2) – *"What factors impact on the effective integration of EK into BI for improved decision-making in building construction projects?"* Answering the RQ2 fulfils the fourth research objective of the study – *"to investigate factors that can impact on the effective integration of EK into BI for improved decision-making"*.

As stated in chapter 3, quantitative and qualitative methods were employed to collect and analyse data regarding the impacting factors. However, the weight is more on the quantitative method than the qualitative (QAUN + qual). Accordingly, the questionnaire survey findings were first presented in section 6.2, followed by the analysis of the semi-structured interviews in section 6.3. An in-depth discussion of the findings is presented in section 6.4. The chapter concludes by highlighting the key findings from the analyses of both quantitative and qualitative data in section 6.5.

6.2 Finding from the Questionnaire Survey

This section presents the results from the questionnaire survey administered on BIM experts within the UK construction industry, seeking their opinion on the factors impacting on the effective integration of EK into BI for improving decision-making.

6.2.1 Factor Impacting on Effective Integration of EK into BI

Twenty-six factors were extracted from the review of the extant literature (see section 2.5.4) and group into three: individual-related factors, team-related factors, and organisation-related factors. Respondents were asked to indicate the extent to which they find the listed factors impactful while integrating EK into BI. As discussed in section

3.7.3.2, respondents were asked to indicate their opinions on a 4-Likert scale ranging from 1 = not impactful to 4 = highly impactful.

Statistical analyses were carried out to determine factors which are most impactful on the effective integration of EK into BI. The analyses included mean ranking, standard deviation, Cronbach alpha and Kruskal-Wallis coefficient of the listed factors. Mean values could help identify factors that may be considered for potential removal. The mean values of all the items should be reasonably close together if they are all tapping into the same concept (Field, 2005). Any item with mean value that is too high or too low may be tagged an outlier, and potentially marked for removal. The descriptive statistical analysis of the factors, on 4-point Likert scale, shows that two factors (IF17 and IF19) have mean values greater than 3.5 while only one of the factors (IF23) has a mean value less than 3.0. The difference in the mean values of the highest and lowest factors (0.60) is not significant enough to warrant flagging any factor for removal. However, Cronbach's alpha test was conducted to determine the internal consistency and reliability of the factors further.

Table 6. 1 presents the results of descriptive and non-parametric analyses of the impacting factors. A reliability test for the 26 factors impacting on the effective integration of EK into BI was conducted within the three groups and overall, as shown in columns 6 and 8 of Table 6. 1. The overall Cronbach's alpha test returned a score of 0.846, which suggest high internal consistency and a reliable questionnaire. However, the Cronbach's alpha coefficients for the three groups are 0.563, 0.760 and 0.617. To increase the internal consistency of the variables within the groups, the 'Cronbach's alpha if item deleted' of each variable was computed and compared with the groups' Cronbach's alpha value, as presented in columns 4 and 6, respectively. The results of the analyses show that one item from each group do not contribute to the internal consistency of their group and should be removed accordingly. The 'Cronbach's alpha if item deleted' of each of the three factors was higher than their group's Cronbach's alpha value, and subsequently removed from further analyses.

After removing the three factors (IF8, IF18 and IF25), the same test was repeated to determine the effects of their removal on the internal consistency and reliability of the variables. Table 6. 2 presents the results of the new tests after deleting the redundant factors. Analyses of the results revealed an increase in the values of the Cronbach's alpha coefficient for each factor, the groups' values as well as the overall value as shown in columns 4, 6 and 8, respectively, indicating an increase in the reliability of the factors.

The overall Cronbach's alpha value rose from 0.846 to 0.861, while the groups' values rose from 0.563, 0.760 and 0.617 to 0.631, 0.768 and 0.654, respectively. All the values showed that there is good internal consistency among the variables measured within the groups, as discussed in subsection 3.7.3.8.

Analysis of the mean values revealed that all the factors, but one (IF23 – Organisational reward systems), were ranked highly impactful by respondents, as shown in the third column of Table 6. 2. Columns 5 and 7 the table presents the group ranking and overall ranking of the factors based on the mean value. The overall five highest-ranked factors (column 7) impacting on the effective integration of EK into BI are:

1. Level of trust among individuals involved in integrating EK
2. Level of face-to-face interaction among individual colleagues
3. Organisation's leadership support for, and commitment to activities relating to the integration of EK
4. Level of involvement and participation of individuals in decision-making
5. Open and collaborative discussions among project team members.

Though the five highest-ranked factors within each of the groups are listed below, however, only factors with the minimum mean values of 3.40 were selected for discussion in section 6.4. The highest-ranked factors (column 5, Table 6. 2) within the groups are:

Individual-related Group:

1. Level of trust among individuals involved in integrating EK
2. Level of involvement and participation of individuals in decision-making
3. Level of face-to-face interaction among individual colleagues
4. Effective and honest communication among individual colleagues
5. Willingness and ability of individuals to freely share EK.

Project Team-related Group:

1. Open and collaborative discussions among project team members
2. A knowledge-oriented culture among the project teams that encourages creative and innovative ideas
3. Project team motivation, and presence of motivational aids

4. Well defined KM processes for integrating EK among the project team
5. Level of commitment to knowledge integration activities among the project team.

Organisational-related Group:

1. Organisation's leadership support for, and commitment to activities relating to the integration of EK
2. Organisational transparency and openness
3. Organisational culture that encourages activities relating to the integration of EK
4. Organisational infrastructural systems that support the integration of EK.

Kruskal-Wallis test was carried to determine if there are statistically significant differences in the pattern of responses within the organisational size and years of experience of the respondents. The results of the Kruskal-Wallis test in columns 9 and 10 of Table 6. 2 shows that there is no significant difference in the opinion of the respondents regarding the job title. However, items IF17 and IF7 indicate slight significant differences along organisational size and years of experience, respectively. This disparity in the opinion of the respondents regarding these two factors is not considered strong enough to affect findings of the analysis adversely.

Table 6. 1: Descriptive and Non-Parametric Analyses of Factors Impacting EK into BI

Label	Factors Impacting EK Integration into BI	Mean	Cronb. Alpha if item deleted	Group Ranking	Group Cronb. Alpha	Overall Ranking	Overall Cronb. Alpha	Kruskal-Wallis Co. (Org. Size)	Kruskal-Wallis Co. (Year Exp.)
Individual-related Factors							.853		
IF1	Level of face-to-face interaction among individual colleagues	3.47	.511	3	.563	4		0.319	0.445
IF2	Willingness and ability of individuals to freely share EK	3.37	.550	5		14		0.997	0.416
IF3	Level of involvement and participation of individuals in decision-making	3.49	.488	2		3		0.405	0.921
IF4	Rewards and incentives for individuals involved in integrating EK	3.05	.530	8		25		0.167	0.481
IF5	Effective and honest communication among individual colleagues	3.44	.495	4		6		0.647	0.781
IF6	Level of training, education and apprenticeship available to individuals	3.36	.522	6		16		0.622	0.170
IF7	Level of trust among individuals involved in integrating EK	3.54	.490	1		1		0.323	**0.031****
IF8	**Individual's level of creativity*	*3.22*	*.632*	*7*		*22*		*0.105*	*0.320*
Team-related Factors									
IF9	Open and collaborative discussions among project team members	3.46	.738	1	.760	5		0.485	0.908
IF10	Availability of adequate time for activities to integrate EK among project team	3.31	.741	7		17		0.233	0.422
IF11	A knowledge-oriented culture among the project teams that encourages creative and innovative ideas	3.42	.737	2		9		0.532	0.663
IF12	Availability of appropriate KM tools for integrating EK among project team	3.27	.728	8		20		0.859	0.293
IF13	Early composition of project team members and their continuity on the project	3.38	.714	6		13		0.906	0.332

IF14	Well defined KM processes for integrating EK among the project team	3.40	.741	4		11		0.123	0.666
IF15	Level of commitment to knowledge integration activities among the project team.	3.40	.726	4		11		0.558	0.431
IF16	Level of mutual understanding and trust among project team	3.26	.750	9		21		0.870	0.435
IF17	Project team motivation, and presence of motivational aids	3.41	.758	3		10		**0.047*****	0.942
IF18	**Level of complexity of the projects*	*3.14*	*.768*	*10*		*23*		*0.108*	*0.538*
Organisational-related Factors									
IF19	Organisation’s leadership support for, and commitment to activities relating to the integration of EK	3.51	.597	1	.617	2		0.103	0.242
IF20	Organisational culture (beliefs and values) that encourages activities relating to the integration of EK (e.g. experimentation)	3.44	.564	2		6		0.311	0.949
IF21	Organisation’s efficiency at leveraging EK to improve decision-making	3.29	.579	6		19		0.508	0.614
IF22	Flexible organisational structure that encourages activities for integrating EK through lateral communication	3.31	.558	5		18		0.686	0.715
IF23	Organisational reward systems that incentivise activities for integrating EK	2.94	.569	8		26		0.829	0.283
IF24	Organisational infrastructural systems that support the integration of EK (e.g. open workspace)	3.36	.565	4		15		0.403	0.582
IF25	**The size of the organisation (e.g. small, medium or large)*	*3.05*	*.654*	*7*		*24*		*0.970*	*0.675*
IF26	Organisational transparency and openness	3.44	.589	2		6		0.378	0.120

Note to Table: *denotes factors that have ‘Cronbach’s Alpha if item deleted’ above the group’s Cronbach’s Alpha, which suggest that the factor should be removed to enhance the group’s reliability.

**denotes factors that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents’ opinion regarding the factors differ based on their years of experience.

***denotes factors that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their organisation size.

Table 6. 2: Descriptive and Non-Parametric Analysis of Factors Impacting EK into BI after removing redundant factors

Label	Factors Impacting EK Integration into BI	Mean	Cronb. Alpha if item deleted	Group Ranking	Group Cronb. Alpha	Overall Ranking	Overall Cronb. Alpha	Kruskal-Wallis Coef. (Org. Size)	Kruskal-Wallis Coef. (Year Exp.)
Individual-related Factors							.861		
IF1	Level of face-to-face interaction among individual colleagues	3.53	.607	2	.631	2		0.319	0.445
IF2	Willingness and ability of individuals to freely share EK	3.37	.614	5		14		0.997	0.416
IF3	Level of involvement and participation of individuals in decision-making	3.48	.557	3		4		0.405	0.921
IF4	Rewards and incentives for individuals involved in integrating EK	3.03	.624	7		22		0.167	0.481
IF5	Effective and honest communication among individual colleagues	3.44	.555	4		6		0.647	0.781
IF6	Level of training, education and apprenticeship available to individuals	3.35	.601	6		16		0.622	0.170
IF7	Level of trust among individuals involved in integrating EK	3.55	.597	1		1		0.323	**0.031****
Team-related Factors									
IF9	Open and collaborative discussions among project team members	3.46	.745	1	.768	5		0.485	0.908
IF10	Availability of adequate time for activities to integrate EK among project team	3.31	.748	7		18		0.233	0.422
IF11	A knowledge-oriented culture among the project teams that encourages creative and innovative ideas	3.42	.745	2		9		0.532	0.663
IF12	Availability of appropriate KM tools for integrating EK among project team	3.28	.738	8		20		0.859	0.293

IF13	Early composition of project team members and their continuity on the project	3.39	.7`32	6		13		0.906	0.332
IF14	Well defined KM processes for integrating EK among the project team	3.42	.753	2		9		0.123	0.666
IF15	Level of commitment to knowledge integration activities among the project team.	3.40	.729	4		11		0.558	0.431
IF16	Level of mutual understanding and trust among project team	3.28	.748	8		20		0.870	0.435
IF17	Project team motivation, and presence of motivational aids	3.40	.777	4		11		**0.047*****	0.942
Organisational-related Factors									
IF19	Organisation's leadership support for, and commitment to activities relating to the integration of EK	3.52	.623	1		3		0.103	0.242
IF20	Organisational culture (beliefs and values) that encourages activities relating to the integration of EK (e.g. experimentation)	3.43	.580	3		8		0.311	0.949
IF21	Organisation's efficiency at leveraging EK to improve decision-making	3.30	.611	6	.654	19		0.508	0.614
IF22	Flexible organisational structure that encourages activities for integrating EK through lateral communication	3.32	.595	5		17		0.686	0.715
IF23	Organisational reward systems that incentivise activities for integrating EK	2.94	.629	7		23		0.829	0.283
IF24	Organisational infrastructural systems that support the integration of EK (e.g. open workspace)	3.36	.609	4		15		0.403	0.582
IF26	Organisational transparency and openness	3.44	.667	2		6		0.378	0.120

Note to Table: *denotes factors that have 'Cronbach's Alpha if item deleted' above the group's Cronbach's Alpha, which suggest that the factor should be removed to enhance the group's reliability.
**denotes factors that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their years of experience.

***denotes factors that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their organisation size.

6.3 Findings from the Interviews

This section presents the findings of the interviews conducted with stakeholders on the factors impacting on the effective integration of EK into BI. During the interview, participants were asked to identify factors that can positively and/or negatively influence the integration process of EK into BI for improved decision-making in building construction project. The parent theme for this chapter (factors impacting on the effective integration of EK into BI) has two sub-themes: the enabling factors (drivers) and the inhibiting factors (barriers). Table 6. 3 highlights the summary of the coding scheme for the factors impacting on the integration process. The analysis of the responses from the interviews regarding the driving factors fall under ten emergent codes while that of the barriers reveals nine code as shown in Table 6. 4 and Table 6. 5, presented in Figure 6. 1 and Figure 6. 2.

Table 6. 3: Summary of the Coding Scheme for the Impacting Factors.

Parent Theme	Sub-Theme	No. of Sources	No. of Codes	No. of Reference
Impacting factors for integration	Enabling factors	30	11	81
	Inhibiting factors	30	9	66

Table 6. 4: Factors Impacting on Effective Integration of EK into BI

Theme	Codes	Sources	Examples of Quotations
Enabling Factors (Drivers)	Culture of sharing best practice	BC3, BC5, BD1, BD3, BD2, BM1, BM2, BM4, BM6, BM9, BM10, CE1, CR1, CR2, IM2, IM3, IM4, IM5	*"I believe that a culture of best practice and continuous improvement within an organisation is considerably more important than education level." BD2* *"Culture is definitely has got a part to play actually. ...and to be honest, the most successful in implementing the technology are the ones where the culture of the project is right." BM4*
	Effective Communication	BD4, CE1	*"If you could have really good communication in big organizations, and you can have really poor communication in small organizations, so and siloed organization." CE1*
	Flat Structure	BC1, BM10, BM4	*"A flat management structure, with a number of individuals, all expected to actually learn and share knowledge, and actually develop at the same pace, is preferred." BC1*
	Leadership Support	BC1, BC4, BD2, BD3, BM1, BM6, CR2, IM2	*"And good leadership I believe is necessary." BM1* *"There are too many factors of why people will not want to share... Whether you can trust the management team, it could be a factor." BC1*

	Learning Capability	BM1, BM11, BM12, BM7, IM1, IM5,	*"I think the new generation has to help the old ones. But it's very important that the old generation, they have to be willing to learn, they have ears to learn. Otherwise, you cannot train someone without this, let's say, mentality, you know. It's very important." BM12*
	Level of Involvement	BM10, IM4 BM6, BM9,	*"The first thing will be definitely, the feeling of belonging to the company. So, the kind of sharing the same attitude, being involved in company's project culture, being aware of it as well." IM4*
	Motivation	BC1, BC5, BD3, BM1, BM4, BM7, BM9, BM10, CE1, IM2	*"you need to also inject the motivation for that, you know, if they share it properly. So that will actually ease up their work." BM1* *"there are two others that, for me, I see as well, which is motivation and engagement of the employee. So, usually when you have a motivated and engaged employee on a project, that person will be very happy to share everything they know." BM9*
	Networking and Open Collaboration	BC5, BM2, CE1, IM2, IM5	*"then actually it's in our interest to collaborate and work together and actually share experiences because we work, we both benefit because of that." CE1* *"So, what you've got to create is a platform where it's an open trust platform where there is space for it, and everybody works together to adjust it." BM2*
	Recognition	BC2, BD3, BD4, BM4, BM8, BM10, IM2	*"So yeah, it's recognizing people's contributions and making sure that people feel proud and responsible for the work they do." BM10*
	Reward and Incentives	BC1, BC2, BC3, BC4, BD1, BD2, BD3, BD4, BM6, CE1, CE2, IM2, IM4, IM5,	*"Yeah, it's that one, unless you give someone incentive, you give them the time, or you give them some kind of financial reward is just keeps us so busy. They don't have time; they are not going to do it." BC3* *"I don't think people should be financially rewarded for sharing ideas, it needs to be part of the company's organisational culture" BD1*
	Trust and Understanding	BC1, BM2, BM9, BM10, IM5	*"There are too many factors of why people will not want to share… Whether you can trust the management team, it could be a factor." BC1* *"So, trust is also another thing. So, I think with blockchain coming in, it is creating a different trust structure with people and trust in sharing knowledge" BM2*

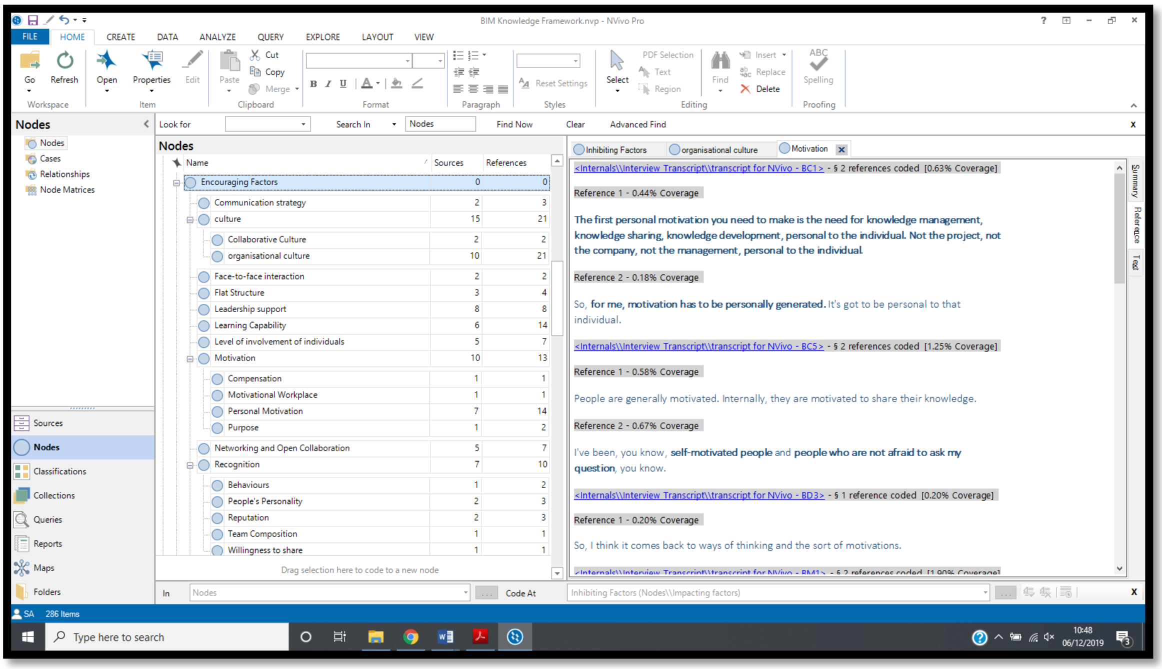


Figure 6. 1: Screenshot from NVivo of Encouraging Factors for Integrating EK into BI

Table 6. 5: Factors Impacting on Effective Integration of EK into BI

Theme	Codes	Sources	Examples of Quotations
Inhibiting Factors (Barriers)	Cultural Resistance	BC3, BD3, BM1, BM2, BM4, BM9, CE1	*"I mean we come from a culture where people keep their experience and knowledge, they try and keep it to themselves because that gives them an edge." BM2*
	Fear of Losing Job (Insecurity)	BM2, BM3, BM8, BM11, CR2, IM3, BC1	*"some people feel scared that this new way of working may stop them from performing. They may feel like they might lose the job, which is a big one actually." BM3* *"Protectionism of either a good innovation, their intellectual property, either they are doing good stuff, or protectionism of they don't want to tell their competitors what they're doing…" BC1*
	Finance	BC2, BC3, BM4, BM12,	*"Money is always a limiter. So, obviously, you know, it's having the budget to give the time and the budget to make sure you get the right people in place, …" BM4* *"if you do an hour of learning from experience workshop, the company is going to pay for hours everyone's time, which is a big cost to them." BC3*
	Legal Framework	BM2, BM7, BM9, IM3	*"I think, especially in the UK, I think the legal frameworks and insurance framework needs to look at how they can accommodate collaborative working." BM2* *"There is a fear around the legalities of sharing information, sharing knowledge. The legal situation, you know." BM7*
	Level of Education	BC1, BD2, BM11, CE1	*"I believe that a culture of best practice and continuous improvement within an*

			organisation is considerably more important than education level." BD2
	Organisational Size	BC3, BC4, BC5, BD1, BD3, BM11, BM2, BM4, BM6, BM8, BM9, CE1, CE2, CR1, IM2, IM4, IM5	*"I don't think it's a major difference. I think that, a large company or small company, generally they tend to do the same kind of thing."* *"When a company is very big, it means that they have a lot of divisions, like they have a lot of departments, a lot of experts, and people are more constraint in things that they do." IM5*
	Organisational Structure	BC3 BC1, BD2, BD3, BM10, BM4, CR1, IM2, IM3, IM5	*"Yeah, I mean, absolutely. The way that the organisation is setup and the way that the decisions get made and then once made, how they are passed out across the organisation is also important." BD3*
	Procurement Method	BC3, BD2, BM1, BM2, BM6, BM7, BM11, CR1, CR2, IM1, IM3	*"I think the primary thing is through the procurement, you need to make the procurement fully integrated to foster collaborative culture." CR1* *"I think if you were to have formal knowledge sharing agreement as part of contractual arrangements that would help," CR2*
	Time	BC2, BC3, BD3, BM4, BM12	*"Time is very important because time means money. So, if they we are saving time because of this new technology, spot on, it is something very good. So, to me, the factors are: cost, efficiency and time." BM12*

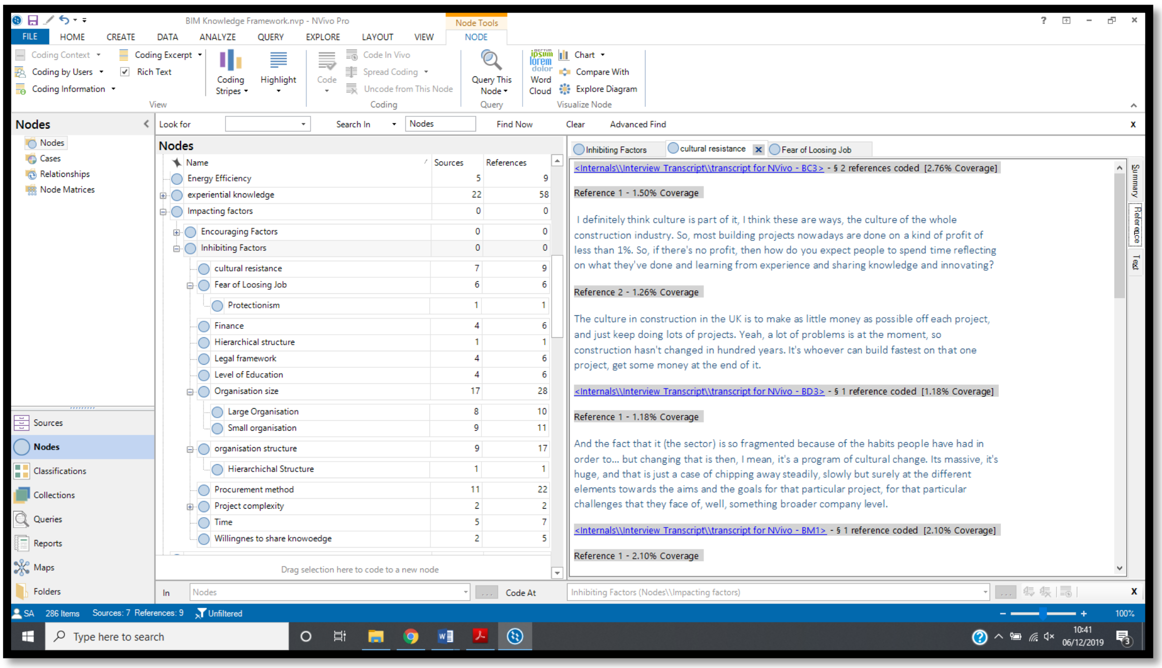


Figure 6. 2: Screenshot from NVivo of Inhibiting Factors for Integrating EK into BI

6.4 Discussion of Findings

Based on objective 4 and second research question (RQ 2) established in Chapter 1, this section discusses findings from the investigation and exploration of factors impacting on the effective integration of EK on BI. A combination of findings from the literature review, interviews and questionnaire survey resulted in total of 30 factors impacting on effective integration of EK into BI. These factors are presented in Table 6. 6 and discussed under four sub-headings.

6.4.1 Individual-related Factors

These are factors that have to do with individuals involved in knowledge integration in BI. These factors can affect the willingness of individual stakeholders to participate in KM processes for EK integration. Despite acknowledging the critical role of individuals in KM processes (Nooshinfard & Nemati-Amaraki 2012; Judge & Bono, 2001), only a few studies have empirically investigated the impacts of individual-related factors on knowledge integration, especially in BIM environment. Based on the results presented in Table 6. 2, only factors with a minimum mean value of 3.40 (on 4-point Likert scale) are considered most highly impactful. Among the individual-related factors, four factors that met this requirement are: Level of trust among individuals involved in integrating EK; Level of involvement and participation of individuals in decision-making; Level of face-to-face interaction among individual colleagues; and Effective and honest communication among individual colleagues, as presented in Figure 6. 3.

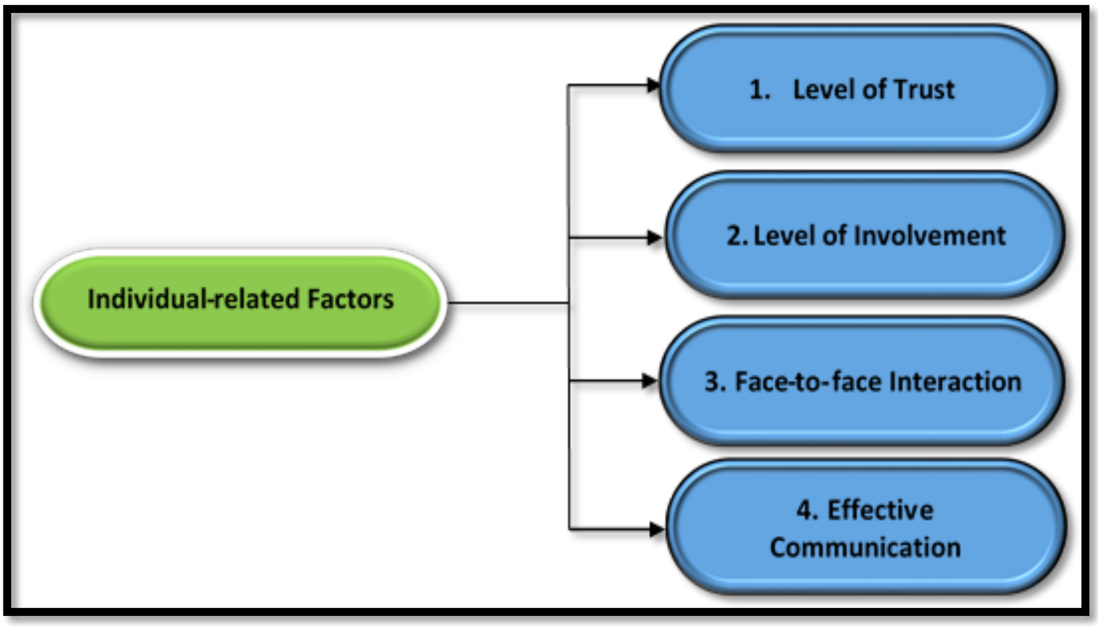


Figure 6. 3: Individual-related factors impacting on the effective integration of EK into BI.

Table 6. 6: Combination of the Findings from the Study on Factors Impacting of Effective Knowledge Integration into BI

Factors	References	Group Ranking	Overall Ranking	Interview
Individual-related Factors				
Level of face-to-face interaction among individual colleagues	Goh (2002); Amuda-Yusuf (2018); Antwi-Afari et al. (2018); Clarke and Rollo (2001), Manasi & Chuboda, (2000), Cascio and Shurygailo (2008).	3	4	BM11
Willingness and ability of individuals to freely share EK	Fischer (2013); Wu (2013), Pinto (2007); Manataki (2007); Adetunji (2005); Wong (2005); Goh (2002); Egan (1998)	5	14	
Level of involvement and participation of individuals in decision-making	Fong and Chu (2006); Takhtravanchi and Pathirage (2018); Chong and Choi (2005)	2	3	BM10, IM4 BM6, BM9,
Rewards and incentives for individuals involved in integrating EK	Liebowitz (1999); Shin et al. (2001); Fong and Chu (2006); Bloice and Burnett (2016); Hsiu Fen (2016)	8	25	BC1, BC2, BC3, BC4, BD1, BD2, BD3, BD4, BM6, CE1, CE2, IM2, IM4, IM5,
Effective and honest communication among individual colleagues	Shang and Shen (2014); Yaakob et al. (2016); O'Reilly III et al. (1989); Sebastian, (2007), Dainty et al. (2006), Armstrong (2001); CEN (2004)	4	6	BD4, CE1
Level of training, education and apprenticeship available to individuals	Ozorhon and Karahan (2016); Wong (2005); Chong and Choi (2005); Enegbuma and Ali (2011); Shang and Shen (2014); Yaakob et al. (2016);	6	16	BC1, BD2, BM11, CE1, IM4, BM3
Level of trust among individuals involved in integrating EK	Arif et al. (2015), Lau and Rowlinson (2011), Lau and Rowlinson (2010), Khalfan et al. (2007), McDermott et al. (2005), Weber and Carter (1998); Goh (2002); Fong and Chu (2006); Shang and Shen (2014);	1	1	BC1, BM2, BM9, BM10, IM5
Individual's level of creativity	*Baskerville & Dulipovici (2006), Baird & Henderson, (2001)*	*7*	*22*	
Project Team-related Factors				
Open and collaborative discussions among project team members	Clarke and Rollo (2001); Goh (2002); Antwi-Afari et al. (2018); Gold et al. (2001)	1	5	CE1, IM2, BM11, BM3, BM5
Availability of adequate time for activities to integrate EK among project team	Fong and Chu (2006); Takhtravanchi and Pathirage (2018); Holsapple and Joshi (2000); CEN (2004)	7	17	BC2, BC3, BD3, BM4, BM12
A knowledge-oriented culture among the project teams that encourages creative and innovative ideas	Skyrme and Amidon (1997); Davenport et al. (1998); Lee and Choi, (2003); Chong and Choi (2005); Khorakian et al. (2015); Ayub et al. (2016)	2	9	BM10, CE1, CR1, CR2, IM2, IM3, IM4, IM5

Availability of appropriate KM tools for integrating EK among project team	Liebowitz (1999); Takhtravanchi and Pathirage (2018)	8	20	
Early composition of project team members and their continuity on the project	Takhtravanchi and Pathirage (2018)	6	13	BM2, CR1
Well defined KM processes for integrating EK among the project team.	Skyrme and Amidon (1997); Tan (2012); Arif et al. (2015), Balasubramanian (2012), BIS (2011a, 011b), Khalfan et al. (2007), Wong (2005), Yusuf et al. (1999), Egan (1998)	4	11	BD2, BM9, BM10, CE1, CE2
Level of commitment to knowledge integration activities among the project team.	Al-Alawi et al. (2007); Du et al. (2012); Dulaimi (2007); Peet (2012); Wu and Lee (2016); McKenzie et al., (2001); Yongsun et al., 1996).	4	11	BC1, IM5
Level of mutual understanding and trust among project team	Arif et al. (2015); Lau and Rowlinson (2011); Lau and Rowlinson (2010); Khalfan et al. (2007); McDermott et al. (2005); Weber and Carter (1998); Goh (2002); Takhtravanchi and Pathirage (2018); Fong and Chu (2006); Shang and Shen (2014)	9	21	BC1, BM2, BM9, BM10, IM5
Project team motivation, and presence of motivational aids	Arif et al. (2015); Aiyewalehinmi (2013); Lau and Rowlinson (2011); Rose and Manley (2011); Lau and Rowlinson (2010); Tabassi and Bakar (2009); McDermott et al. (2005); Wong 2005); Goh (2002)	3	10	BC1, BC5, BD3, BM1, BM4, BM7, BM9, BM10, CE1, IM2
Level of complexity of the projects	*Kanter, 1998); Jin and Kotlasky (2012)*	*10*	*23*	
Organisational-related Factors				
Organisation's leadership support for, and commitment to activities relating to the integration of EK	Maier (2007), Wong (2005); Tiwana (1999); Egan (1998); Chong and Choi (2005); Arif et al. (2015); Fong and Chu (2006); Humayun & Gang (2012); Issa and Haddad (2008); Jain et al. (2007); Ruikar et al. (2005); Liu et al. (2015); Ozorhon and Karahan (2016); CEN (2004)	1	2	BC1, BC4, BD2, BD3, BM1, BM6, CR2, IM2
Organisational culture (beliefs and values) that encourages activities relating to the integration of EK (e.g. experimentation)	Shin et al. (2001); Newell et al. (2004); Fong and Chu (2006); Xie Hongming et al., (2007); Zhou Xiao, (2007) Ruan et al. (2012); Shang and Shen (2014); Yaakob et al. (2016); Ozorhon and Karahan (2016); Takhtravanchi and Pathirage (2018)	2	6	BC3, BC5, BD1, BD3, BD2, BM1, BM2, BM4, BM6, BM9, BM10, CE1, CR1, CR2, IM2, IM3, IM4, IM5
Organisation's efficiency at leveraging EK to improve decision-making	Wong and Radcliffe (2000); Egbu (1999); OST (1995); Lu et al. (2018)	6	19	

Flexible organisational structure that encourages activities for integrating EK through lateral communication	Lin et at. (2012); Shin et al. (2001); Tan (2012)	5	18	BC1, BM10, BM4
Organisational reward systems that incentivise activities for integrating EK	Fong and Chu (2006); Fong and Chu (2006); Liebowitz (1999); Shin et al. (2001)	8	26	BC1, BC2, BC3, BC4, BD1, BD2, BD3, BD4, BM6, CE1, CE2, IM2, IM4, IM5
Organisational infrastructural systems that support the integration of EK (e.g. open workspace)	Davenport et al. (1998); Shin et al. (2001); Wong (2005); Zhang et al. (2008);	4	15	
The size of the organisation (e.g. small, medium or large)		*7*	*24*	BC3, BC4, BC5, BD1, BD3, BM2, BM11, BM4, BM6, BM8, BM9, CE1, CE2, CR1, IM2, IM4, IM5
Organisational transparency and openness	Casimir (2012); Lee et al. (2010); O'Neil and Adya (2007); Smith (2005)	2	6	BC5, BM2, CE1, IM2, IM5
Others (Interview-induced) Factors				
Financial budget for knowledge integration				BC2, BC3, BM4, BM12
Legal Framework				BM2, BM7, BM9, IM3
Procurement (contractual) Method				BC3, BD2, BM1, BM2, BM6, BM7, BM11, CR1, CR2, IM1, IM3
Fear of losing job				BM2, BM3, BM8, BM11, CR2, IM3, BC1

Note to Table: *denotes factors that have 'Cronbach's Alpha if item deleted' above the group's Cronbach's Alpha, which suggest that the factor should be removed to enhance the group's reliability.

**denotes factors that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their years of experience.

***denotes factors that have significant Kruskal-Wallis coefficient at 95% confidence level, which indicates that respondents' opinion regarding the factors differ based on their organisation size.

1. **Level of Trust:**

Many previous studies have indicated that the level of trust among individuals on a project or in an organisation can affect their participation in KM processes (Al-Alawi et al., 2007; Wu & Lee, 2007; Nooshinfard and Nemati-Amaraki, 2012; Arif et al. 2015; Shang and Shen, 2014). Trust refers to the confidence that the reciprocal exchange of knowledge between two parties will be met with a positive outcome for both (McManus et al., 2016). High level of mutual trust can positively impact of effective knowledge integration and increase collaboration among individuals on a project. This probably suggests why trust among individuals involved in integrating EK into BI was ranked overall first among all the factors. Without trust, people will live in mutual suspicion and will never share their knowledge.

Many of the interviewees also identified trust among colleagues as a key factor in knowledge integration. They corroborated previous findings that suggested trust as a good driver that impact KM processes. Trust was also identified as a vital link and strong building block for networking and good relationships that can facilitate effective knowledge integration into BI.

"we relate to other people; we build networks, and we tap into those
Networks and build relationships. To build relationships, you need links.
These links are trust, care, reputations, and knowledge. Knowledge
sharing is a good driver to build reputation and to be helpful.
So, for me and others, these are three important
guidelines on a personal level" IM5

2. **Level of Involvement in Decision-making:**

When individuals are involved in decision-making, they see themselves as stakeholders in the decisions. They will be willing to share and integrate their experiences with other colleagues to facilitate decision-making. Authors have recognised peoples' participation and involvement in decision-making as a critical factor that can influence individuals' willingness to freely share their knowledge (Takhtravanchi & Pathirage, 2018; Chong & Choi, 2005). Organisations that use bureaucratic approach to decision-making hardly benefit from the wealth of experience of individuals in the firm.

Respondents submitted that involving people in decision-making gives them a sense of belonging, which will positively impact on the participation in knowledge integration during BI. Some of the BIM managers observed that:

"The first thing will be, definitely, the feeling of belonging to the company.
So, the kind of sharing the same attitude, being involved in the company's

project decisions, being aware of it as well… making people aware that whatever the decision they make, they make it for reasons and to just participate in that decision-making as well." BM6
"the best project in BIM we've worked on is projects where everybody has been involved, and had a say, and they knew exactly what was happening." BM2

When individuals are involved in decision-making, the implementation becomes easier as a collective responsibility. However, when people are not involved, they feel used like tools. Hence, one of the respondents counselled:

"Try to get the people involved in decision-making as well. Not that they have to get, for example, an instruction to use a tool, and they use it. In that way, they think they are part of the team, and they are doing something for the company rather just receiving to use tools and just doing the job." BM9

There appears to be a direct relationship between the level of involvement, motivation, and the willingness to share knowledge as observed by a respondent:

"usually when you have a motivated and engaged employee on a project, that person will be very happy to share everything they know." BM9

3. Level of Face-to-face Interaction:

The level of face-to-face interaction plays a vital role among colleagues (Maznevski & Chuboda, 2000) in terms of building trust and good relationships that can encourage knowledge integration. It allows instantaneous feedback which is not guaranteed by other forms of communication like email. There is an agreement in the literature on the necessity for some level of face-to-face interaction on projects, despite the difference in opinion on when the interaction should be (Cascio & Shurygailo, 2008; Kelly & Sankey; 2008). However, Kirkman and Mathieu (2004) did not agree on the necessity of face-to-face interaction where there is trust among colleagues. This opinion, which assumes trust as static and permanent, contradicts many of the findings that show that trust is dynamic and context specific. The dynamic nature of trust suggests that face-to-face interactions as against virtual meeting, especially at the early stage of the project, is an important factor impacting on knowledge integration and trust-building.

Face-to-face meeting stimulates positive interaction and ensures true collaboration. According to one of the interviewees, real collaboration requires physical interaction:

"the real collaboration would be sitting around the table for a couple of hours in a workshop, talking over a model, looking at the CoBie spreadsheet, looking at the EIR all the time." BM11

4. Effective and Honest Communication:

Effective communication has been identified as a critical factor for successful project delivery by many scholars (Shang & Shen, 2014; Yaakob et al., 2016). The essence of communication is to disseminate information and knowledge between people using body language, verbal speech, writing, graphical representation, electronic media or any combination of these forms (Dainty et al., 2006; Liebowitz, 2002). Effective communication can improve relationships, encourage teamwork, build trust, enhance productivity, and lead to better collaboration. Poor communication, on the other hand, can cause misunderstanding, litigation, delays and misinterpretation of decisions. BIM helps streamline the construction processes through effective communication and collaboration among different stakeholders on construction projects.

According to some of the interview respondents, effective communication has nothing to do with the size of the organisation; it is an attitude and a skill that should be developed.

"I think big companies can be a lot better if they are run well. it's about the nature of the business and the people in it. If you could have really good communication in big organizations, and you can (as well) have really poor communication in small organizations" CE1

Emphasising the importance of effective communication in disseminating BIM awareness within an organisation, another respondent said:

"we tried to have an internal communications campaign which is based on the relevance of BIM to different groups. So, we identify types of generic groups, it might be senior managers, might be project managers, business managers, senior engineers, graduate engineers, modellers and technicians, each person has got different reasons why they should understand and adopt BIM in the context of their own roles. So, we developed an internal communication strategy that is kind of targeted at different internal groups of people based on why it's of interest to them in their roles and why they should want to adopt it to help themselves, basically." BM1

6.4.2 Project Team-related Factors

These are factors that relate to a team of people who usually belong to different disciplines, have different functions but assigned to some activities to work together on the same project over some time. By nature, construction projects often involve large numbers of people from diverse professional backgrounds working together as a team. Project teams have tasked specific deliverables, which will require bringing their diverse specialised knowledge and previous experiences together for the attainment of the project goals. Previous reports about the UK construction industry (such as Egan Report, 2002; Latham Report, 1994) have described relationships within the industry as fragmented and adversarial. Establishing collaborative practices and ensuring a free flow of knowledge among the project teams becomes very important for successful project delivery.

Previous studies identified critical factors affecting project performance (Chan et al., 2004; Jha & Iyer, 2006). Based on different levels on knowledge integration, this study investigated and explored the team-related factors that can impact on the effective integration of EK into BI. The analysis of questionnaire survey revealed that 5 of the 10 factors have a minimum mean value of 3.40, and therefore considered highly impactful for knowledge integration. These factors are presented in Figure 6.4 and triangulated with the findings from the interviews.

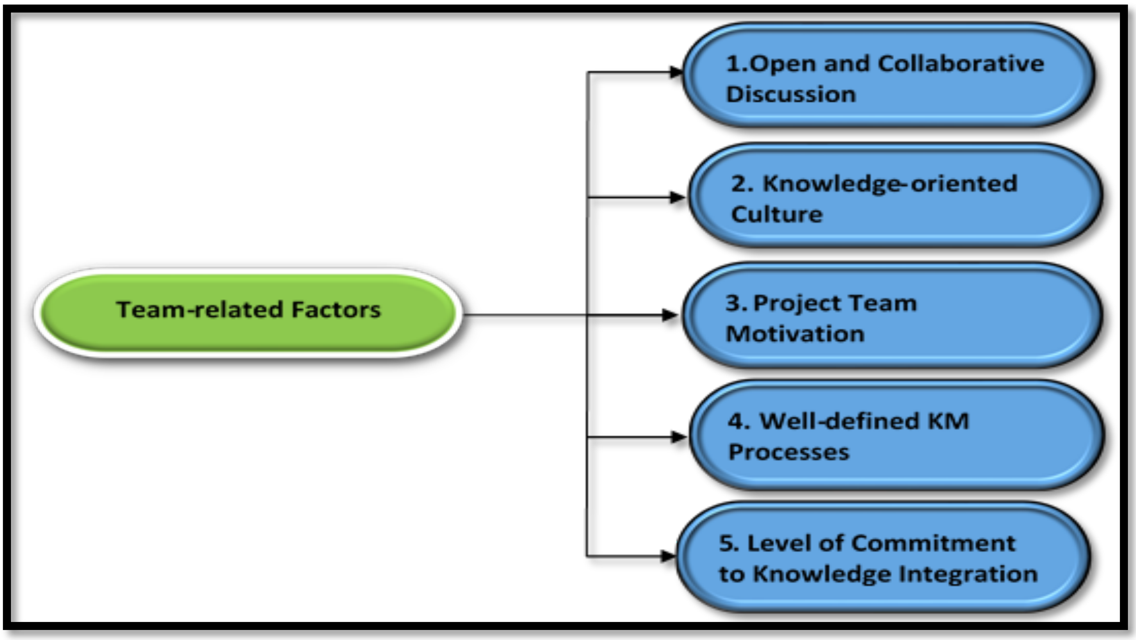


Figure 6.4: Team-related factors impacting on the effective integration of EK into BI

1. Open and Collaborative Discussion:

Open collaboration among members of a project team is very vital for knowledge integration and a critical success factor for BI (Antwi-Afari et al., 2018). Members of the project team should be able to express themselves freely without any fear of intimidation. Team composition should be carefully selected such that every member has equal opportunity to participate and contribute to the discussion. One of the most celebrated promises of BIM is its ability to enhance collaboration and remove the silo ways of working (Kivits & Furneaux, 2013; Taylor, 2007). However, lack of effective collaboration among project teams is still a major barrier to BI (Becerik-Gerber et al., 2011).

Underscoring the importance of open and collaborative discussions, one of the BIM managers explained what true collaboration is and it is not thus:

"in terms of sharing knowledge about particular security-affected design or safety or fire, the (truth about the) whole thing is: all the project (team) are not engaging in a collaborative manner to have a BIM project. But the only thing about them is that every two weeks, they'll put a modelling over there. So, they upload it all together there. They think that's collaborative, but the real collaboration would be sitting around the table for a couple of hours in a workshop, talking over model, looking at the CoBie spreadsheet, looking at the EIR all the time, and call, 'can you do that?' 'I can do it if you do this'. 'Okay. We'll do that. We'll do that here'. Then put the model Over here. So, you know, that is corroborating truly. You need a real, you need all these different consultants to work completely together." BM11

1. A knowledge-oriented Culture:

Good knowledge-oriented culture among project teams in organisations has been identified to promote creativity and innovation (Khorakian et al., 2015) and as a key enabler of KM process for enhanced organisational performance (Ayub et al., 2016). Its presence can mediate the effect of KM on innovation (Mehta, 2008) and encourage knowledge integration amongst project team members. A well-nurtured knowledge-oriented culture among project team engenders the right attitude and behaviour, which allows free exchange of knowledge and ideas, which increases the effectiveness of KM processes. Trust, openness and collaboration are ingredients of a knowledge-oriented culture, which can positively impact on the effectiveness of knowledge integration into BI to improve decision-making (Lee & Choi, 2003).

Many of the interviewees acknowledged the need to encourage habits and behaviours that can facilitate knowledge integration among the people. They decried the silo way of working, which stifles knowledge integration. Some of them observed that:

"Ultimately, it comes back to behaviours and habits. BIM in itself is a Collaborative tool, they're bringing bring people together to look at something and work together on that particular problem, which in and of itself is moving away from the silo mentality that pervades across the sector." BD3

"Culture definitely has got a part to play actually. And I've worked on kind of many projects and many different companies, and to be honest, the most successful in implementing the (BIM) technology are the ones where the culture of the project (team) is right. A lot of time, it's the culture of the people that are leaving the project. So, the people who are the senior people in the projects. They've got the right culture to want to adopt new technologies and actually develop the way they work rather than the culture of the people who think: 'well, I've always done it this way, so why am I changing the way I've done it?" BM4

It appears that a knowledge-oriented attitude and behaviour among project team will minimise the silo ways of working within construction organisations and have a significant positive impact on knowledge integration into BI to improve decision-making.

2. Project Team Motivation:

Effects of motivation on KM processes have been widely studied in the literature (Martin & Dowson, 2009; Wang et al., 2011). EK is embedded in the heads of the people, and its integration involves time and change process, which can be achieved through motivation and recognition (CEN, 2004). Without adequate motivation, other factors may fall short of ensuring effective knowledge integration. Monetary rewards, recognition, promotion, and praise are some of the ways to motivate members of a project team to participate in knowledge integration processes (Nooshimfard & Nemati-Anaraki, 2012).

All the stakeholders interviewed agreed on the need to motivate team members to participate in knowledge integration. However, they disagreed on the type of motivation that should be provided. Some of the respondents opined that motivation should be personally generated and people should be made to see the benefits from within. For example, one of the BIM coordinators argued thus:

"For me, motivation has to be personally generated. It's got to be personal to that individual. The first personal motivation you need to make is the need for knowledge management, knowledge sharing, knowledge integration, personal to the individual. Not the project, not the company, not the management, (but) personal to the individual." BC1

Other people buttressed the point and posited that personal motivation is very important.

"If you don't have that personal connection to the initiative. It's not going to work. Simple as that. You don't have to think about things like financial reward or status." "Real motivation for people to share knowledge? I think personal enhancement is a massive thing for people to share knowledge." BM4

Majority of the respondent discouraged the culture of monetising knowledge integration processes. They argued that knowledge integration should instead be embedded as part of the organisation culture.

"I don't think people should be financially rewarded for sharing ideas, it needs to be part of the company's organisational culture. I think it is about trying to create that culture that the idea of the mechanisms is there to make it happen." BD1

"Good businesses looking to work in the best possible way will more often than not provide a motivational workplace which can adapt to the evolutions such as BIM." BD2

However, few respondents insisted on financial reward, along with other incentives, as a practical means of motivation without which people may not yield, especially going by the present state of the industry. A BIM coordinator suggested that:

"They got to give people that time to do it, or you've got to financially reward them for doing it. Unfortunate, at the moment, in the construction industry, that's the only way that you get things done, or some kind of incentivize methods…Yeah, it's that one, unless you give someone incentive, you give them the time, or you give them some kind of financial reward. It is just to keep us so busy. They don't have time, they are not going to do it." BC3

A cost estimator gave an example of how financial reward was used in one of the companies he had worked:

"People would come up with new innovations. It could not necessarily be about BIM, but you know, they might think of really good way of doing something and that was actually, rewarded financially. They (also) had incentives where they gave prizes or financial rewards at the end of each month for innovations." CE2

However, it was argued that motivation is very dynamic, context-specific, and fast-changing from monetary reward to other intangible forms like opportunities to network, exposure to adequate training and ability to use state-of-the-art technologies.

3. Well-defined KM Processes:

Knowledge has long been recognised as a critical resource that should be well managed for effective organisation performance (Pathirage et al., 2007). Accordingly, many processes have been suggested on how best to manage and capitalise on the benefits of knowledge in the literature. A well-defined KM process is, therefore, essential for effective integration of EK into BI. Such a process should necessarily include knowledge generation, knowledge capturing/codification, knowledge sharing and transferring, and knowledge application (Davenport & Prusak, 1998). KM process can vary from a very formal and rigid process to an informal and flexible process across construction organisations.

According to some of the respondents, small organisations tend to be very flexible and informal, while large organisations are usually very rigid and formal in the process of managing knowledge.

"When you're like working in smaller teams or smaller practice, the knowledge management processes a lot more informal because it's quite easy for you if you're, basically, in one office, and you're in one area, it's quite easy to turn around to your colleagues and say, 'oh, have you ever come across such and such?' and they go, 'Oh, yeah, we have', or you can say: 'how to do this?' And I'll then explain that. That kind of KMP is quite informal." CE2

"in a small company, let's say small architectural practice with five people, it's very likely that everyone knows what the other person is doing because they sit together on the same table, everything they say. So, the knowledge might be better communicated on a one-to-one basis. But usually, bigger companies are more structured in the way processes work as a big corporation." BM9

However, another respondent criticised the rigid process in the large firms as monotonous, describing the informal process of the smaller company as agile:

"I think bigger organisations can become a bit monolithic in some instances, and people don't feel they have the contact across the business. Smaller ones can be more agile. I suppose there will be more contact with different levels of the business, different spectrums of the business" CE1

The complexity of the KM process to be adopted also depends on the size of the project. A well-structure KM process will be required for a massive project because of the volume of knowledge and information that will be generated. Whereas, a small project may not require such a complex and structured process.

"the project is so big, and they go on for such an amount of time that the process and the standards and knowledge management, they take quite big strides, they're not smooth strides like in a small firm or in little projects that happened quite rapidly." BM10

Some of the respondent boasted of a well-defined KM process based on the size of their organisation.

"Our team (organisation) is very good at making sure that assignment is part of our PRM review process of employees. We do monitor; we ask people if their peers are sharing knowledge with them, we have got groups of people who, that is their job in terms of KM as well. It is a well-managed-process." BD2

"we have our processes; we are very process-driven… But, obviously, as I mentioned, the company is complicated" BM9

It can be inferred from the above that the presence of a well-defined KM process can be very impactful on knowledge integration, but the impact may be more felt in larger organisations and big projects.

4. **Level of commitment to knowledge integration activities among the project team:**

This factor refers to the degree of dedication given by members of the project team to activities relating to knowledge integration. It is the willingness to exert oneself towards achieving a goal, out of strong desires to belong (Yongsun et al., 1996). It reflects people's solidarity with the goals and values set up within a team or organisation (McManus et al., 2016).

Motivation, reward and recognition can be used to improve members commitment to participate in knowledge integration activities (Chen et al., 2018). The level of trust and leadership support from the management will also influence the level of commitment of members (Arif et al., 2015). Trust in leadership was highlighted as one of the psychoanalysis drivers of members' commitment to KM activities by a BIM coordinator:

"Unfortunately, I think when it comes down to what drives people to either share or not share knowledge, there is really every single realm of psychoanalysis you have to look at. There are too many factors of why people will not want to share, and many, many, external factors. Whether you can trust the management team, it could be a factor." BC1

Provision of adequate feedback and allowance to learn from mistakes can help enlist members commitment to KM activities (McKenzie et al., 2001). Commitment can also be influenced by the kind of relationships that exist among team members. An information manager echoed this opinion during an interview:

"Relationships, we prefer we work better with others than alone, right? In general, I mean, not all the time. But you know, we relate to other people, we build networks, and we tap into those networks and build relationships. To build relationships, you need links. These links are trust, care, reputation, and knowledge." IM5

Those factors that influence level people's commitment to KM activities should be critically considered during BI to ensure that members are committed to knowledge integration and willing to participate in activities that will lead to the achievement of project goals.

6.4.3 Organisation-related Factors

Organisation-related factors refer to those factors that impact on knowledge integration within a construction firm. Organisations, as the highest level of integration within the industry, plays a significant role in providing a conducive environment and enabling platform for KM processes. Only three of the organisational-related factors met the minimum mean value of 3.40 set for the highly impactful factors (see Table 6. 2). The three factors are represented in Figure 6.5 and discussed below.

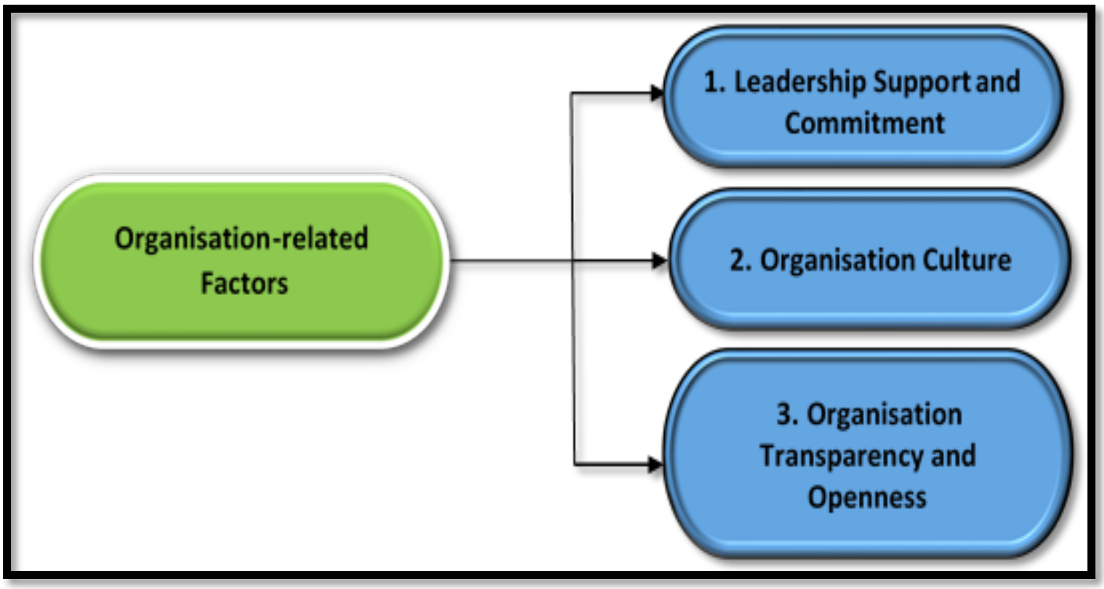


Figure 6.5: Organisation-related factors impacting on the effective integration of EK into BI

1. Organisation's leadership support:

Previous studies have investigated the relationship between management support and KM activities (Jain et al., 2007; Haddad & Issa, 2008; Arif et al., 2015). Organisational leadership is responsible for providing enabling environment for KM activities among workers to build mutual trust and collaboration, especially in the construction industry where relationships are adversarial. Leadership support plays an important role in the success of KM activities and motivates employees to share knowledge (Humayun & Gang; 2012). Assurance of leadership support reduces the fear of sharing unique knowledge and increases social connections and interaction among workers (McManus, 2016). Similarly, management support is also essential for minimising barriers to BI (Ruikar et al., 2005; Liu et al., 2013) and the process of integrating knowledge into it. Ozorhon and Karahan (2016) identified leadership support as one of the three most important factors for BI.

Respondents agreed that good leadership support is essential for knowledge integration and that leaders should be responsible for encouraging KM activities such as the provision of incentives for knowledge sharing and integration, as observed by respondents:

"And good leadership, I believe is necessary." BM1
"we don't incentivize knowledge sharing. There's no sort of bonus or anything like that. Because I think that again, that's, wrong. I think that ultimately it is a management issue." BC4

It can be deduced that strong leadership support can positively impact on the willingness to participate in knowledge integration.

2. **Organisational culture:**

Organisational culture refers to the norms, beliefs and values adhered to by organisational members for the sustenance and development of their goals and objectives. There are numerous studies on the effects of organisational culture on KM and the relationship between the two (Ahmady et al., 2016). Nooshinfard and Nemati-Anaraki (2012) identified organisational culture as a positive predictor of organisational leadership support for KM activities. Takhtravanchi and Pathirage (2018) found the culture of an organisation as one of the most critical factors impacting the process of integrating tacit knowledge within the construction traditional procurement system.

Enabling organisational culture promotes an open and transparent environment for honest communication and the exchange of ideas and experiences during BI (Yaakob et al., 2016). Right organisational culture was identified as one of the most impactful factors for BI by a BIM manager during an interview:

"Culture, definitely, has got a part to play actually. And I've worked on
Kind of many projects and many different companies, and to be honest,
the most successful in implementing the technology are the ones
where the culture of the project is right." BM4

The construction industry is renowned for a culture of fragmentation which BI hopes to correct by endearing collaborative ways of working. People hoard knowledge because of the culture of 'knowledge is power' which gives them a competitive advantage over their peers.

"I mean we come from a culture where people keep their experience and
knowledge, they try and keep it to themselves because that gives them an edge.
With BIM lead things to want to push for collaborative, and shared information" BM2

Unfortunately, this culture has not changed significantly. A culture where people compete to complete as many projects as possible for a little profit without adequate time for KM activities. A BIM coordinator described the culture of the UK construction thus:

"The culture of construction in the UK is to make as little money as possible off
each project, and just keep doing lots of projects. Yeah, a lot of problems is at the
moment, so construction hasn't changed in hundred years. It's whoever can build
fastest on that one project, get some money at the end of it. There's nothing there
to do with skill or knowledge management" BC3

Organisation culture should allow people to learn from mistakes, thereby encouraging innovation and continuous learning. Respondents advised that organisational culture should not stigmatise people who make mistakes, but they should be encouraged to learn from their mistakes.

"And I think in organizations where people are allowed to make mistakes, you know, where the idea of making mistakes isn't seen as a negative thing. So, I think the idea of, in the construction industry, you know, if you make a mistake, it can be hugely costly. So, that's what I think, that's where it comes from. It's like you're scared to make a mistake in the industry because they see that the costs can be huge. But I think within an organization, you should be allowed to make errors and learn from them. Yeah, otherwise how do you learn? I mean you can learn from this, you can only learn so much from somebody else's experience, but you have to also be able to learn from yourself, you have to learn from your mistakes. There should be an allowance for making certain types of mistakes." IM2

"you go to certain organizations, and they have this culture of innovation. So, when you bring up anything that goes above ability, you know, they will generally go for it. So, to some extent, you can call that organisational culture."CR1

3. **Organisational transparency and openness:**

A transparent and open organisation environment is critical to the free flow of information and knowledge. An open environment provides a trusted working environment for workers to dedicate sufficient time for knowledge integration activities (Takhtravanchi & Pathirage, 2018).

"some structures allow open discussions. You know, anybody can talk to you, bring new ideas and they will take it. Other structures are not that open, as fast as that. You have an idea, you will write the most superior, it will take years before it gets to the top. Then, it won't be funded." CR1

Organisational transparency and openness are directly related to the level of trust, especially when dealing with inter-organisational relationships. There are limits to which organisations can be open when working with other organisations because of the competitive nature of the industry. The culture of the UK construction industry was cited as a reason while openness across organisations may be hindered.

"We're working with external partners. There's a lot of barriers to them been open and honest. You know, they want information about what they could have done better to be shared with competitors." CR2

"I think that private organizations, there's all sorts of barriers to them really. seriously working in partnership with other organizations and the culture in this country is people to be very protective of their own organizations. And I think that is just the culture in the construction industry in this country." BM1

However, the legal consequences of exposing mistakes and security issues around some projects may inhibit organisational openness and willingness to share lessons learnt from past mistakes. Organisations do not want to share their mistakes for fear of litigation as pointed out by a BIM manager.

"problem of sharing and openness in the industry is that you expose yourself to legal or, you know, to litigation. So, if you made a mistake and it is open for everybody to see, then you can get into trouble. And that's what prevents too much (openness)." BM2

"Security is a problem. So, in terms of sharing knowledge about particular security-affected design or safety or fire, the whole thing's for all or projects not engaging in a collaborative manner to have a BIM project" BM11

6.4.4 Other Factors (from the Interviews)

These are factors that emerged from the analysis of the interviews. They were not included in the extract from the literature and survey questionnaire. These factors are contained in Table 6. 6 and presented in Figure 6.6 for discussion.

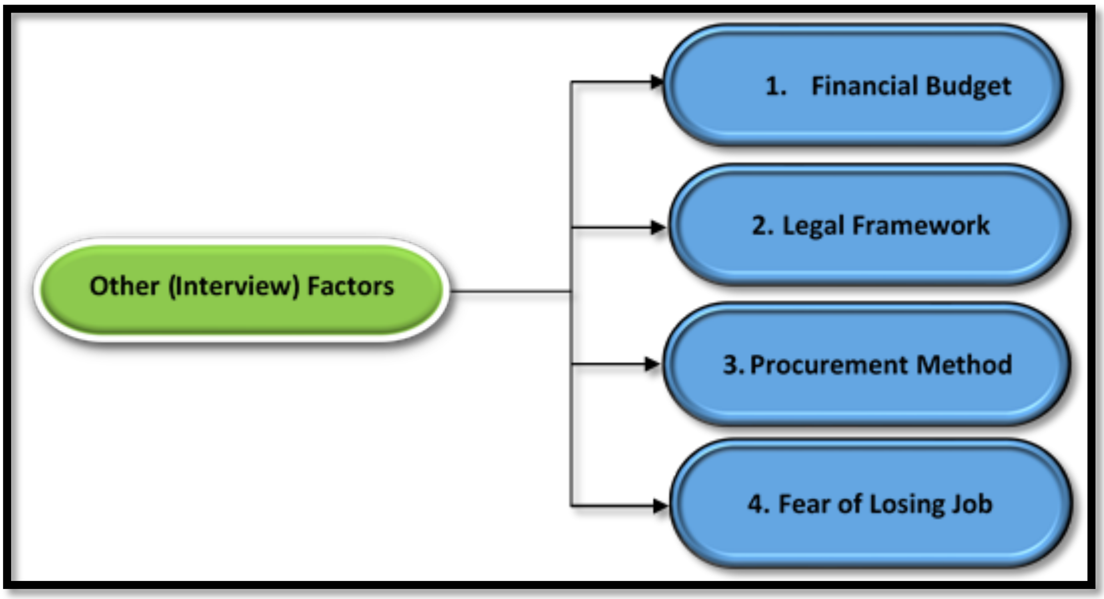


Figure 6.6: Other factors impacting on the effective integration of EK into BI

1. **Financial budget for knowledge integration:**

Organisations interested in knowledge integration activities should provide an adequate financial budget for it. Motivation, incentives and other knowledge integration factors are closely related to the availability of funds. Lack of adequate funding for knowledge integration was identified as a key inhibitor by the respondents:

"Money is always a limiter. So, obviously, you know, it's having the budget to give the time and the budget to make sure you get the right people in place, and then given the time, I guess. The typical limiter, for me, would be those two things." BM4

"I think finance does all these things. And people normally ignore energy related advice because of money... So, I think money is critical." CR1

According to some of the respondents, construction organisations are not buoyant enough to invest in KM activities because of the low profitability in the industry, especially when compared with other industries like the automobile. For example, a BIM coordinator observed that:

"Most building projects nowadays are done on a kind of profit of less than 1%. So, if there's no profit, then how do you expect people to spend time reflecting on what they've done and learning from experience and sharing knowledge and innovating? They just don't have the budget for it. So, they go, they build the projects, they take their half a per cent profit, and they move on to the next one as quick as possible." BC3

He went further to compare the two industries in terms of profit margin and their commitment to KM activities. He argued that the low-profit margin accruable from construction does give time for innovation and experimentation.

"if you look at the automotive industry, you can, well they're very innovative, they come up with new ideas, they come up with new designs, they share their experience of what works, why it failed, and they're working on big profit margin of, maybe 20 - 30%. So, they've got the money, the time, the investment to actually make the changes. In construction, if a client wants a building, he says like: 'who can build this and who's prepared to do it for the least money?' And therefore, there's no budget left there for any of kind of good stuff that goes on in the background." BC3

KM activities take time, and time is costly. This probably explains why some interviewees kicked again motivating workers with money. Some of the organisations have, therefore, devise means of cutting cost on incentivising workers for KM activities.

"It costs a lot of money if you start to incentivise people financially, but you Know what we do (in our firm) is to offer up free tickets to attend events. If you submit stuff, they offer free CPD, free or cheaper subscriptions. So, pre-access to things like that. So, I think that's probably the best way of incentivizing." CE2

"Time is very important because time means money." CE1

To facilitate knowledge integration into BI, construction organisations interested in BIM must make adequate budgetary allocation for it.

2. **Legal Framework:**

There is a need to develop a practical legal framework to encourage knowledge integration and protect innovations. The law should encourage collaboration and shared responsibilities. Workers are likely going to share knowledge freely when they feel protected by the law.

"I think, especially in the UK, I think the legal frameworks and insurance framework needs
to look at how they can accommodate collaborative working. So, it might become project-based insurance, and so, it's a shared responsibility. So, it's famous, if you put a team together and say: you go off and do this and that, nobody is focused on the bigger goal because everybody is disconnected. So, I think what need to happen is a platform for shared insurance, shared responsibility, and that needs to be created." BM2

The fear of prosecution and exposure to litigation inhibits knowledge sharing and integration, especially across organisations. It causes organisations to be protective of their knowledge base and reduces openness and transparency, as explained by a BIM manager:

"so, problem of sharing and openness in the industry is that you expose yourself to legal or, you know, to litigation." BM2

The issue of Intellectual property and liability was raised as barriers to knowledge sharing. A BIM manager explained how legal issues could inhibit knowledge sharing from an engineer's point of view:

"There is a fear around the legalities of sharing information, sharing knowledge. The legal situation, you know. People were afraid of sharing knowledge … Well, imagine if I come up with a new way to design an element. A new way of doing a design calculation on the elements and I shared that information with other people and then they designed using my system, my ways of doing it, using my knowledge. And then the element failed, and you know, it is legal for me to be sued. Exactly." BM7

There is the need to improve the existing legal framework to accommodate collaborative working envisioned by BI and reduce the legal bottlenecks associated with knowledge integration.

3. **Procurement (Contractual) Method:**

Procurement method refers to the process of allocating design and construction responsibilities to ensure quality project delivery to time and on budgets (Daniel, 2006; CIOB report, 2010). It has to do with the way the contract is set up from the beginning to the end, including risk allocation and individual obligations. There are different types of procurement methods within the industry such as traditional method, design and build, management or construction contracting, and public-private-partnership with their benefits and weaknesses (Babatunde et al., 2010). The choice procurement method to adopt should be made early during BI and determined by the client business case for the project (CRC Report, 2008).

The contractual method adopted can positively or negatively impact on the KM activities during BI. Some methods allow competition and conflicts. Competition among firms discourages knowledge sharing and integration. It sometimes led to conflicts and litigation as pointed out by an information manager:

"I also think the contracts have got a lot to do that as well. So, the way contracts are set up. Traditional contracts have been set up in a kind of 'design and build' for people. It encourages conflict within teams in the competitive way. It encourages blames, as well. So, people pointing accusing fingers at each other, saying well it's your fault, you didn't provide this information. So, I think contracts need to change for people to share better" IM2

Some of the BIM managers draws a correlation between the contract method adopted for BI and legal issues arising from KM activities. The called for official incorporation of KM activities into contract documents in order to reduce litigation and encourage openness and transparency.

"I think if you were to have formal knowledge sharing agreement as part of contractual arrangements that would help" BM1

"As far as legal stance, and all of that, so if you look at the traditional-way projects, the contractual parts of it, and the legal part was, it's kind of forces the parties involved to always want to protect themselves. But if you start creating environments where everybody takes ownership together for the project, and is less of a finger-pointing environment, and everybody is interested in doing the best project, and it is starting to change. You can start seeing the ways contractors are being changed and for this purpose, and so it's all transparent. So, yeah, let's hope it goes for the next generation." BM2

To minimise the negative impacts of the adopted contractual method on knowledge integration; all available options must be carefully considered with their legal implications right from the early stage of the project. KM clauses that encourage collaborations, openness and knowledge integration should be included in the contract documents for project procurement.

4. **Fear of Losing Job (Insecurity):**

The fear of losing one's job may be born out of lack of trust in the management, which may inhibit the willingness to participate in KM activities (Abu Mansor, 2008; Skyrme, 2002). Another form of fear is the fear of losing relevance and power by sharing one's knowledge with colleagues in a knowledge-intense environment like construction. This fear may be heightened by the culture of 'knowledge is power' and the competitive nature of the industry, which serves as barriers to KM activities (Chaudhry, 2005). The fear creates a feeling of insecurity which affect relationships with colleagues and negatively affect their psychology.

Speaking on this factor, some BIM managers explained that people protect their knowledge because of the fear of losing their power.

"Some people want to make sure they're doing authority in that field. So, they can either protect their job or, you know, get pay rise, that could be another barrier. They don't want to share what they know because they feel I've spent years accumulation this knowledge so, why should I just share with you. (laughing mode) the human factor, yeah." BM8

"I think the inhibitors that there may be an issue that I've seen before, some people feel scared that this new way of working may stop them from performing. They may feel like they might lose the job, which is a big one actually" BM3

"Protectionism of either a good innovation, their intellectual property, either they are doing good stuff, or protectionism of they don't want to tell their competitors what they're doing, so the competitors copy them or protectionism as in particular brand and reputation out in the marketplace. So, when it comes to knowledge management, I think that's one of the key things" BC1

Corroborating the point, another BIM coordinator gave a life experience where people have been sacked or made reductant after being asked to share their knowledge with colleagues. He, therefore, warned that people must be cautious with sharing their knowledge indiscriminately.

"So, you got to be really careful on things like these assessments and knowledge sharing. You know, I have seen people being asked to go out and tell the rest of the company all of their knowledge and then actually, get rid of them or made redundant of that task." BC1

It is essential to build trust by letting people appreciate the benefits of participating in KM activities. They need to be always reassured that they will not lose their job by sharing their knowledge, as suggested by some respondents:

"To integrate people's experience into BI. So, you know, if they see the benefits, I mean, for example, if they think that sharing will help their job, they will share it." BM1

"Look, this is relevant to you, this is going to help you, this is going to make you better. And by the way, you won't lose your jobs on the back of it'. Yeah, it'll just make things better." BC1

Fear and insecurity can inhibit knowledge integration into BI if it is not well-addressed. Creating an enabling environment that encourages good relationship, building trust and understanding personal benefits of KM activities can mitigate the negative impacts.

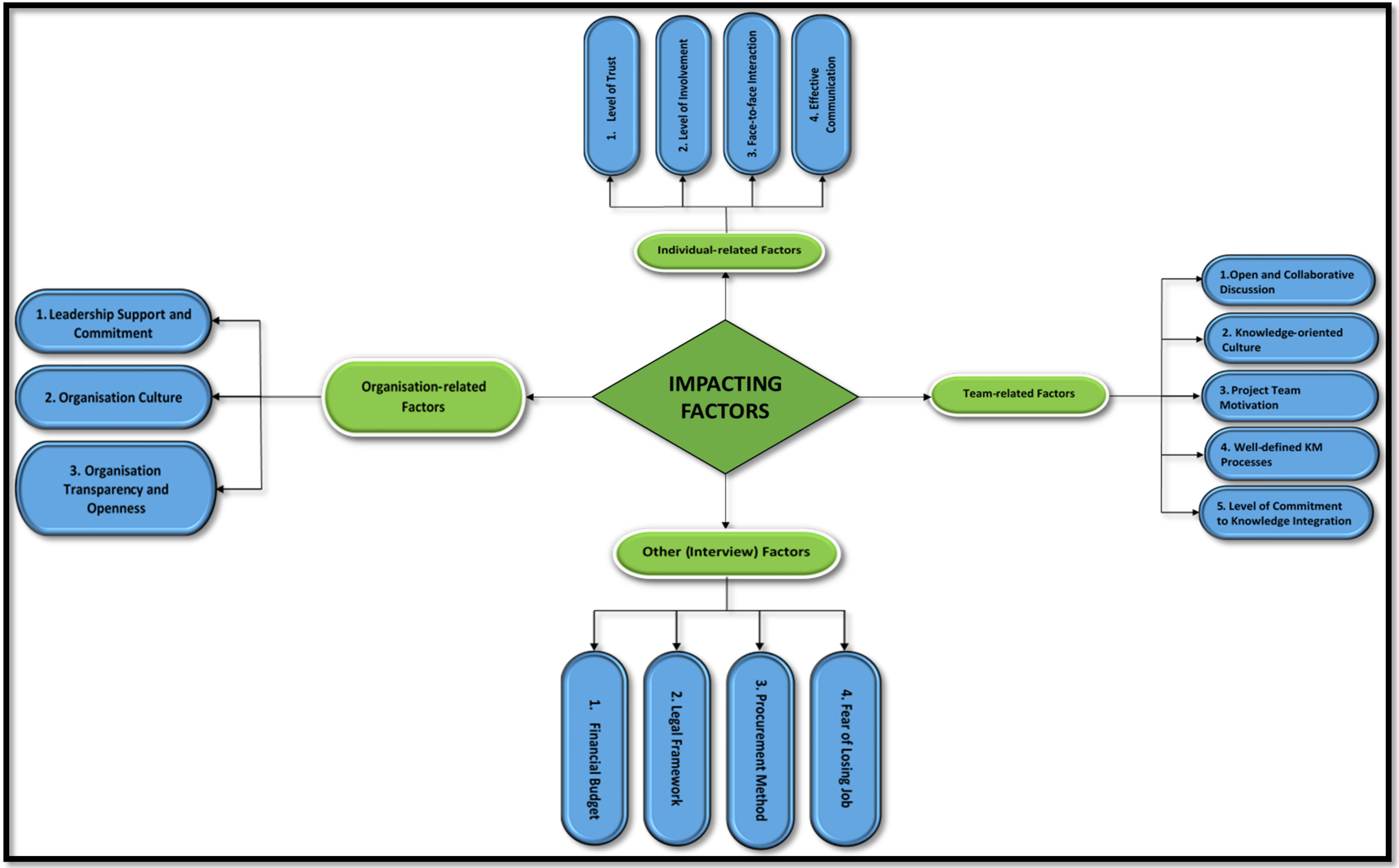
Some of these factors have been identified in previous studies, especially with relation to BIM adoption and knowledge integration into other systems (such as information system). However, no previous study has considered the impacts of these factors on the integration of EK into BI in the context of decision-making specifically. Analyses of the interviews further revealed the need for a strong legal framework and adequate budgetary allocation as additional measures for effective integration of EK into the mainstreams of BI.

6.5 Chapter Summary

In fulfilment of research objective 4, and in providing answer Research Question 2, this chapter presented the findings and discussions of investigation and exploration of factors impacting the effective integration of EK into BI in building construction projects. Twenty factors were extracted from the interview analyses. Eleven factors were considered drivers of the integration process, while nine of them could create barriers for integrating EK into BI. From the surveys' analyses, twenty-two of the twenty-six factors in the survey were ranked highly impactful for effective integration of EK into BI, as shown in Table 6. 1.

However, sixteen most impactful factors from both interviews and questionnaires, were included in a framework and presented in Figure 6. 7. Four of these factors are related to individuals, five are related to the project team, and three are related to the organisation. Additional four factors were deduced from the interviews conducted with stakeholders within the construction industry. In the process of integrating EK to BI, decision-makers in BI should critically consider the impacts of these factors on their decisions. The factors could positively or negatively impact the decisions depending on how they manage them.

Having identified the factors that can impact on the effective integration of EK on BI, the next chapter will explore the key decision-makers in BI. The skills and knowledge that are important to these decision-makers to perform optimally will also be explored.



1. Level of Trust
2. Level of Involvement
3. Face-to-face Interaction
4. Effective Communication
Individual-related Factors
1. Leadership Support and Commitment
2. Organisation Culture
3. Organisation Transparency and Openness
Organisation-related Factors
IMPACTING FACTORS
Team-related Factors
1.Open and Collaborative Discussion
2. Knowledge-oriented Culture
3. Project Team Motivation
4. Well-defined KM Processes
5. Level of Commitment to Knowledge Integration
Other (Interview) Factors
1. Financial Budget
2. Legal Framework
3. Procurement Method
4. Fear of Losing Job

Figure 6. 7: Framework of factors impacting on effective integration of EK into BI

CHAPTER 7: SKILLS AND KNOWLEDGE INVENTORY (SKI) OF DECISION MAKERS IN BI

7.1 Introduction

Chapters 4 and 5 provided the explanations on the required knowledge and processes for integrating EK into BI. Chapter 6 highlighted factors that impact on the effective integration process. The essence of the integration is to improve the decision-making process during BI. The need to identify the key decision-makers in BI, and develop an inventory of important skills and knowledge for the decision-makers led to the formulation of the third research question (RQ3) – *"what are the skills and knowledge required by the key decision-makers in BI?"* Research objective five - *"to develop skills and knowledge inventory (SKI) of key decision-makers in BI"* was meant to provide answers to the RQ3.

This chapter presents results from the questionnaire survey and interviews regarding skills and knowledge important to BI's key decision-makers based on the knowledge-based theory adopted in section 2.7.1. Decision-making is perceived as a task, and it is essential to understand the competencies (skills and knowledge) required to perform this task within the context of BI. This chapter starts with results from the analysis of the questionnaire survey (Section 7.2) regarding the skills and knowledge important to key decision-makers in BI from three perspectives:

1. The skills and knowledge considered important now;
2. The skills and knowledge considered important in future (5 years); and
3. The training/education needs to develop the skills and knowledge now over the next five years.

Section 7.3 presents the results from the interviews, governed by two main interview questions:

1. Who are the key decision-makers in BI?
2. What skills and knowledge are important to the identified decision-makers in order to make effective decisions in BI?

Section 7.4 presents a discussion of the findings from both questionnaire survey and interviews regarding the skills and knowledge considered important to BI's key decision-makers. The chapter ends with a summary of the key findings in section 7.5.

7.2 Findings from the Questionnaire Survey

This section is meant to seek a broader opinion from experts from the industry on skills and knowledge considered important to the key decision-makers in BI based on extracts of skills and knowledge generated from the literature (see section 2.7.2). Twenty most frequently cited skills and knowledge from the literature were compiled, and respondents were asked to indicate their degree of importance to the key decision-makers in BI now and in the next five year (future). The ranking is done on a 4-Likert scale, from 1 = not important to 4 = highly important.

Besides, respondents were asked to rank the skills and knowledge for training and education needed now to take decision-makers to where they should be in the next five years. This survey is to help identify areas of skills and knowledge where training will be needed now to improve the decision-making process in BI in the future. The data collected from the survey were subjected to various statistical analyses using SPSS (version-21), as explained in sections 3.7.3.5 and 3.7.3.6. The findings from the analyses are presented under three headings. Section 7.2.1 presents the result of the skills and knowledge considered important now while section 7.2.2 shows what skills and knowledge the respondent consider to be important in future. The results of the skills and knowledge where more training/education are required is presented in section 7.2.3.

7.2.1 Skills and Knowledge Important to key Decision-makers in BI (Now)

A descriptive analysis was carried out to determine skills and knowledge that are considered very important to the decision-makers in BI now. Table 7. 1presents values of ranked item-total statistics for each of the variables (Important SKI – now) tested in the questionnaire. With the mean values ranging between 3.51 and 3.14, the result shows that all the factors were considered highly important by the respondents. Analysis of the result presented in Table 7. 1 revealed that six skills/knowledge were ranked most highly important now with mean values of not less than 3.40. These are:

1. Teamwork/collaboration,
2. Leadership,
3. Communication,
4. Strategic planning,
5. Scope and schedule management, and
6. Change management.

Table 7. 1: Ranked Item-Total Statistics: Important SKI (now)

Factor	SKI of Decision Makers in BI (Now)	Mean Value	Mean Ranking	Cronbach alpha if item deleted
SK1	Strategic planning	3.42	4	0.943
SK2	Leadership	3.49	2	0.943
SK3	Scope and schedule management	3.41	5	0.942
SK4	Communication	3.46	3	0.941
SK5	Human resource management	3.22	18	0.940
SK6	Procurement and material resource management	3.22	17	0.941
SK7	Time management	3.30	14	0.941
SK8	Conflict management	3.23	16	0.942
SK9	Change management	3.41	6	0.942
SK10	Financial management	3.20	19	0.943
SK11	Risk management	3.35	11	0.941
SK12	Project management	3.38	7	0.941
SK13	Quality management	3.34	12	0.942
SK14	Teamwork/collaboration	3.51	1	0.941
SK15	Negotiation	3.24	15	0.942
SK16	Multi-tasking and organisation	3.14	20	0.941
SK17	Software management	3.37	8	0.943
SK18	Motivation	3.34	13	0.942
SK19	Critical inking and Analysing	3.35	10	0.942
SK20	Policy knowledge	3.37	9	0.942

Cronbach alpha test (α) was conducted to determine the reliability and internal consistency of the variable. The result of the Cronbach alpha test, as presented in Table 7. 2, regarding the 20 variables on skills and knowledge shows a value of α = 0.944, which is excellent. This shows that all the variables are reliable, with a high degree of internal consistency. Hence, none of the items on the list will be deleted.

Table 7. 2: Reliability Statistics: SKI of Decision Makers in BI (Now)

Cronbach's Alpha	Cronbach's Alpha Based on Standardised Items	No of Items
0.944	0.945	20

Factor Analysis: After ascertaining the importance of each variable, in order to unravel the dominant structure underlying various skills, exploratory factor analysis was conducted. Factor analysis is a statistical technique meant to reduce data or detect underlying structure in observed factors (Meredith, 1993). It can also be used to unravel a set of uncorrelated factors from the reduced data. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett test of sphericity values were 0.884 and 0.000, respectively (see Table 7. 3). The two values of KMO (higher than 0.5) and Bartlett test (less than 0.05) confirm that the data is suitable for factor analysis.

Table 7. 3: KMO and Bartlett's Test of SKI (now)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.884
Bartlett's Test of Sphericity	Approx. Chi-Square	1261.747
	Df	190
	Sig.	0.000

Principal component analysis and varimax rotation were used for criterial extraction and rotation, respectively. For the interpretation of findings, all factors with an eigenvalue not less than 1 were extracted. Furthermore, all variables with a factor loading of 0.40 and above were selected for grouping the variables (Tucker & Lewis, 1973). The analysis shows a three-factor solution with an eigenvalue greater than 1 as shown in Table 7. 4. Figure 7. 1 shows the associated scree plot, revealing the graphical representation of the three groups of skills and knowledge important to decision-makers in BI in the UK now. The three-factor solution accounts for 62.065% of the total variance.

Table 7. 4: Factor Analysis for the SKI (now)

Factors		Component			Eigenvalue	% variance
		1	2	3		
Factor 1	***Soft Skills and Knowledge***				***4.579***	***22.895***
SK18	Motivation	0.745				
SK19	Critical thinking and Analysing	0.695				
SK8	Conflict management	0.669				
SK9	Change management	0.616				
SK20	Policy knowledge	0.615				
SK14	Teamwork/collaboration	0.615				
SK7	Time management	0.587				
SK5	Human resource management	0.573				
SK4	Communication	0.531				
SK16	Multi-tasking and organisation	0.515				
Factor 2	***Management Skills***				***4.512***	***22.560***
SK10	Financial management		0.816			
SK13	Quality management		0.720			
SK11	Risk management		0.699			
SK6	Procurement and material resource management		0.673			
SK15	Negotiation		0.661			
SK12	Project management		0.655			
Factor 3	***Leadership Skills***				***3.322***	***16.610***
SK2	Leadership			0.812		
SK1	Strategic planning			0.796		
SK17	Software management			0.578		
SK3	Scope and schedule management			0.488		
Total						***62.065***

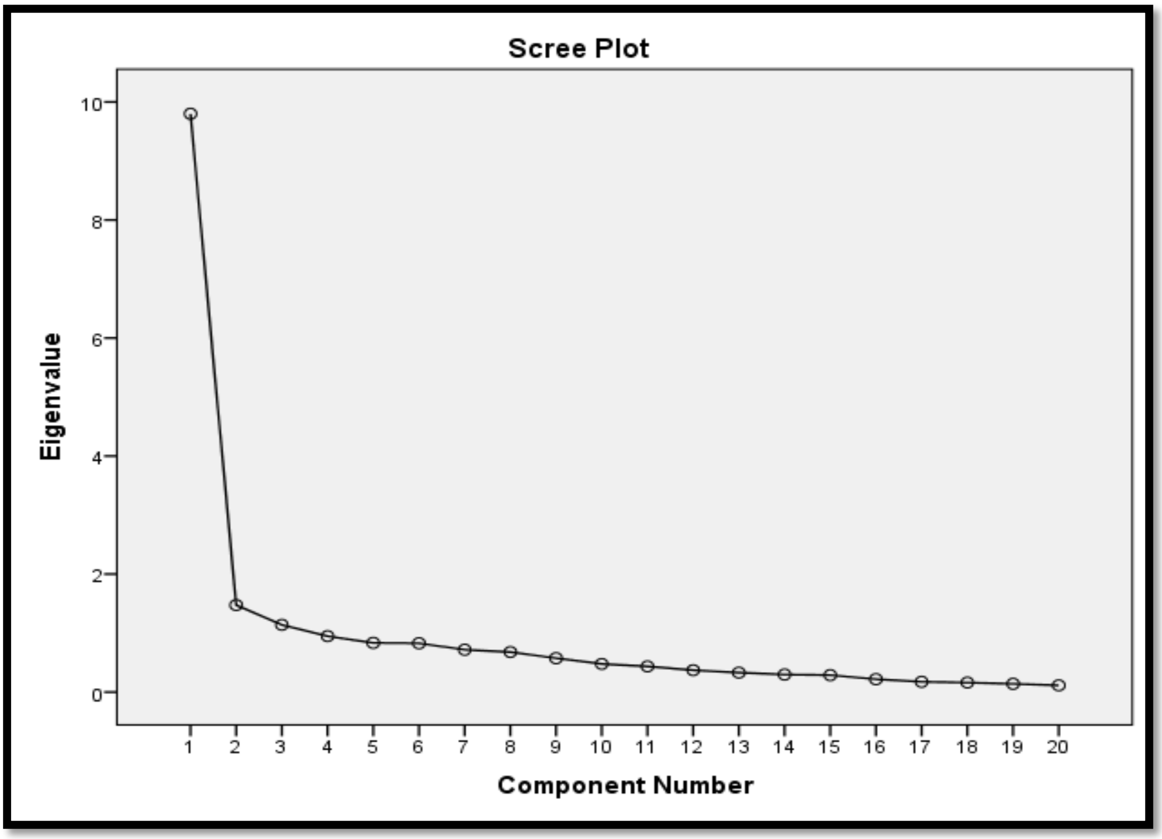


Figure 7. 1: Screed plot showing the three groups of SKI.

7.2.2 Skills and Knowledge Important to key Decision-makers in BI (Future)

Skills and knowledge required for task performance are very dynamic. They change over time due to many factors such as level of technology, cultural change, socio-economic factor, among others. In order to determine skills and knowledge that will be important to the key decision-makers in BI in future, respondents were also asked to indicate their opinions on the degree of importance of the listed variables in the next five years. The result will help determine if respondents foresee possible changes in the skills and knowledge already identified in section 7.2.1 over the next five years. Table 7. 5 presents the descriptive statistical analysis of the skills and knowledge important in the next five year. The mean values for the first variable (strategic planning) and the last variable (multi-tasking) are 3.55 and 3.18, respectively. The difference in their mean values is less than 0.5, which shows closeness among the variables. The result of the analysis shows that the five variables had a mean value of 3.40 and above, ranking them as the most important skills/knowledge in the next five years. The skills/knowledge are:

1. Strategic planning skills,
2. Leadership skills,
3. Teamwork/collaboration skills,
4. Change management skills, and

5. Scope and schedule management skills.

Table 7. 5: Ranked Item-Total Statistics: SKI (Future)

SKI Factors	SKI of Decision Makers in BI (Future)	Mean Ranking	SD
SKI	Strategic planning	3.55	.681
SK2	Leadership	3.50	.640
SK13	Teamwork/collaboration	3.47	.750
SK9	Change management	3.43	.760
SK3	Scope and schedule management	3.40	.646
SK17	Software management	3.36	.790
SK11	Project management	3.35	.747
SK12	Quality management	3.34	.811
SK20	Policy knowledge	3.33	.837
SK4	Communication	3.33	.794
SK7	Time management	3.31	.764
SK18	Motivation	3.30	.799
SK10	Risk management	3.28	.806
SK19	Critical thinking and Analysing	3.26	.824
SK5	Human resource management	3.25	.797
SK14	Negotiation	3.24	.794
SK6	Procurement and material resource management	3.23	.753
SK8	Conflict management	3.20	.863
SK19	Financial management	3.20	.874
SK15	Multi-tasking and organisation	3.18	.817

It is noteworthy that communication dropped from the list of the five highest-ranked most important skills/knowledge in the future (see Table 7. 1 and Table 7. 5). Another significant observation is the rise in the ranking of strategic planning from the fourth position to the first position. This reason for the rise might be because decision-makers are expected to be more informed over the next five years to participate in strategic planning activities. The rate of their consciousness and level of involvement in strategic planning is expected to increase over the next five year. The strategic planning skills and knowledge will ensure their full and effective participation in strategic decision-making during BI and increase in demand for more values for their money.

It is interesting to note that opinions on the position of leadership factor did not change with time. Regardless of the time factor, key decision-makers will still be playing the leadership role in decision-making. Teamwork/collaboration is still ranked as one of the most highly important skills/knowledge in the next five year, along with the ability to manage changes that are likely to occur.

7.2.3 Skills and Knowledge Important to key Decision-makers in BI (Training and Education now)

The analysis of important skills/knowledge in future (see section 7.2.2) revealed some paradigm shift in what will be considered important in the future. In preparation for this change, respondents were asked to indicate skills /knowledge requiring training and education now in order to meet the need of the future. Table 7. 6 presents the mean value and the standard deviation of the variables tested. The descriptive statistical analysis of the variables revealed that all their mean value falls within 3.40 and 3.10 on a 4-point Likert scaled. This result shows a high degree of internal consistency and reliability among the variables and removes the possibility of any outlier. Using the mean value, Table 7. 6 shows that the highest-ranked variables include:

1. Strategic planning,
2. Scope and schedule management,
3. Change management,
4. Communication,
5. Project management, and
6. Motivation.

Table 7. 6: Ranked Item-Total Statistics: SKI (Training and Education now)

SKI Factors	SKI of Decision Makers in BI (Training and Education now)	Mean Ranking	SD
SK1	Strategic planning	3.39	.733
SK3	Scope and schedule management	3.38	.688
SK9	Change management	3.36	.765
SK4	Communication	3.34	.761
SK11	Project management	3.33	.800
SK18	Motivation	3.33	.821
SK12	Quality management	3.32	.795
SK13	Teamwork/collaboration	3.28	.809
SK10	Risk management	3.26	.851
SK20	Policy knowledge	3.26	.906
SK17	Software management	3.25	.801
SK19	Critical thinking and Analysing	3.23	.831
SK2	Leadership	3.22	.863
SK6	Procurement and material resource management	3.21	.848
SK15	Multi-tasking and organisation	3.19	.817
SK5	Human resource management	3.17	.818
SK7	Time management	3.14	.879
SK14	Negotiation	3.14	.852
SK19	Financial management	3.14	.841
SK8	Conflict management	3.12	.852

In line with the position of respondents on skills/knowledge that will be important to decision-makers in the next five years, analysis of Table 7. 6 shows that respondents suggested that education and training should be focussed on most of the skills/knowledge identified earlier. Respondents suggested that decision-makers need to develop competencies in strategic planning, change management and, scope and schedule management through education and training for them to function effectively and efficiently in the nearest future. These skills/knowledge areas have earlier been identified as very important to decision-makers in the future. It is not unexpected that training and education are focussed on them.

7.3 Findings from the Interviews

This section presents the results of experts' responses from the interviews regarding the two questions raised above. It identifies the key decision-makers in BI. Skills and knowledge considered important to the key decision-makers now and in the future are also documented.

7.3.1 Key Decision-makers in BI

As stated in section 2.3.5, there are many stakeholders involved or affected by construction projects. The level of involvement and the degree to which they are affected varies considerably. In order to clarify the notion presented in some literature that classified all these stakeholders as decision-maker (Jin et al., 2017), this section seeks to investigate who the key decision-makers in BI are. Accordingly, participants in the interviews were asked to identify the key decision-makers in BI. Table 7. 7 presents the summary of the codes along with the number of codes and references for each code. Table 7. 8 cites some of the quotations in support of the identified codes while Figure 7. 2 shows a screenshot of key decision-makers from NVivo.

Table 7. 7: Summary of the Coding Scheme about key Decision-makers in BI.

Theme	Codes	Total No of Sources	No. of Codes	No. of Reference
Key Decision-makers in BI	Client/Employer	30	23	52
	Lead Designer/Architect	30	17	25
	Contractor	30	9	13
	Cost Estimator	30	1	2
	Director	30	1	1
	Facility manager	30	1	1
	Information/BIM manager	30	1	1
	Project Board	30	1	2
	The Industry	30	1	2

Table 7. 8: Examples of Quotations about key Decision-makers in BI.

Theme	Codes	Quotations

Key Decision-makers in BI	Client/Employer	*"the client is the key decision makers. At the end of the day, the clients have got the budget, the clients got the requirements, you know, you're there to fulfil the clients' requirements." BM4*
	Lead Designer or Architect	*"So, you see that the architect or the client is the one that is going to approve or whoever seems to be the lead designer is." BC5*
	Contractor	*"It depends on the contract. if it's a design and build contract then, it's a contractor." BM7*
	Cost Estimator	*"Ultimately it's still the lead design that will be the decision-maker, generally the architects, or the client, and those who cost." BC4*
	Director	*"So, as a critical decision maker for the project, you're the first one, the first layer of decision-making will come from the Directors." BM3*
	Facility manager	*"Then as much as the facility management is important. I think facility managers are the next before it comes to the contractor." CR1*
	Information/BIM manager	*"The information manager will be the key reporter. The client is always the decision maker. But yeah, the information manager is the person, not the project manager" BM11*
	Project Board	*"I don't think it's one person, and I think it's probably the Project Board. So, any critical decisions for the design of that building go through to the Project Board" CR2*
	The Industry	*"So, we are all the decision makers but, the big one to me is the industry, the lead designers, and the contractors." BM12*

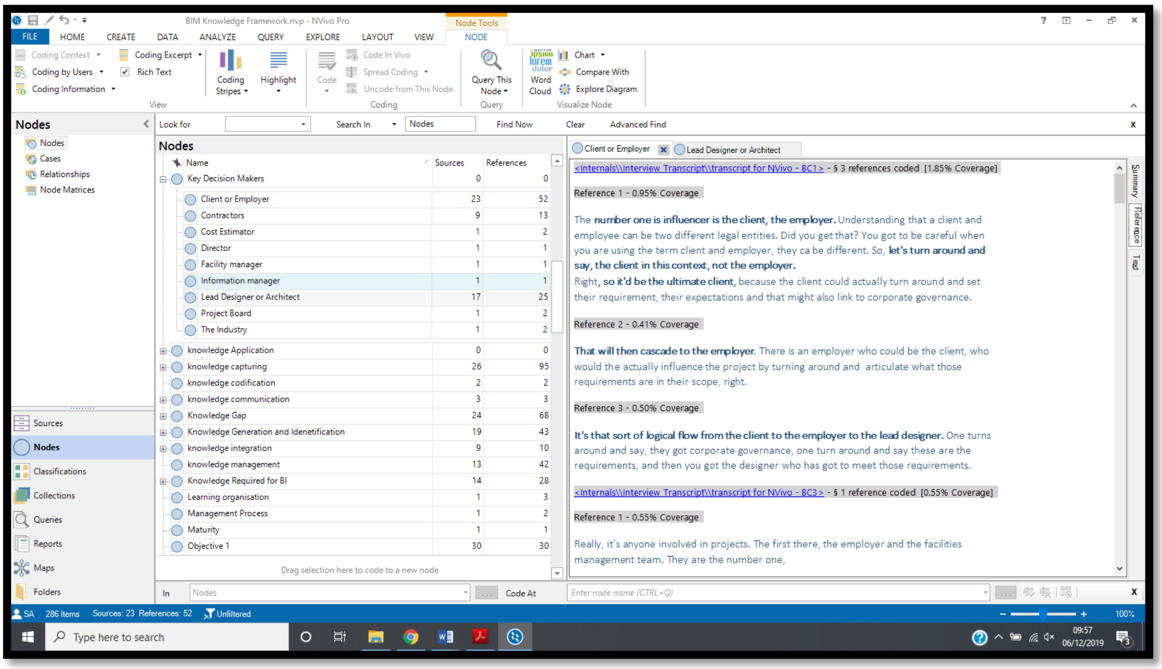


Figure 7. 2: Screenshot from NVivo of Key Decision-makers in BI

The analysis of the interview shows that majority of the respondents said the client is a key decision-maker. The client is sometimes referred to as the employer or the owner.

However, some of the respondents argued that the client might sometimes be different from the owner or employer, as stated by one of the BIM Coordinators:

"Understanding that a client and employer can be two different legal entities. Did you get that? You got to be careful when you are using the term client and employer, they can be different." BC1

In justifying the choice of the client as the ultimate key decision-maker, the respondents argued that the client is responsible for financing the project and set the requirements.

"At the end of the day, the clients have got the budget, the clients got the requirements, you know, you're there to fulfil the clients' requirements." BM4

"so, it'd be ultimately the client, because the client could actually turn around and set their requirement, their expectations and that might also link to corporate governance. There is an employer who could be the client, who would actually influence the project by turning around and articulate what those requirements are in their scope, right." BC1

"The clients are always critical because he provides the money needed. You get it? If you tell something and he doesn't want to pay for it. Definitely, client is important in the decision-making." CR2

"It will be the clients because it is the clients that will provide (EIR) employer's information requirements and that is where he or she will specify energy efficiency requirements."BM8

However, some respondents pointed out that the clients are usually not well-informed to articulate their needs. They often rely on the advice of the professionals, such as architects or cost estimators, to make decisions. The professionals, therefore, become advisers or influencers, to the key decision-maker. One of the BIM managers, who is an architect, observed that:

"Obviously, the client is the first one, but the client usually doesn't know what they want. So, as professionals, we will need to create the actual goal. So, it is the design team; probably I would say, that needs to be the critical decision-makers but then, basically this is saying we help, we basically, present the client with what they actually thought they wanted. So, I just say yes. We basically help the client make the decision." BM2

Similar position was expressed by a Cost Estimator who observed that:

"The key decision maker should be the client. Mostly, their decision-making is influenced by a wide range of people. In some instances, the architect becomes the kind of key, not necessarily key decision maker, but a key influencer." CE2

As advisers to the client, the professionals should listen to the client and avoid getting carried away by the influence on the client. One of the client representatives observed that the professionals, especially the architects, often forget that they are meant to work for the client. He said:

"Yeah. What I find with architects they often forget they work for you, particularly, yeah. So, we very regularly have to remind the architect that, you know, it's not just about designing a building which looks great and might win awards, it's about making sure what they designed meets our requirements, and isn't about creating a statement building, a building that works for what we want to do with it, basically." CR2

A BIM manager advised the architects to always listen to other stakeholders and mediate between the client and other professionals accordingly:

"The architect role should be to listen to all of them and to mediate between all of the needs between each craftsman" BM10

Although many of the respondents agreed on clients as the key decision-makers in BI, there are some minority differing opinions as documented in Table 7. 8. Most of those who expressed this dissenting view still agreed that clients are the key decision-makers. However, they argued that decision-making is a complex process requiring the collaboration of many professionals. The level of their involvement will depend on the nature of the project or type of contract. What can be deduced from the analysis of the interview is that the key decision-makers in BI are the clients. However, their decisions are usually influenced or informed by advice or support they get from the professionals such as the architects, cost estimators or engineers.

Having postulated the clients as the key decision-makers, some respondents called for empowerment of the client in terms of adequate skills and knowledge. A competent client will be a good decision-maker. Some of the respondents advocated that:

"I think it's worth saying that ultimately, we need better qualified clients within the industry and that's something that's really difficult to achieve because anybody with some money who wants to build something can be our client. They don't have to be developers and so how we train our clients to work within the industry is a tricky one." BM7

It is, therefore, important to investigate the skills and knowledge important to the key decision-makers in performing their role effectively. The next session of this chapter explores the important skills and knowledge required by the key decision-makers in BI.

7.3.2 Skills and Knowledge of Decision Makers in BI

In the previous section, clients were identified as the key decision-makers in BI. Professionals, such as architects, engineers, cost estimators, information managers, were also acknowledged as major influencers or advisers, whose professional advice guide the decisions of the client. The need to improve the competencies of the construction clients and their advisers to be able to make informed decisions, and meaningfully participate in the BI process was raised. Consequently, the interview participants were asked to identify important skills/knowledge required by the key decision-makers in BI. This section presents a summary of the analysis of the respondents' answers to the question, as shown in Table 7. 9 and Figure 7. 3.

Some of the codes include BIM and software management, communication skills, human resource management, knowledge of BIM standards and policies, leadership skills, domain knowledge and practical BIM experience, time management skills, team management and collaboration skills, and change management. Others include the ability to multi-task, strategic planning skills, quality management, organisation skills and knowledge, negotiation skills, financial management, and analytical skills. It is important to note that most respondents expect the key decision-makers to be competent in technical area like "BIM and software management" and "construction-domain knowledge and practical experience of BI" and "knowledge of BIM standards and policies" as indicated in the numbers of codes sources and references linked to these skills and knowledge (see Table 7. 9 and Figure 7. 3). Communication, leadership and human resources management top the "soft skills" identified by the respondents.

Table 7. 9: Skills and Knowledge Required by Key Decision-makers in BI

Theme	Codes	Sources	Examples of Quotations
Important Skills and Knowledge	Analytical skills	BD3, BM4, BM12	*"They have to be able to analyse problems. Problem analysis is very important." BM12*
	BIM Software management	BC4, BD2, BD3, BM1, BM12, BM7, BM8, BM9, CE1, CE2, CR2, IM2	*"First of all, you got to understand BIM as a system, you know. Excluding the technology, is going to understand what it is you're trying to achieve; you know." BM7* *"he needs to at least have a knowledge of some software platforms, okay, to allow BIM to coordinate the models produced by the design team, and ensure that there are no clashes, or unacceptable clashes." BM8*

	Change management	BC2, BC3, BC4, BD2, IM2, IM5	*"someone to stand up and push that change across the business is the important bit for me. Yeah, change management and a personal skill setup" BC3*
	Communication skills	BC2, BC3, BC4, BD3, BD4, BM1, BM11, BM2, BM4, CE2, IM3	*"Second to that is, the person is really friendly, able to communicate really well and communicates (with) different types of people really easily." BM11* *"generally speaking, the competencies they will have would be good communication skills, an eye for detail, obviously the ability to do 3D modelling." BM4*
	Domain Knowledge and Practical Experience of BIM	BC1, BD2, BM1, BM3, BM4, BM6, BM7, BM8, BM9, BM11, CE1, CE2, CR1,	*"you need to understand how projects is actually run from design through to construction into facility management." BC1* *"But I think the biggest thing the biggest attribute is knowing the information that you need." CE1* *"Then, there is the need for strong understanding of materials. Materials, Building Science and building physics." CR1*
	Financial management	BC1, BM6, CR1	*"Managing people and all the aspects of project management: financial management, construction management, those things that BIM management should have that those abilities and to know it." BM6*
	Human resource management	BC3, BC5, BM10, BM7, BM11, BM6, BM8, CE2, IM2	*"A good client has got that kind of interaction with people,"BM7* *"He has to have good people skills, people's management skills, and the ability to assess the competence of his team. First of all, he needs to know how to choose the right people for the job, that's the first thing." BM8*
	Leadership skills	BD3, BD4, BM1, BM10, BM12, BM3, BM8, CR1, IM2	*"And good leadership I believe is necessary. And also, clear description of roles and responsibilities." BM1* *"For me, the skills and knowledge for person or company, for me they have to have leadership qualities, very important." BM12*
	Multi-tasking	BC4, BM4, BM5, BM6, CE2, IM4	*"With small companies is issue with being committed to not one thing as you will want, you will be doing multiple things, multiple tasks It is very difficult to drive things." BM6*
	Negotiation skills	BC1, BD2, BM12, CE2	*"Two key soft skills are: both good clients have to persuade and negotiate. Those soft skills but I don't think they are necessarily specific to BIM enabled project." CE2*

	Organisation skills and knowledge	BM12, BM3, BM8, BM9	*"Organizational skill is also very, very important" BM12* *"Second thing is, it needs to be organized and set the right task for the team." BM8*
	Project Contract management	BC1, BM6, IM4	*"honestly speaking, there needs to be more project management, and probably more contractual awareness for those particular roles." BC1*
	Quality management	BM12, BM2, BM3, IM2	*"And then they have to be quality oriented. If they don't look for quality, it is very difficult to find the best solution for the project. If we're not quality, forget about the project." BM12*
	Risk management	BC1, IM5	*"So, one of those might be risk management, risk management process. If you go into our main contractor, it's all about risk management or risk opportunities management." BC1*
	Knowledge of BIM standard and policy	BC2, BC3, BC4, BD2, BD4, BM11, CE1, IM3, IM4	*"I think to have that skill set, you need to have a background in almost what everything is: what the standards are, what a product should look like at each stage." BC4* *"And on top of that, the standards and the BIM level standards and specifications." BM11*
	Strategic planning	BD2, BD3, BM2, BM4, IM2	*"But as you go more up to the senior BIM managers and the regional BIM managers, they're going to be more strategic." BM4* *"So, you can think that a little bit more strategically rather than being focused on the narrow technology and tactical activity." BD3*
	Team management and Collaboration	BC3, BC5, BD3, BM2, BM5, IM5	*"So, that collaboration skills and being able to unlock or enhance collaboration within people and facilitate it. That's a really important skill." BD3* *"And then, for me, one very, very important skill that we tend to lack is collaboration skill. Collaboration, like, how to work together." IM5*
	Time management	BC2, BC3, BC4, BD1, BM12, BM2, BM6, IM4	*"So, to me, the factors are: cost efficiency and time." BM12* *"It's about giving the employees time to explore basically the new technologies, new way of working by themselves," IM4*

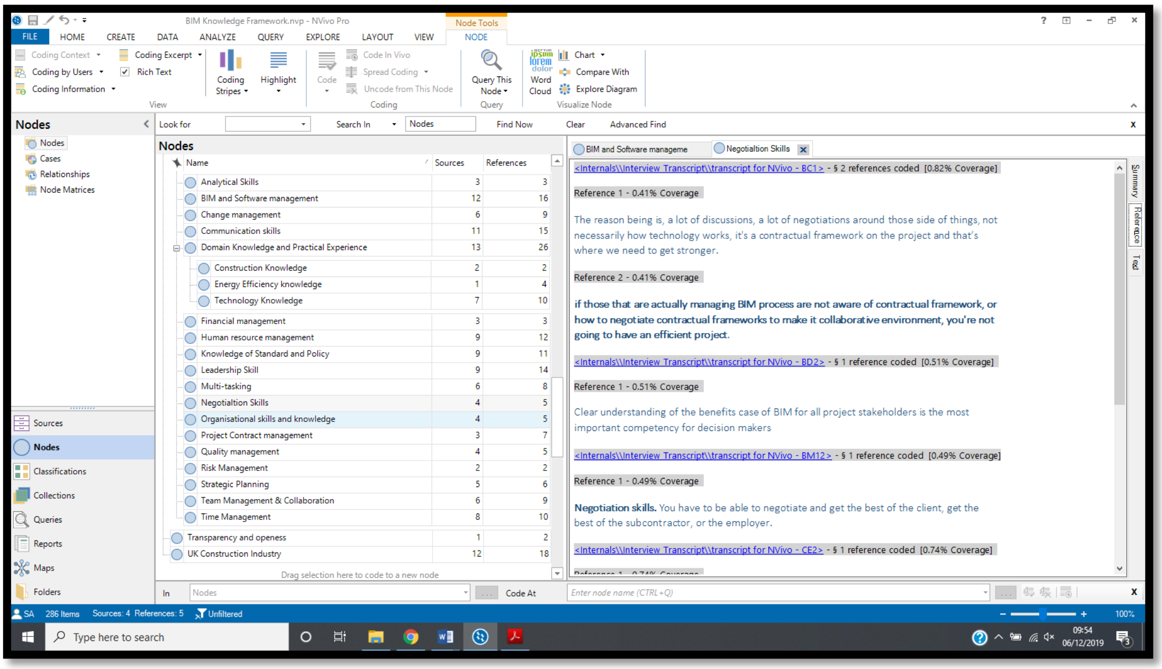


Figure 7. 3: Screenshot from NVivo of Skills/Knowledge Important to Key Decision-makers in BI

7.4 Discussion of Important Skills/Knowledge to key Decision-makers in BI

Based on objective 5 established in chapter 1, this section seeks to develop a skills/knowledge inventory of key decision-makers in BI. Towards achieving this objective, both quantitative and qualitative methods were used to collect data. Results of the analysis of interviews on skills/knowledge considered important to the key decision-makers in BI (see section 7.3.1) revealed that majority of the respondents agreed that the key decision-maker is the client. However, it was suggested that the client often relied on the professional opinions of other stakeholders for their decisions. The need to increase their competencies through adequate training was advocated so that they can make more effective decisions during BI. Non-involvement of clients in decision-making is a major problem in construction projects (Althynian, 2010). Their involvement in decision-making reduces problems such as poor quality, design failure, project abandonment and litigation (Bambang, 2017). Every successful project starts with the client who usually initiates the project and employs professionals to actualise his project (Xu & Miao, 2010).

Statistical analysis of 20 variables derived from the literature review shows that respondents consider all the skills/knowledge as highly important, with a minimum mean value of 3.10 on a 4-point Likert scale. A close evaluation of the results of important skills/knowledge, now and in future, shows that all the most important skills/knowledge in future were equally considered highly important now. The six highest-ranked important skills/knowledge from the survey analyses will be discussed and triangulated with the opinions expresses by the BIM experts during the interviews.

1. Teamwork/Collaboration

This factor refers to the ability to work in collaboration with other team members or stakeholders during BI. It includes the ability to manage a group of people from diverse background and make them work together as a team to achieve a common purpose via interactions, knowledge sharing, and coordinated activities (Jassawalla & Sashittal, 1998). The construction industry has been described as fragmented (Egan Report, 1998 and Latham Report, 1994). The advent of BIM has not totally changed the fragmented nature of the industry, despite the benefits recorded in project coordination and improved productivity (Lu et al., 2014). Çıdık et al. (2013) argued that there is no correlation between the increase in the use of BIM tools alone and collaborative culture among the BIM user in the industry. They argued that the use of BIM does not automatically transform into collaboration and that there no clear evidence that those using BIM are necessarily collaborating on projects delivery. Although some authors argued that effective inter-organisation collaboration and teamwork could lead to better project outcome, facilitate innovation, improve competitive advantage, and increase stakeholders' satisfaction (Lu et al., 2014; Amabile et al., 2001; Dyer & Singh, 1998). However, practice-based evidence shows that current BI has only improved design coordination among design team with no significant change in the level of collaboration with other components of the construction process (Cidik et al., 2013, Homayouni et a., 2010). This position underscores why respondents identified collaboration/teamwork as the topmost important skills/knowledge for decision-makers in BI.

Many of the interviewees agreed that collaboration/teamwork is one of the most important skills/knowledge required by the decision-makers while condemning the present poor collaborative state within the industry. According to an information manager, hierarchical structure within the industry impacts negatively on collaboration.

"For me, one very, very important skill that we tend to lack is collaboration skill. Collaboration, like, how to work together. We are so used to the hierarchical power structure that we are not very good. We're not so trained at being collaborative. And this affects all levels, from how you have a meeting, which languages you use, and how do you hold the space for others to participate? And the whole collaboration sphere is very poor at the moment in our industry." IM5

Collaboration among project team was regarded as an important soft skill capable of unlocking difficulties through networking and talking to others within communities of practice as expressed by the interviewees:

"And so being sort of community or network focused and so being willing to talk to that network and to the team that you've got. So, that collaboration skills and being able to unlock or enhance collaboration within people and facilitate it. That's a really important skill. The sort of collaboration skills and facilitation is something that's really important. Lot of it just is awareness of the other people and the world around you, and the sort of ability to be a bit humble and recognize that you don't necessarily have all the answers, but confident enough to know that nobody else do." BD3

"I think it is much more about soft skills than hard skills. I think it is About collaboration rather than anything, rather than hard skills." BD1

This position was in line with the earlier findings that a high level of collaboration/teamwork is critical to project success and effective decision-making in construction (Lu et al., 2013; Shelbourn et al., 2007; Jassawalla & Sashittal, 1998). This study also confirmed that collaboration/teamwork is the most important skill/knowledge required by key decision-makers in BI. The factor analysis grouped teamwork/collaboration, communication, motivation, critical thinking and analysis along other factors under the soft skills and knowledge competency factors.

2. Leadership

Several studies have identified leadership skill as critical to decision-making and successful project delivery (e.g. Khamaksorn, 2016; Odusami, 2002; Egbu, 1999). According to Spatz (1999), leadership involves bringing out the best in others and helping them to channel their energies towards achieving common goals. Effective leaders build teams and facilitate cooperation and collaboration among the team through open communication, honesty, respect, and motivation (Heldman, 2018).

Skills/knowledge were generally classified into technical and soft skills. Technical skills have to do with the use of technologies relevant to BI, while soft skills/knowledge are management related. Some of the interviewees identified leadership skill as one of the most important soft skills/knowledge required for effective decision-making that can lead to successful project delivery.

"For me, the skills and knowledge by decision-makers, the person, for me they have to have leadership qualities, very important. Organizational skill is also, very, very important. Negotiation skills. You have to be able to

negotiate and get the best of the client, get the best of the subcontractor, or the employer. They have to be able to analyse problems." BM12

"There are other soft competencies that I think can generally for everything to be successful, like leadership, you know, leadership is so critical. So, those are soft skills. I acknowledge all of those soft skills. you might find them in many places. So, broadly, I say soft skills are important." CR1

The study concluded that leadership skills are very important to decision-makers in BI. This conclusion is corroborated by previous studies Ozorhon & Karahan (2016); Wong (2005); Egbu (1999), emphasising the criticality of effective leadership to project success. Leadership is one of the three major competency factors that emerged from the factor analysis.

3. **Communication**:

Similar to collaboration and leadership skills, effective communication ranked highly important for effective decision-making in BI. Communication skill, an act of giving and receiving information, involves listening, speaking, observing, and empathizing. Sebastian (2007) identified effective communication among project stakeholders as critical to decision-making. Davies et al. (2015) highlighted communication as the most important soft skill required by BIM practitioners in New Zealand. Effective communication is directly related to negotiation and persuasion skills. Good communication requires that the message must be explicit, clear, and complete (Heldman, 2018). Though not peculiar to BI alone, every good client should be able to clearly communicate the project objectives to other stakeholders and negotiate the budget.

"A good client has got that kind of interaction with people, the understanding of different level of objectives, the ability to kind of communicate clearly, kind of coherently with people. Two other key soft skills are: good clients have to be able to persuade and negotiate. Those soft skills but I don't think they necessarily specific to BIM enabled project." CE2

Most of the interviewees are unanimous on the importance of good communication for effective decision-making and successful project delivery. The means of communication can be oral, written or graphical using drawings and 3D models. The BIM environment is not meant for people who are not friendly and do not like to communicate:

"So, you actually have to have a lot more communication. We use a lot of platforms where we just communicate, communicate and capture decision-making. So, it's not an environment really for people who do not like to communicate. So, when that happens, typically knowledge grows." BM2

“the person should really be friendly, able to communicate really well and communicates with different types of people really easily. So, you can then use the experience that
isn't information, people and processes, nice to people and friendly.” BM11

“So, it's having the skill to be able to communicate with lots of people.
I think, actually, be able to effectively communicate your ideas, actually,
and also, be able to be honest with other different types of people is also,
you know, you have to be able to say, ‘I don't think’, for instance,
this particular team I work with is engaging properly with BIM processes” IM1

Communication is regarded as one of the highly important interpersonal skills, along with collaboration and teamwork.

“Yeah, change management and a personal skill setup: communication,
collaboration, teamwork, interpersonal skills are the most important things.” BC3

“Seriously, communication skills, interpersonal skills and also,
you know, good theoretical knowledge about BIM.” BM1

“generally speaking, the competencies they will have would be
good communication skills, an eye for detail….”BM4

The positions expressed by the interviewees corroborated the findings from previous studies (e.g. Heldman, 2018; Kwofie et al., 2015; Egbu,1999) that identified effective communication as critical to successful project delivery and decision-making and reinforced the opinions of practitioners in the survey. Communication skill appeared under the soft skills in the factor analysis result.

4. Strategic Planning:

Strategic planning involves clear defining and planning the goals and objectives to be achieved from implementing BIM on a project as one of the key tasks at the predesign phase. Preparation of a robust strategic project brief is one of the two outputs of BI at the pre-design phase (Sinclair, 2019). The brief preparation is preceded by a strategic appraisal of the business needs of the project and the possible associated risks involved in actualising the project (Heldman, 2018). Many studies have linked decision-making with strategic planning (e.g. Khamaksorn, 2016; Hwang and Ng, 2013; Choban et al., 2008).

One of the BIM managers interviewed argued that the decision-makers and the BIM leader should write a company-wide BI strategic plan. Another interviewee observed that there had been a shift from technical competencies towards strategic competencies among the senior managers whose responsibility is to develop the organisation BI strategy.

"But as you go more up to the senior BIM managers and the regional BIM managers, they're going to be more strategic. So, I think there's definitely a shift in competencies; a shift from the more project based practical to the higher levels which are more strategic and less project practical." BM4

"BIM decision makers, BIM lead will have to write a standard, a company-wide BIs strategic plan. He has to have good people skills, people's management skills, and the ability to assess the competence of his team." BM8

A good decision-maker must be a good strategist, who must be visionary with a good knowledge of hindsight. The position expressed by the stakeholders aligned with the position of Succar and Sher (2014) who identified strategic planning, leadership and organisation management as the three important competencies within managerial competency set for BIM stakeholder. However, the factor analysis of this studies categorised strategic planning as one of the factors under leadership skills along with leadership, scope and schedule management, and software management.

5. Scope and Schedule Management:

Defining the project's scope is one of the key tasks and activities at the strategic stage of the pre-design phase. The clients, in conjunction with his team, should clearly define the scope in terms of cost, responsibilities, and BIM deliverables throughout the project lifecycle. Schedule and scope management requires that all the stakeholders are actively involved and properly informed about the progress of the project through effective communication. The essence of scope and schedule management is to ensure that projects are delivered within the approved time and budget. Accordingly, the key decision-makers are expected to be adequately skilled and well-informed about scope and schedule management.

For effective BIM management, one of the BIM managers argued that a good decision-maker must possess many project management skills. He likened the skills/knowledge required to 'T' shape where the top represents broad-based general management skills, and the tail stands for deep technological skills. He identified scope and schedule management as very important aspects of project management.

"I was told times long ago that the best person who would drive the BIs should be somebody, which is called 'T-shaped' person. So, in terms of BIM management, he won't just be BIM software alone. There will be some other management aspects. Managing people and all the aspects of

project management: financial management, construction management, scope management, schedule management those things that BIM management should have that those abilities and to know it. And there's a 'T' shape, that 'T' which goes down, it has to be someone who knows quite well about what's going on with the technology. So, in terms of cases changing is so quick. You have to be really in depth of technological information." BM6

This submission agrees with the position of Heldman (2019), who argued that a project manager is like a small-business owner who needs to know about every aspect of management. The factor analysis, however, aligned scope and schedule management skills under the leadership competency factor along with strategic planning and software management.

6. Change Management:

BIM is regarded as one of the disruptive technologies within the construction industry that has brought significant change to the working process. The changes that come with BIM affect inter-personal relationships, roles and responsibilities, development and knowledge communication, development of new routines and ways of working (Bosch-Sijtsema & Gluch, 2019; Leonardi & Barley, 2010). The ability to manage changes that comes with the advent of BIM was identified as important skills/knowledge to the key decision-makers in BI.

Succar et al. (2013) suggested the development of a well-defined approach to identify resistance to change or change saturation that can occur during BI as an important individual BIM competency. Managing change involves people, process and organisation culture (Gillies & Howard, 2003). One of the interviewees argued that ability to push for change across the business and question the status quo is a more important skill/knowledge for the key decision-makers than knowing BIM.

"So, the ability to go in and question decisions, the ability to come on the Stage and tell people how they should be doing it, the ability to affect change within an organization. So, I think, for me, those things, this specific change management, is a much bigger skill to have than knowing BIM." BC3

"So, it's that change management, changing the culture, actually influencing that across the business. So, the knowledge, BIM knowledge should be easy, but it's really that personality, have someone to stand up and push that change across the business is the important bit for me. Yeah, change management and a personal skill setup: communication, collaboration, teamwork, interpersonal skills are the most important things." BC3

Effecting and managing positive change required strong will and character as people are naturally resistant to change. Changing organisational culture and people's opinion is not an easy task; hence, the need for self-confidence and determination to push for change.

"Yes, right for the BIM management to admit informed decision I think that you need to have a strong character because you need to make decisions without people, you need to make them on your own, you need to change other people's opinions, you need to help them understand new processes. So, you need to have the confidence as well." BM3

The opinion expressed by the interviewees corroborated the survey findings and aligned with previous findings (e.g. Bosch-Sijtsema & Gluch, 2019; Leonardi & Barley, 2010). The study concludes that the ability to manage changes is an important skill for decision-makers, especially in dynamic organisations like construction, where people change frequently, and processes methods vary. The result of the factor analysis categorised change management along with policy management, time management, human resource management under the soft skills and knowledge competency factors. This may not be unconnected with the fact that BI involves change in policy and management of human resources over a period of time in a soft and subtle way.

7.5 Chapter Summary

In fulfilment of the fifth research objective, this chapter explored and investigated the skills/knowledge important to BI's key decision-makers. The chapter started by identifying the key decision-makers in BI as the Clients/Employers, with the architects, engineers, and contractors' support. The factor analysis of the skills/knowledge important to BI decision-maker (now) categorised the factors into three groups: managerial skills, soft skills and leadership skills. The data's descriptive analysis revealed that six of the skills/knowledge identified from the literature were rated highly important to key decision-makers in BI by both participants of the interviews and questionnaire respondents. The most important skills/knowledge are represented in Figure 7. 4.

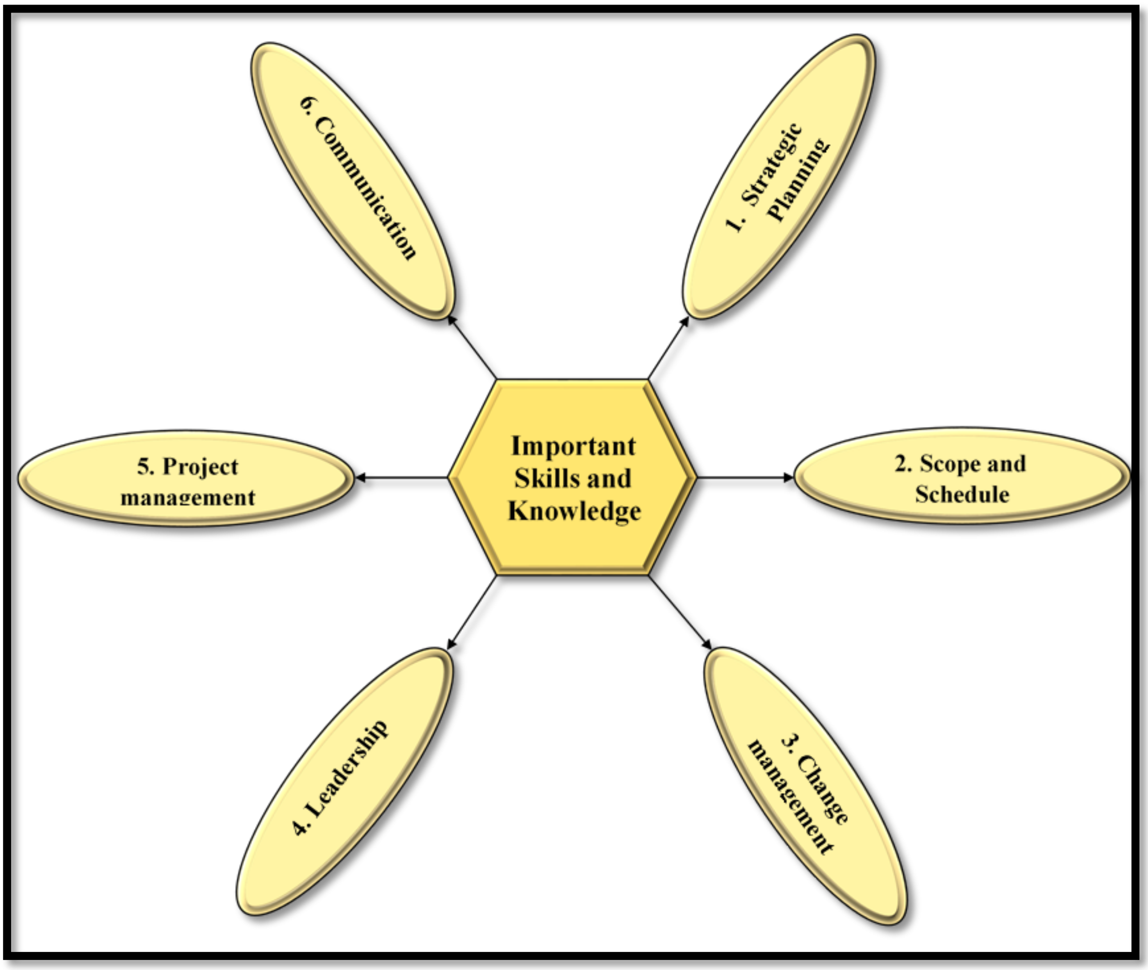


Figure 7. 4: Most highly important skills/knowledge to key Decision-makers in B

CHAPTER 8: DEVELOPMENT OF BIM-KNOWLEDGE (BIM-K) FRAMEWORK

8.1 Introduction

The central aim of this study is to develop a "BIM-Knowledge" (BIM-K) framework that will integrate EK into BI for improved decision-making in BIM projects (section 1.4). The literature review in chapter two culminated in developing of a preliminary framework that serves as the bases for developing constructs that were empirically explored in chapter four to chapter seven, based on mixed-methods research strategy established in chapter three. This chapter seeks to update the preliminary framework in line with the key findings from the data analysis obtained from the field. The chapter presents a refined conceptual BIM-K framework for integrating EK into BI with explanations of its components. Section 8.2.2 explains how the framework could be used with a complementary diagram, while section 8.2.3 provides additional guidance on how to implement the framework in a BIM project. Given the limitations arising from the COVI-19 pandemic lockdown, an attempt was made to validate the framework, and the validation outcomes were used to refine further the framework and the complementary diagram in section 8.3. Section 8.4 presents a summary of the chapter.

8.2 Development of the Conceptual BIM-Knowledge (BIM-K) Framework

This section provides explanations for the development of the proposed BIM-Knowledge (BIM-K) framework. The development of the conceptual BIM-K framework is based on the triangulation of findings from three sources:

1. Findings from the review of extant literature,
2. Findings from semi-structured interviews conducted with 30 stakeholders who have been involved with BI within the UK construction industry, and
3. The findings from analyses of the questionnaire survey from 107 respondents across the UK construction industry.

An explanation of the conceptual framework, linked with discussion and implementation guidelines in practice, is provided in the subsequent subsections.

8.2.1 Explanation of the Proposed Conceptual BIM-K Framework

As stated in the previous section, the proposed conceptual BIM-K framework (Figure 8. 1) is an updated version of the preliminary framework developed in chapter two (see Figure 2. 20) based of empirical findings. The conceptual BIM-K framework can be explained based on the three main components: 1. The BIM-K Core, which consists of three concentric circles; 2. The SKI, which consists of the skills/knowledge important to the framework's users (decision-makers in BI); and 3. The Output, which is the BIM building project resulting from improved decision due to integration of EK into BI. Detailed explanation of the constituents of these components of the framework are as follow:

1. **The BIM-K Core**: The core is the foci-point of the framework. It consists of three layers of concentric circles: the integration layer, the KM process layer and the layer of impacting factors. The integration layer is the innermost circle, the centre of activities where the integration of EK into BI occurs. Within the integration layer, EK regarding BI tasks and activities at different phases of the building project (such as design, construction and operation phases) will be integrated into BI decisions regarding tasks and activities right from the beginning of the project. The key BI tasks and activities requiring integration of EK for improved at different phases of the project lifecycle have been discussed in section 4.3.2 to section 4.3.5. Examples of such tasks and activities include preparation of concept, developed and technical design at the design phase; resolution of design queries from construction sites during the design phase; updating the 'as-built' model with information from the post-construction phase, and making effective decisions regarding tasks and activities like these requires in-depth 'human judgement' rooted in years of EK. While data/information about the project is stored in a Common Data Environment (CDE) as the project repository, the EK required to make informed decisions, using the available BIM-based information resides in the decision-makers. The required EK (such as knowledge best practices; lessons learned from past mistakes; creative ideas and suchlike) can be sourced and acquired from years of actual participation in BIM projects, knowledge from research conference, communities of practice, training and skill acquisition; knowledge from brainstorming and group discussions on BI (section 4.3.1). EK from previous projects by different project's stakeholders could be brought forward to enrich BIM-based information, thereby enhancing decision-making regarding BI tasks and activities within a given context.

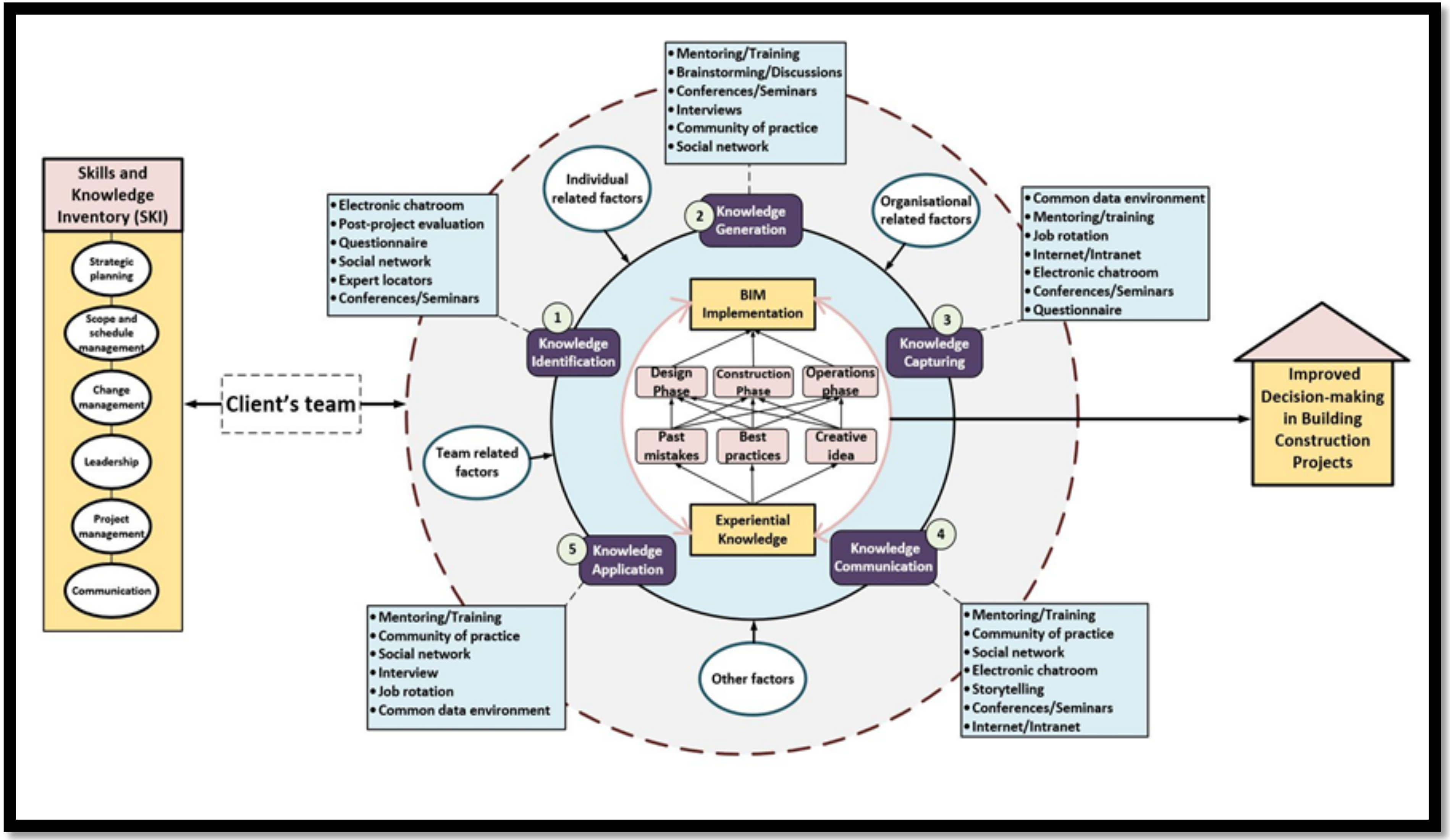


Figure 8. 1: Proposed Conceptual BIM-Knowledge (BIM-K) Framework

The second layer of the concentric circles consists of five KM processes meant to facilitate integrating the EK into BI. The five KM processes model was adapted from the CEN framework after a comprehensive literature review on KM processes (see section 2.5.2). The five KM processes form the basis for developing the KM process map for this study (see Section 5.4, Figure 5. 1). These KM processes are knowledge identification, knowledge generation, knowledge capturing, knowledge communication and knowledge application. Knowledge identification helps identify the EK knowledge required for specific BI tasks and activities at a particular phase of the project, people with such experience and sources of the EK. Knowledge generation involves the process of creating new knowledge from existing information through internalisation. New knowledge can also be sourced and acquired from the sources previously identified to improve the decision-making process at any phase of the project.

The generated knowledge will need to be captured and 'stored' appropriately, given the nature of EK. Subsequently, the EK can be communicated to those who need it to transfer or share it for decision-making. Once the knowledge is communicated appropriated, it can then be integrated by applying it to improve decisions. Upon making the decision, new knowledge may be identified in the form of a novel application of existing knowledge in a different context, leading to continuous learning. The whole essence of KM process is to make the required knowledge available to those who need it, when they need it, where they need it, and in the form, it is needed. It is important to state that this is not always a straightforward process. The process can be looped such that a generated knowledge may have to be applied immediately without following this idealistic process.

Nevertheless, the process provides a form of framework for the integration process. Each of these processes is supported by a list of appropriate KM tools and techniques, depending on the context of the application of the process (see sections 5.2 & 5.3). The tools and techniques also facilitate the KM process. For example, interviews, expert locators, and CVs can help identify people with EK while mentoring, communities of practice and brainstorming can help with the generation of knowledge and creative ideas. The choice of tools and techniques and the KM process could be impacted or influenced by different factors. Accordingly, these factors constitute the third the last layer of the BIM-K core.

The third layer of the core circles contains factors impacting on the effective integration of EK into BI. These factors can either positively or negatively impact the integration. The factors were grouped into four: individual-related, project team-related, organisational-related, and other factors (see section 6.4). Individual-related factors refer to those that can either encourage or discourage individuals working on a project to freely integrate their EK into BI to improve a BIM project's decision-making. According to findings from this study, the level of trust among individuals working on a project, their level of involvement in the decision-making process, the level of face-to-face interaction, and individual's communication skills are the major factors that can impact on individual's participation in the integration of EK into BI for improved decision-making in BIM project. Similarly, the open and collaborative discussion among project team members, a knowledge-oriented culture, and team members' motivation for knowledge integration were regarded as the critical team-related factors impacting effective integration of EK into BI.

On the other hand, leadership support and commitment to the knowledge integration process, an organisational culture that encourages integration process, and transparency and openness in the organisational decision-making process are leading factors that can impact the integration of the process. Other factors include an adequate financial budget for the integration process, a legal framework that protects people and firms involved in knowledge integration and procurement method adopted for the project. A framework of highly impactful factors in each group was presented in Figure 6. 7. These factors should be carefully considered while undertaking BIM projects as they can drive or inhibit the integration of EK into BI.

2. **The SKI:** The second component of the framework consists of an inventory of skills and knowledge important to BI's key decision-makers. The literature review and interview findings revealed that clients are the key decision-makers in BI (see section 7.3). It was also suggested that most clients are not knowledgeable enough to make informed decisions alone, thereby relying on advice from professionals who constitutes the stakeholders. Accordingly, this study seeks to develop a set of

skills and knowledge important to BI's decision-makers now and in the future. After a thorough literature review on skills and knowledge important to BI decision-makers, a list of 20 most frequently cited skills and knowledge in the literature (see Table 2. 12) was compiled and converted to a questionnaire survey. The statistical analysis of the factors indicated that they are all essential skills now and, in the future, (see section 7.2.1 – 7.2.3). Analysis of the interviews data confirmed the importance of these factors to decision-makers (see section 7.3.2). The important skills and knowledge now were grouped into three using factor analysis: management skills and knowledge; soft skills; and leadership skills. The six highest-ranked important skills/knowledge (see Figure 7. 4) were included in the framework. The SKI included in the framework include teamwork and collaboration, leadership, communication, strategic planning, scope and schedule management, and change management. Decision-makers in BI who want to leverage EK to improve their decision-making should develop their competences in these areas.

3. **The Output:** The whole essence of integrating EK into BI is to help improve the decision-making process regarding critical tasks and activities in BIM projects. The critical BI tasks and activities requiring improvement through the integration of EK at this phase include establishing realistic project scope and BIM deliverables; determining actual BIM competencies of the project teams, developing achievable project goals and objectives, identifying valuable business case for the client, and defining clear roles and responsibilities for all stakeholders (see section 4.3.2). Although existing BIM processes, as contained in UK BIM Framework ISO 19650, have significantly improved the quality of information used to inform decision-making about these tasks and activities within the industry. However, the human-centric judgement, based on EK, that is required to make improved decisions regarding these tasks and activities is still yet to be fully and effectively captured and integrated into the BI process. Moreover, according to Crotty (2016), the construction industry will continue to rely on professional with experience to make many decisions in the next foreseeable years. While these professionals will be using high-quality information in BIM models, they will rely on their EK to make decisions and judgements. Existing information-rich models are yet to acquire the power of judgement and decision-making (Crotty, 2016). In line with Sinclair's (2019) submission, a successful integration leading to

improved decisions regarding these tasks and activities should produce two vital outputs: A Robust Project Brief and Collaborative Project Teams.

After explaining the proposed conceptual BIM-K components, the next subsection will be dedicated to explaining the linkages between EK and BI towards practical implementation of the framework in BIM projects. The framework and the linkages were sent out to some of the interviewed experts during data collection to participate in the validation process virtually. The validation outcomes were used to refine the framework and the linkages, as explained in section 8.3.

8.2.2 Linkages Between EK and BI in the Conceptual BIM-K Framework

This section explains the link between key concepts in the BIM-Knowledge framework to facilitate the framework's practical implementation. EK refers to experiences and insights learned from direct participation in BI, such as lessons learned from mistakes made from past projects, best practices and creative ideas. Figure 8. 2 is a schematic diagram that further explains linkages between the concepts in the framework's inner cycle, where the integration takes place, to facilitate practical implementation.

EK such as experiences gained from past mistakes, best practices and creative ideas about BI tasks and activities from previous projects would be integrated to improved decision-making in BIM project. The key BI tasks and activities at various phases of the project lifecycle regarding which EK could be required have been documented in section 4.3. For example, the key BI tasks and activities requiring integration of EK at the pre-design phase include establishment project scope and BIM deliverables, determination of BIM competencies of project teams, development of project goals and objectives, identification of client business case, and definition of roles and responsibilities of various stakeholders (section 4.3.2).

The integration, as stated earlier, is facilitated by KM process using appropriate KM tools and techniques. Decision-makers in BI, including clients and all other stakeholders, will make decisions regarding these BI tasks and activities collaboratively, leveraging their EK. An example of guidelines of how to integrate EK into BI (i.e., implement the BIM-K framework) on a building project is presented below.

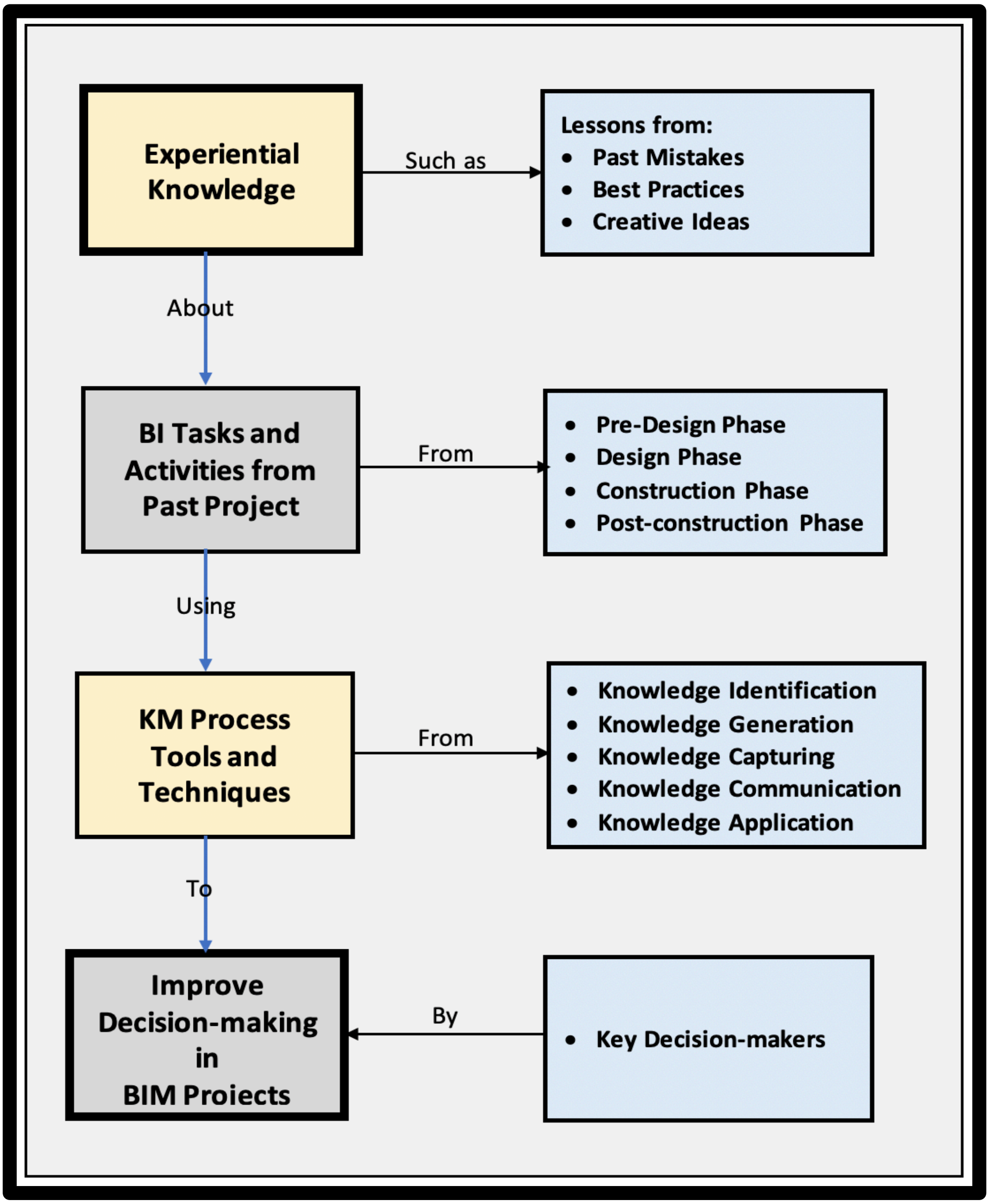


Figure 8. 2: Linkages between EK and BI for Practical Implementation of the Framework

8.2.3 An Example of Practical Implementation of the Framework

Based on the above discussions, an example of guidelines to help decision-makers understand how to improve BI tasks and activities decisions by integrating EK into BI using the KM processes BIM project.

The following steps explain how to use the KMP adopted in section 2.5.2 for the study to EK into BI decision-making process.

<u>Guidelines for Integrating EK into BI using KM Process</u>

1. **Start:** A Client desires to construct a building using BIM.
2. He wanted to make a critical decision regarding a BI task/activity
3. Example of the BI tasks: Establishment project scope and BIM deliverables
4. The client assembles a project team (comprising client or his representatives, design team, main contractors)
5. The project team is presented with the BI task/activity requiring decision. To make effective decision regarding the BI task/activity, the team will follow the following KM process to capture and integrate their EK into BI.
6. **Knowledge Identification**
   - What is EK required to deliver the BIM project?

     6.1 Identify the required EK to deliver the project.

     6.2 Identify the available knowledge within the team.

     6.3 Map out the knowledge gap.

     6.4 Employ appropriate tools and techniques to identify the required knowledge.

7. **Knowledge Generation**
   - Can we generate the required EK?

     7.1 Create the knowledge from within using appropriate tools and techniques, or

     7.2 Acquire the knowledge from outside using appropriate tools and techniques

8. **Knowledge Capturing**
   - How can we preserve the generated knowledge?

     8.1 Capture the generate knowledge using appropriate tools and techniques

     8.2 Store the generated knowledge using appropriate tools and techniques

9. **Knowledge Communication**
   - How can we disseminate the captured knowledge to the point of need?

     9.1 Transfer the capture EK using appropriate tools and techniques

     9.2 Share the capture EK using appropriate tools and techniques

10. **Knowledge Application**
    - What to do with the communicated EK?

      10.1 Adapt the knowledge to the immediate context

      10.2 Utilise the knowledge to improve the decision

10.3 Evaluate the impact of EK on the decision

11. Identify new EK gained based application of the knowledge generated within the new context for possible reuse and continuous learning

12. In doing all these, they will carefully consider various factors that might impact the process's effectiveness

13. The decision-makers' skills and knowledge (competencies) should be continuously updated using the SKI for effective decision-making.

To validate the suitability of the proposed framework for practical implementation in practice, some form of validation was done using expert validation approach. The next section provides details of the validation process and how the outcome of the validation was used to refine the figure for clarity.

8.3 Validation Process and Outcomes

The preceding sections explained the proposed framework, described its linkages and gave an example of its implementation in practice. This section describes the validation process and the subsequent refinement to the framework. The initial full validation could not be done through focus group discussion because of the national lockdown arising from the COVID-19 pandemic. Nevertheless, the framework was still validated through virtual meetings with some of the industry experts who had earlier agreed to participate in the framework's validation during the data collection process. The framework (Figure 8. 1) and the linkage diagram (Figure 8. 2), accompanied by the explanations and guidelines for the integration, were sent to seven experts via email for their comments. Three separate online meetings were arranged with the three experts who showed interest in the validation, to get their feedback and suggestions on how to refine the framework and the linkage for practical implementation.

After robust discussions around the complexity of capturing EK for integration into BI, the following suggestions were made towards improving the framework for easy implementation in practice:

i. It was suggested that a legend should be provided to explain the framework's contents for easy understanding. This legend has been introduced to the refined BIM-Knowledge framework, as shown in Figure 8. 3.

ii. That the Client's Team in the framework should be replaced with Decision-makers for it to be all-encompassing; this suggestion was based on the argument that decision-makers in BIM projects go beyond the client team only. Other stakeholders such as design leads, contractors and suppliers could be decision-makers in BIM projects depending on the issue.

iii. It was also suggested that the final output of the framework should be changed from "Improved Decision-making in Building Construction Projects" to Improved Decision-making in BIM Projects" to reflect the study's scope.

iv. It was further suggested that the link indicating the integration between EK and BI in the linkage diagram (Figure 8. 2) should be more conspicuous and direct, as reflected in Figure 8. 4.

v. That key components of BIM relevant to the research could be incorporated into the linkage diagram for further clarity as BI could mean different thing to different people. Examples of such components considered relevant to this study are collaborative processes, technology as the vehicle (CDE, software, hardware), and an integrated data/information using ISO 19650 standards.

vi. That there should be a link between decision-makers and key tasks and activities requiring decision-making in BIM implementation throughout the project lifecycle such that decision-makers could identify the right skills and knowledge to improve decision-making in BIM projects.

These and other suggestions have been incorporated into the framework (Figure 8. 3) and the linkage diagram (Figure 8. 4) to facilitate the implementation of the BIM-Knowledge framework in BIM projects. As stated earlier, the protracted COVID-19 lockdown has limited the validation to online meetings with some of the industry experts who participated in interviews during the qualitative data collection of the study. It is believed that their suggestions have significantly helped refine the framework for practical implementation.

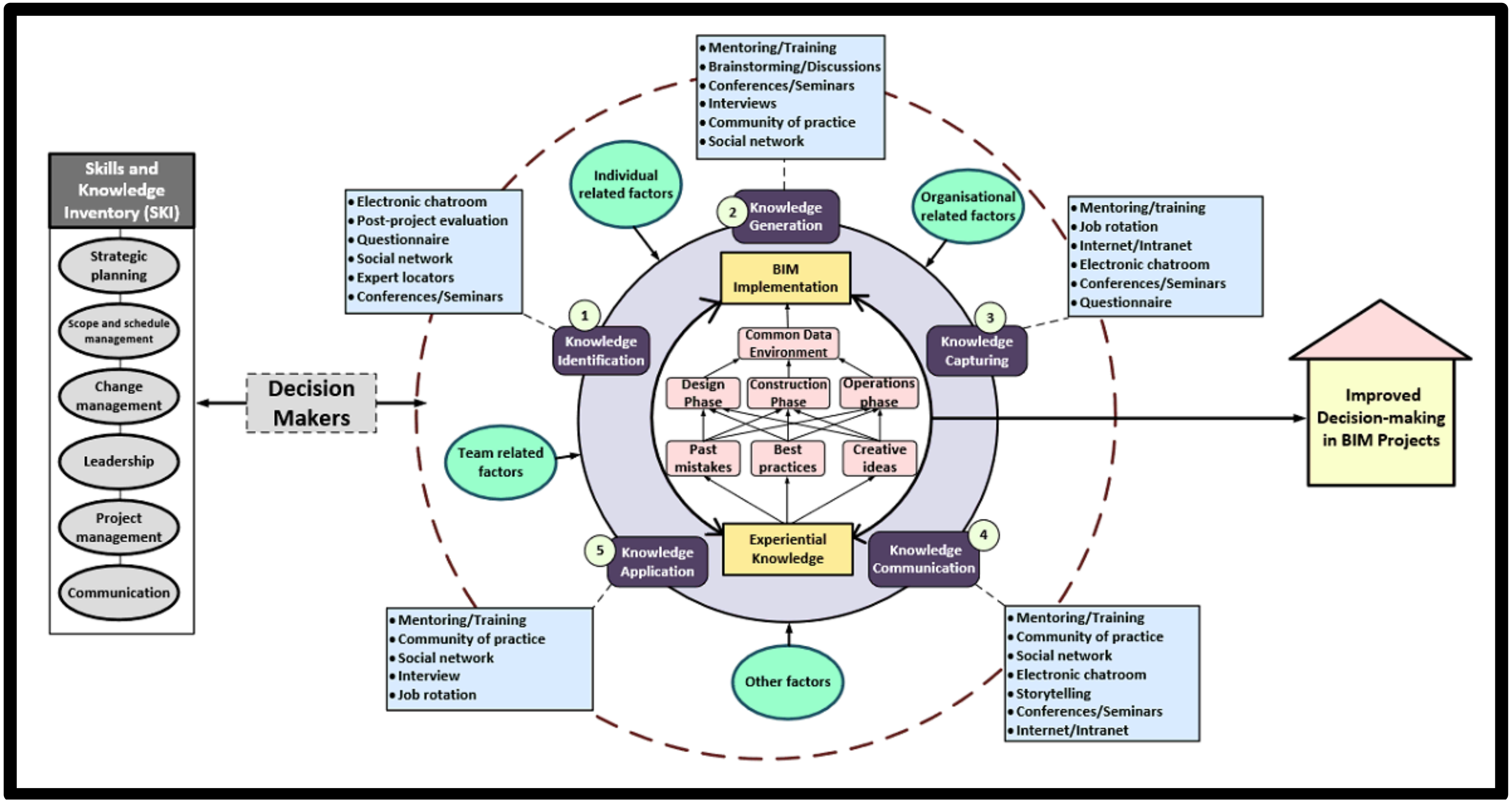


Figure 8. 3: Refined BIM-Knowledge (BIM-K) Framework based on Feedback from Validation Process

Legends: [yellow box] = Integrated Concepts (EK and BI); [pink box] = Components within the Integration; [dark purple box] = KM Processes

[light blue box] = KM Tools and Techniques; [green oval] = Impacting Factors; [grey oval] = Skills and Knowledge Inventory for Decision-makers

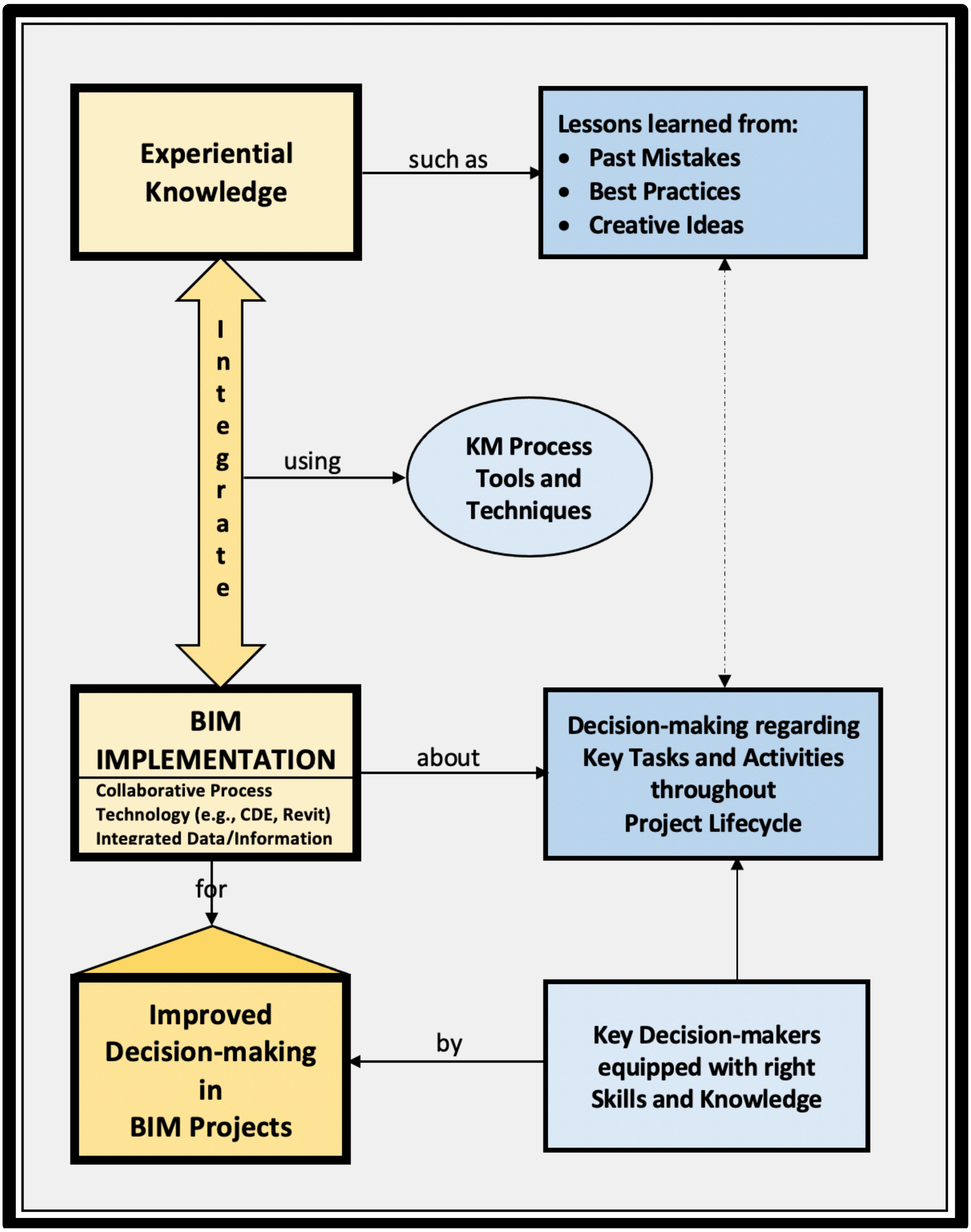


Figure 8. 4: Revised Linkages between EK and BI based on Feedback from Validation

8.4 Chapter Summary

This chapter brings together findings from the literature review, qualitative analyses and quantitative analyses to develop a conceptual BIM-Knowledge framework (Figure 8. 1). The Conceptual BIM-Knowledge Framework was based on the preliminary framework proposed in chapter 2 (see Figure 2. 20). The framework was refined using expert validation approach for practical implementation. The refined Conceptual

Framework (Figure 8. 3) comprises of three main sections: i. the BIM-K Core, which consists of three concentric circles where the integration of EK into BI takes place, ii. the SKI, which is an inventory of skills and knowledge important to the decision-makers, and iii. the Output, which is the BIM project delivered based on improvement in decision-making resulting from the integration of EK into BI. A supplementary linkage diagram (Figure 8. 2) was developed and revised (see Figure 8. 4) based on feedback from the industry experts who participated in the validation process to facilitate an easy understanding of the framework for practical implementation. The essence of the Conceptual BIM-Knowledge Framework is to improve decision-making in BIM projects through the integration of EK into BI. The next chapter concludes the thesis with a summary of key findings, implications and limitations of the study as well as areas for future research.

CHAPTER 9: CONCLUSION AND RECOMMENDATIONS

9.1 Introduction

This chapter presents a summary of the study in line with the aim and objectives of the study. The study's primary aim is to develop a "BIM-Knowledge" (BIM-K) Framework that will integrate EK into BI for improved decision-making in BIM projects. Six objectives were formulated to achieve this aim. The study used a combination of phenomenology and survey as research strategies to collect primary data via semi-structured interviews and questionnaire survey. The collected qualitative and quantitative data were analysed using NVivo and SPSS, respectively. Findings from the analyses were triangulated to achieve the research's stated aim – developing a conceptual BIM-Knowledge Framework for improved decision-making in BIM projects.

The chapter summarises the study in section 9.2, covering the research aim and objectives, research design, data collection and data analysis techniques adopted for the study. The key findings of the study are presented in section 9.3. Implications of the study are discussed in section 9.4, while section 9.5 presents the study's limitations. The final section, section 9.6, provides some directions for future research.

9.2 Summary of the Study

UK BIM Framework ISO 19650 defines the information management principles and requirements within the built environment. Its implementation is supported by the UK BIM Framework standards, guidelines and information protocols to help individuals and organisations in the UK to understand the fundamental principles of information management using BIM. The recent wide adoption of BIM as a way of working by many UK construction firms has significantly improved the quality of information used in the industry compared to traditional drawing-based information. While BIM-model information has improved the information quality, it has not effectively captured the "animating judgement" relating to people's experience and intuition required for decision-making in BI. The current BI approach focuses more or less on digital data management and information exchange which are better managed by technology at the expense of experience-based knowledge generated by the people from previous projects. The inadequacy of the present BIM in capturing EK, which is more valuable than information, has been widely acknowledged (Liu et al., 2013; Latiffi et al. 2017; Likhitruangslip & Kiet, 2019). Similarly, the need for a framework that will integrate knowledge into BIM practices to enable continuous improvement has also been advocated (Boyes, 2016; Deshpande et al., 2014).

However, existing frameworks seeking to integrate BIM and KM have all focussed on either the design phase (e.g. Wang & Leite, 2015; Park 2013) or construction phase (e.g. Lin, 2014; Ho et al., 2013) or operation phase (Motawa & Almarshad, 2015; Charlesraj, 2014) with none addressing the pre-design phase where vital decisions that could affect the whole phases of BI are made. Furthermore, the majority of these studies aligned with the technology-perspective of BI. The limitations of existing frameworks, as evident from the literature review, include:

- lack of a framework for knowledge integration at the pre-design phase of building projects;
- emphasis on technology-perspective of BI at the expense of the peoples-perspective of BI; and
- little consideration for the BIM professionals' experience-based knowledge for reuse and continuous learning, even within the phases under consideration.

Therefore, to overcome these limitations, this study seeks to develop a BIM-Knowledge framework that will integrate EK into BI for improved decision-making in BIM projects within the UK construction industry. EK from the whole project lifecycle could be captured and integrated into BI to improve decision-making, using the proposed BIM-Knowledge framework, right from the pre-design phase of the building construction project.

The specific objectives of the study are:

1. to explore the knowledge required for implementing BIM projects through investigation of the decision-making process in BI;
2. to investigate how KM can help capture EK for integration into BI for improved decision-making in BIM projects;
3. to map out a KM process that could enhance the integration of EK into BI for improved decision-making in BIM projects;
4. to investigate factors that can impact on the effective integration of EK into BI for improved decision-making in BIM projects;
5. to develop skills and knowledge inventory (SKI) of key decision-makers in BI; and

6. to develop a conceptual BIM-Knowledge framework that enables the integration of EK into BI for improved decision-making in BIM projects.

The study adopted a convergent parallel mixed-methods approach based on the pragmatic paradigm, which combines both qualitative and quantitative methods simultaneously in a single study. The study started with a review of the extant literature of the key concepts in the study. The outcome of the review led to the development of a preliminary framework in section 2.8 that forms the basis for investigating and exploring the key concepts (such as EK, KM, BIM BI, decision-making). Consequently, semi-structured interviews were conducted with 30 stakeholders who have been involved with BI within the UK construction industry. The purpose of the interview was to update and enrich findings from the literature and explore how EK could be integrated into BI based on their lived experiences. Constructs from the literature review were also converted into variables and developed into questionnaires for a survey to corroborate the interview findings. The survey aimed to elicit broader opinions among the industry practitioners in the UK regarding the usefulness and importance of these constructs towards integrating EK into BI.

The conceptual framework was developed by triangulating findings from the literature review, semi-structured interviews, and questionnaire surveys to achieve this study's aim. The conceptual BIM-Knowledge (BIM-K) framework integrates experience-based knowledge from previous projects into BI to improve decision-making in BIM projects. The proposed framework was validated for practical implementation using experts' opinions and subsequently refined based on the experts' feedback. The integration of EK into BI could be facilitated by five KM processes, supported by appropriate KM tools/techniques. For effective integration of EK into BI, the study took account of major factors that could positively or negatively impact the integration process. Key decision-makers in BI were identified, and the key skills/knowledge important for their effective performance were also documented.

9.3 Key Findings of the Study

The study's key findings are presented by placing the study results into perspective in line with the research questions set out in chapter 1. The key findings are presented under three main sub-sections based on the research questions (RQ). Subsection 9.3.1 presents findings relating to RQ1, which is: "*What is EK and how can it be* *integrated/validated in BIM environment to improve decision-making?"* Because this research question is critical to the research aim's achievement, the first three research objectives were set to provide a comprehensive answer to the question. After the extant review of literature on BIM and BI as decision-making, EK and KM for integrating EK into BI, a convergent parallel (concurrent) mixed methods strategy was used. A combination of content and statistical analyses was employed to obtain the results. The first research question ends with developing a preliminary framework and a KM process map to capture and integrate EK into BI in BIM projects.

The second section focuses on RQ2: *"What factors could impact on the effective integration of EK into BI for improved decision-making in building construction projects?"* After a combination of statistical and content analyses of factors collected from the literature and interviews, four broad categories of factors impacting EK's effective integration into BI were developed into a framework (Figure 6. 7). The third section provides an answer to RQ3: *"What skills and knowledge are considered important by the key decision-makers in BI to be effective in their role?"* A combination of exploratory factor analysis and content analysis was employed to provide an inventory of skills and knowledge considered to be important to decision-makers in BI.

9.3.1 Framework for Integrating Experiential Knowledge into BIM Implementation

Evidence from the literature revealed that knowledge is critical to successful project delivery and survival of construction organisations (Pathirage et al., 2007; Ping & Yu-Cheng, 2004; Deshpande et al., 2014). The construction industry is a knowledge-intensive industry renowned for generating abundant knowledge throughout the project lifecycle. The knowledge generated based on experiences from various projects and across project lifecycle can help improved decisions made during BI in building construction projects. Accordingly, the study was premised on the assumptions that it is possible to capture and integrate 'EK' into 'BI' and that the integration could improve decision-making in building construction projects. Therefore, the study seeks to find out *how* EK can be integrated into BI to improve decision-making in BIM projects.

A mixed-methods strategy was adopted to answer all the research questions to give a holistic view of the phenomena under investigation. It provides a complete and comprehensive perspective on the phenomena and generates new insights into the interaction between concepts under investigation (EK and BI). However, the weight allocated to each of the methods depends on the nature of the question to be answered. The nature of the question under investigation here deals with explorations of lived experiences on integrating EK into BI in BIM practice. Accordingly, semi-structured interviews were adopted as the primary instrument for collecting data, based on the need to explore stakeholders' personal lived experience involved in BI within the UK construction industry. Hence, thirty highly experienced and information-rich BIM professionals were selected for the interview. Interviewees were asked to share their experiences about BI and how they overcame challenges associated with capturing EK during BI. Besides, questions relating the decision-making process in BI and KM processes, and KM tools/techniques they employ in the projects, were explored. Data from the interviews were transcribed and subjected to content analyses using NVivo. To complement the interview, some of the survey questions investigated the sources of EK required for improving decision-making in BIM projects. Statistical analysis was used to obtain the result of the survey. The analyses were triangulated to develop a conceptual BIM-Knowledge framework for integrating EK into BI for improved decision-making in BIM projects.

Findings from the study suggested that the integration of EK into BI is not a straight-forward process. This is due to EK's nature, which is sticky and personally embedded, and the complexity associated with BI. Findings from the study revealed that EK from best practices, lessons learned from past mistakes and creative ideas are the most important EK required for integration into BI to improve decision-making in BIM projects. While EK gained from best practice are easily shared among professionals, lessons learned from past mistakes are not usually made public because of legal consequences and stigma associated with failed projects. However, the industry stands to benefit more by learning from these mistakes by avoiding continuous repletion of errors, if the stigma and litigations associated with such mistakes are reduced.

A five-step KM process was adopted to develop a KM process map (Figure 5. 5) to integrate EK into BI in BIM projects effectively. The five steps in the KM process map are knowledge identification, knowledge generation, knowledge capturing, knowledge communication and knowledge application. The KM process map provides a structured process for integrating EK from across previous projects into BI to improve decisions as early as possible during the BIM project. Results of the analyses showed that each of these processes is supported by appropriate KM tools and techniques. Findings revealed that non-IT tools and techniques such as mentoring, post-project evaluation, experience swapping, and job rotation are the most effective tools for integrating EK into BI. However, the research findings also indicated that IT tools such as knowledge portal, multi-media platforms, and such systems could complement non-IT techniques.

Research findings also indicated that the pre-design phase is the most critical phase for decision-making, where EK should be integrated into BI. Accordingly, capturing and integrating EK to improve decision-making in BI should be initiated as early as possible. Decisions made regarding the key tasks and activities at the pre-design phase usually have ripple effects on subsequent tasks and activities in the whole project lifecycle. The study revealed that key BI tasks and activities requiring EK for decision-making at that phase are project scope and BIM deliverables, BIM competencies of the project teams, project goals and objectives, client's business case, and defining roles and responsibilities of various stakeholders. In line with Chegu-Badrinath and Hsieh (2019) position, this study also identified clients as the key decision-makers during BI. However, the result revealed that most clients do not have sufficient knowledge about construction to make informed decisions about key BI tasks and activities. They often rely on advice from other stakeholders (such as architects, engineers, contractors) for their decisions. Accordingly, these stakeholders are seen as part of the key decision-makers in BI.

9.3.2 Factors Impacting on Effective Integration of Experiential Knowledge into BIM Implementation

To investigate and explore the factors impacting EK's effective integration into BI, quantitative and qualitative methods were used to collect and analyse relevant data from stakeholders within the UK construction industry. Due to the nature of the research question, which seeks to identify factors that impact the effective integration of EK into BI in BIM projects, the emphasis was placed on the quantitative method but augmented with the qualitative method. Through a comprehensive review of the extant literature on factors impacting integrating EK into BI (section 2.5.4), twenty-six relevant factors were extracted for further analysis. For ease of analysis, these factors were grouped into three categories based on Lertpittayapoon et al. (2007) framework: individual-, team-, and organisational-related factors (Table 2. 10). Semi-structured interviews were conducted to explore additional factors that stakeholders considered impactful on the integration process, based on current practices, to enrich and update extracted factors from the literature. These factors were subjected to a combination of statistical and content analyses to determine the most impactful factors.

Findings from the statistical analysis revealed that four of the individual-related factors were impactful on the integration process. These factors are level of trust, level of involvement in decision-making, face-to-face interaction, and effective communication (Figure 6. 3). On the other hand, the five factors that ranked as highly impactful among team-related factors include open and collaborative discussion, knowledge-oriented culture, the project team members' motivation, well-defined KM processes, and level of commitment to know/edge integration (Figure 6.4). Regarding organisational-related factors, the three most impactful factors on the effective integration of the EK into BI are leadership support and commitment, organisational culture, and organisational transparency and openness (Figure 6.5). Furthermore, the overall factor ranking analysis also confirmed that the level of trust among individuals participating in BIM projects is still considered the most critical factor impacting on the integration of EK into BI. This factor is followed by the organisation's leadership support for, and commitment to knowledge integration activities. Other critical factors in ranks are the level of involvement and participation of individuals in decision-making, level of face-to-face interaction among colleagues, and open and collaborative discussions among the team (Table 6. 6).

Furthermore, findings from the analysis of semi-structured interviews revealed additional four critical factors that could impact EK's effective integration into BI. These are adequate financial budget for knowledge integration, a legal framework that accommodates learning from mistakes, procurement methods that encourage early collaboration and communication, and fear of losing their jobs due to knowledge sharing activities (Figure 6.6). The combined findings from quantitative and qualitative analyses were developed into a framework of factors impacting the effective integration of EK into BI, as presented in Figure 6. 7. Finally, there is a consensus among the survey participants and interviewees that organisation size does not significantly impact EK's effective integration into BI.

9.3.3 Skills and Knowledge Inventory (SKI) for Key Decision-makers in BIM Implementation

Though the need to improve decision-making through the integration of EK into BI has been advocated, the literature review suggested that most key decision-makers lack requisite important skills/knowledge to make effective decisions in BIM projects. Consequently, the study relied on KBT as a theoretical basis for identifying the skills and knowledge important to decision-makers and adopted a combination of quantitative and qualitative methods to investigate and explore these skills and knowledge. After a comprehensive review of the extant literature on skills and knowledge (SKI variables) relevant to decision-makers in BI (section 2.7.2), a list of twenty most frequently sited skills/knowledge was compiled (Table 2. 12) and converted to a questionnaire survey. The questionnaire was structured and analysed to reveal important skills/knowledge now and in the future. In addition, skills and knowledge requiring training and education (now) were also identified from the analysis. The survey data was subjected to statistical and factors analyses to rank the level of importance and unravel the dominant structure underlying the skills/knowledge, respectively.

Findings from the statistical analysis revealed that skills/knowledge considered as most important to key decision-makers now are: teamwork/collaboration, leadership, communication, strategic planning, scope and schedule management, and change management skills. BI and knowledge integration are essentially teamwork and collaborative activities. Decision-makers should be able to leverage the diverse experiences of team members through collaboration to improve decisions during BI. The result of the factor analysis grouped skills and knowledge important to key decision-makers now under three-factor solutions. Soft skills, management skills and leadership skills constitute the dominant three-factor solutions (Table 7. 4). Soft skills/knowledge include motivation, critical thinking, conflict management, teamwork and collaboration. Financial management, quality management, risk management, project management came under management skills/knowledge. Leadership, strategic planning, software management, scope and schedule management were grouped under leadership skills.

Furthermore, findings on skills/knowledge considered important to decision-makers in the future show no significant difference from what is currently important to them now, except in ranking. The five most important skills/knowledge in future are strategic planning, leadership, teamwork/collaboration, change management, and scope and schedule management skills (Table 7. 5). These variables are all contained in the six most important skills/knowledge now. However, strategic planning was considered the most important skills/knowledge in the future instead of teamwork/collaboration. Surprisingly, teamwork/collaboration ranked as the most important skill (now) was not ranked among the five most important skills/knowledge in the future. Findings regarding important skills/knowledge (now) requiring training and education now revealed that decision-makers needed to be educated and trained in strategic planning, scope and schedule management, change management, communication, project management and motivation for them to be more effective in future (Table 7. 6). Most of these skills were considered very important to BI decision-makers in future.

In compliance with the mixed-methods adopted, interview respondents were asked to identify the key decision-makers in BI. Their understanding of the skills and knowledge required by these decision-makers were also explored to enrich the survey's findings. Findings from the interviews' analysis suggest that BI's key decision-makers are clients, lead designers, contractors, cost estimators, and suchlike (Table 7. 7). In addition, analysis of interviews with the thirty experts confirmed that BI's decision-makers require all twenty skills and knowledge extracted from the literature (Table 7. 9). The essence of the interview was to corroborate the skills and knowledge extracted from the literature. The amalgamation of findings revealed that the six critical skills and knowledge important to decision-makers in BI are strategic planning, scope and schedule management, change management, leadership, project management, and communication skills (Figure 7. 4).

9.4 Implications of the Study

This research has implications for decision-making in BIM projects that would be of interest to professionals and other stakeholders involved in the implementation of BIM. These implications are discussed under two categories of practical and theoretical implications in subsequent subsections. The discussion is meant to incite thinking on how decision-making in BIM projects can be improved based on the research findings.

9.4.1 Implications for Practice

Findings from this study confirmed that the integration of EK into BI could improve decision-making in BIM projects. This study provides a new dimension to the concept of BI by shifting emphasis from the information and technology-driven perspective to knowledge and people-driven perspective. The study identified EK as a vital resource for consideration while making decisions regarding BIM tasks and activities at the very early stage of the project. While confirming that BIM models have provided professionals in BIM projects with a higher quality of information, the study developed a conceptual BIM-Knowledge framework that could be used to improve decision-making by integrating EK into BI. The developed conceptual framework can capture lessons learned from past mistakes and best practices across projects for integration into BI, thus ensuring continuous learning in BIM practice. Integrating EK into BI implies that all stakeholders on a BIM project must be ready to share their experiences of lessons learned from past mistakes and best practices to inform present decisions to avoid repetition of errors and mistakes. This integration could help overcome challenges associated with effective communication and collaboration during BI in practice.

Many factors could impact effective decision-making in BIM practice. This research identified critical factors relating to individuals, project team, and construction organisations that could impact EK's integration into BI to improve decision-making in BIM projects. Therefore, this study has implications for construction organisations interested in leveraging EK to improve decisions in BIM projects because it developed a group of factors that need to be considered at the individual, team and organisational levels. For example, the study revealed that trust among individuals, leadership support for the knowledge integration process, level of involvement in decision-making, increased face-to-face interaction, open and collaborative discussion are highly impactful and should be seriously considered while integrating EK into BI for improved decision. Furthermore, procurement methods that encourage collaboration and knowledge integration, and a legal framework that protect people who share their experience regarding past mistakes on BIM project are equally critical to the effective integration of EK into BI for improved decision-making.

The study identified the pre-design phase of building projects as the most critical for decision-making where EK should be integrated during BI. This position challenged undue traditional emphasis placed on design and construction phases at the expense of the pre-design phase, where critical decisions that have vast implications on the project lifecycle are made. This finding implies that adequate attention should be given to the BI tasks and activities at the pre-design phase of BIM projects because any wrong decision made at this phase could have adverse negative effects on other phases of the project.

Evidence has shown that many of the stakeholders involved in decision-making on BIM projects do not have requisite contemporary skills and knowledge to make informed decisions. Many of the construction industry professionals' traditional skills may not be very relevant in BIM projects. The preceding, thus, revealed the importance of developing skills and knowledge inventory (SKI) of key decision-makers in BIM projects. Consequently, the study developed a skills/knowledge inventory (SKI) important to BI's key decision-makers. The implication of this to practice is that the SKI developed can be used to identify important skills/knowledge to decision-makers in BIM projects now and skills/knowledge required by them in the future.

Similarly, areas requiring training and education (now) that will position them as effective decision-makers in the future equally identify. Construction firms can use the SKI to gauge their staff's skills/knowledge and identify required training and education for them. The study identified clients as the key decision-maker in BI, especially at the pre-design phase. This finding aligns with Chegu Badrinath and Hsieh (2019) finding, who identified the owner as one of the principal decision-makers in BIM at the planning stage. Although the professionals' advice influences clients' decisions, clients are still responsible for the project's final decision on BIM projects. This responsibility implies that clients and their advisers should improve and update their competencies to make better decisions.

9.4.2 Theoretical Implications of the Study

A major theoretical implication of this study is that EK is a critical resource for project-based organisations that could be used to improve decision-making. As a critical resource, the study affirms that integrating EK into BI, using a KM process map that is supported by appropriate KM tools and techniques, could improve decision-making in BIM projects. This confirms the relevance of knowledge-based theory (KBT), to the study. The study satisfied the theory's underlying assumptions and affirmed that EK is a specialised and personal knowledge acquired by individuals over some time and stored in their memory. One of the theory's fundamental assumptions is that knowledge encompasses information, technology, know-how (experience) and skills. This assumption forms the basis for identifying and developing skills and knowledge inventory (SKI) important to key decision-maker in a technology-dominated and information-rich domain like BIM. The study's findings confirmed that key decision-makers must develop competencies in critical areas to perform their decision-making tasks effectively.

A vital requirement of this study is developing a KM process map that could facilitate the integration of EK into BI. To effectively integrate EK into BI, the study identified efficient KM process as a viable mechanism for the integration. The KM process development was based on the KM framework proposed by the European

Committee for Standardisation (CEN, 2004). In line with the findings of Kraaijenbrink and Wijnhoven (2008) who utilised the KBT for external knowledge integration, this study developed a cyclical KM process map (Figure 5. 5) comprising of knowledge identification, knowledge generation, knowledge capturing, knowledge communication, and knowledge application for integration identified EK to BI for improved decision-making in BIM projects. Each of the processes was supported by appropriate KM tools and techniques.

9.5 Limitations of the Study

Although the study has achieved the set aim and objectives, nevertheless it has some limitations that need to be acknowledged. First, the research adopted concurrent mixed methods design for primary data collection. The study relied on experts' narrations using semi-structured interviews to technique extract from relevant information. Therefore, the information retrieved is limited to the extent to which they can recollect their lived experience during the interview. Efforts have been made to enhance the generalisability of findings using survey research to complement the limitation imposed by the number of interview participants. The adopted mixed methods approach was able to complement one another to extract relevant information about respondents' experience with the phenomena under investigation.

Secondly, the developed conceptual framework has not been fully validated on a real-life BIM project. The main reason for the inability to fully validate the framework in a real-life project is the national lockdown imposed on the UK due to COVID-19 pandemic. However, efforts have been made to provide some validation using an online platform to get feedback from some experts who participated in the interview during the data collection. Outcomes of the feedback have been used to refine the framework to facilitate its practical implementation in a real-life BIM project. If the framework is carefully implemented, and all the impacting factors are adequately considered, there would be some improvement in BIM projects' decisions. The improved decisions could reduce repetition of errors, increase continuous learning, and improve client satisfaction. Despite these limitations, the study has been able to fulfil its aim and provides answers to the research questions. It has increased the frontier of knowledge by providing a new perspective on BI's concept as a decision-making process. It has equally raised the awareness of EK's value within the UK construction industry by calling for its integration into BI to improve decision-making in BIM projects.

9.6 Areas for Future Research

This section suggests areas for future research where further studies could enhance the present research outcome. The limitations encountered in the course of the research have inspired directions to areas for future research. Future research could investigate the findings of the study through the adoption of some other research methodologies. Future studies may wish to measure how EK's integration into BI could improve decision-making in BIM projects using a purely quantitative method. Others may adopt a different framework to determine key factors impacting the effective integration of EK into BI. Future researchers can also review the suggested skills and knowledge inventory to determine their relevance and appropriateness to the reality of the time.

Other studies could also investigate the generalisability and the applicability of the research findings to other countries outside the UK. Moreover, future studies could consider integrating EK into BI to cover other infrastructural and industrial projects. Finally, given the nature of the study's questions, a conceptual framework was produced to allow EK to be mainstreamed into BI. Finally, future researchers can fully validate the framework in real-life BIM projects once the pandemic is over and the lockdown is lifted. This validation may take the form of longitudinal qualitative research that will involve the whole project lifecycle to test the practical implementation of the conceptual framework in a real-life project. Doing this will help identify the extent to which the integration of EK into BI can improve decision-making in BIM projects.

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Appendix

Appendix 1: The Letter of Ethical Approval

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Direct line: 02 08 815 7264
E-mail: kaluaray@lsbu.ac.uk
Ref: RME1

17th May 2018

Dear Ganiyu Sikiru Abiodun,

Re - DEVELOPING A 'BIM-KNOWLEDGE' (BIM-K) FRAMEWORK FOR IMPROVED DECISION MAKING IN SUSTAINABILITY OF CONSTRUCTION PROJECTS

Thank you for submitting this proposal for ethical review.

I am pleased to inform you that Dr Yamuna Kaluarachchi, on behalf of the School of the Built Environment & Architecture, has given full Chair's Approval for your review.

I wish you every success with your research.

Yours sincerely,

Yamuna Kaluarachchi

Chair, Research Ethics Coordinator
School of the Built Environment & Architecture
London South Bank University

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Appendix 2: Invitation Letter to Participate in Research Interview

Developing a BIM-Knowledge (BIM-K) framework for improved decision making in building construction projects

The AEC/FM industry is a knowledge-intensive project-based industry where abundant knowledge is being generated. However, fragmentation of construction information and knowledge has been a major challenge facing the industry for a long time, even though BIM is starting to improve collaboration. This fragmentation of knowledge (coupled with the temporary project-based nature of construction projects) makes post-project communication of valuable information and knowledge difficult among participants. This eventually leads to the loss of knowledge within the industry, whereas knowledge from experts' and the experience of participants could be a major asset and a competitive resource for many organisations. The need to capture this invaluable asset (within BIM-enabled projects) should facilitate better decision-making on future projects and will go a long way to reduce loss of knowledge and experience due to death, retirement or transfer. This is the hypothetical position that we need to validate.

This study is therefore aimed at developing a "BIM-Knowledge" (BIM-K) Framework that will capture and integrate experience-based knowledge of BIM experts into BIM implementation for improved decision making in building construction projects.

To achieve this aim, it is very important that we get the views of **UK-based BIM experts or BIM managers** to participate in a 45 to 60-minute interview at place/time of their choice, via phone calls, web conference or face to face. All the information collected during the interview will be kept strictly confidential and will only be used for academic purposes only.

Can you be of help? Please get in touch with me using the following contact details:

Email: ganiyus@lsbu.ac.uk
Telephone: +44(0)7422849120

Appendix 3: A copy of the Consent Form

London South Bank University

Letter Seeking Permission to Participate in Interview

Dear David Philp,

I am conducting a research study on the "Development of BIM-Knowledge (BIM-K) Framework for impactful Decision Making" in partial fulfilment of my doctoral degree at the London South Bank University, UK. A separate questionnaire will be sent to all the consultants in the construction industry in the UK to seek their opinions on factors that are critical to the integration of knowledge to the implementation of BIM on projects. I am seeking your permission to participate in an interview for exploring how knowledge of lessons learned and experiences gained from previous projects can be integrated to implementation of BIM for impactful decision making.

The outcome of this research would be beneficial to construction industry in several ways:

i. It would help establish the decision-making process in the implementation of BIM and the role of knowledge in that regard;
ii. It would provide valuable insight into how knowledge management (especially tacit knowledge) can enhance the use of BIM through integration;
iii. Determine what factors impact on the effective integration of knowledge into the use and exploitation of BIM implementation;
iv. Establish the skills and knowledge required by key decision makers in the use of BIM-infused knowledge for decision making; and
v. Make useful suggestions and recommendations on how to enhance decision-making during BIM implementation through knowledge integration.

Consent: Please note that your confidentiality is guaranteed. Your participation is entirely voluntary. You may answer or choose not to answer a particular question as you wish, and you may end the session at any point. Your participation and information provided will be strictly confidential and your identity will be separated from your answers so that it will not be attributed to you.

Please indicate whether or not you wish to participate: **Yes**

I appreciate your willingness to contribute to this project and to set aside time for the interview.

Yours sincerely,

Ganiyu Sikiru Abiodun
PhD Research Student
London South Bank University
T: 044(0)7422849120
Email: ganiyus@lsbu.ac.uk

Appendix 4: A Copy of the Interview Questions

DEVELOPING A BIM-KNOWLEDGE (BIM-K) FRAMEWORK FOR IMPROVED DECISION-MAKING IN CONSTRUCTION PROJECTS

INTERVIEW QUESTIONS

Introduction: Thank you for accepting to participate in this interview. As mentioned earlier, this study is about developing a framework that will integrate experience-based knowledge into BIM implementation (BI) for improved decision-making in the context of building construction projects. Based on your wealth of experience in these areas, I shall be asking questions to explore your take on these concepts. I hope it is OK by you for me to record this interview. I assure you that the content of the interview shall be strictly treated as confidential.

The Interview:

Obj. 1 – BIM Challenges and KM for Capturing EK

1. Please, can you briefly share with me some of your experiences of "BI" within the UK construction industry?
2. There are those who have raised issues around the inability of the current BI to capture experience-based knowledge for use and re-use, what is your take on this?
3. There appears to be knowledge gap between those who have spent longer time in the construction industry (old generation with little or no BIM competencies) and the new entrants who recently join the industry (new generation with BIM competencies), in what ways do you think the EK of these old generations can be captured and integrated into BI to improve decision-making on construction projects?

Obj. 2 – Required Knowledge for improved decision-making

As the one who is responsible for the implementation of BIM in your organisation,

4. What kinds of knowledge are usually required to implement BIM in other to improve decision-making in building construction projects?
5. How do you identify those people with the required knowledge to implement BIM on building construction projects?

Given the fact that decision-making is a complex process, and not a punctual thing:

6. Given a specific context, can you kindly take me through a typical decision-making process in BI?
7. What phase(s)/stage(s) of building projects will you consider as the most critical in terms of decision-making during BI?
8. Who will you consider as the key decision makers during BI in (energy efficient) building projects?

Obj. 3 - Knowledge Management Process (KMP)

The essence of KM is to ensure that the right knowledge gets to the right people at the right time,

9. KMPs involve knowledge generation, knowledge capturing, knowledge sharing, etc.:
    a. What methods do you employ to **generate** the EK required for BI on your projects?

    b. What methods do you employ to **capture** the EK required for BI on your projects?
    c. What methods do you employ to **share** the EK required for BI on your projects?
10. KM instruments refer to tools and techniques employed to facilitate the KM process:
    a. What instruments (tools and techniques) do you employ to **generate** the EK required for BI on your projects?
    b. What instruments (tools and techniques) do you employ to **capture** the EK required for BI on your projects?
    c. What instruments (tools and techniques) do you employ to **share** the EK required for BI on your projects?

Obj. 4 – Impactful factors for integration of EK into BI

The willingness to participate in the KM processes for the purpose of integrating EK into BI to improve decision-making in building construction projects can be influenced by some factors, from your experience,

11. What factors do you think encourage people to generate, capture and share their EK with others for integration into BI?
12. What factors do you think discourage people to generate, capture and share their EK with others for integration into BI?

Obj. 5 – Skills and knowledge inventory (BIM Competencies for delivering BIM project)

13. What important skills and knowledge do you think is required by the key decision makers in BI?

Conclusion: Thank you for your time sir, I shall be grateful if you can share with me contacts of other people you think may also contribute to this research through interview. I assured you that the information from these interviews shall be treated with utmost confidentiality and used for academic purposely only.

Appendix 5: A Copy of the Questionnaire Survey

DEVELOPING A ‘BIM-KNOWLEDGE’ FRAMEWORK FOR IMPROVED DECISION MAKING IN BUILDING CONSTRUCTION PROJECTS

Page 1: Section 1: Introduction

This questionnaire survey is part of an on-going PhD research at London South Bank University (LSBU), UK. The aim of the research is to develop a ‘BIM-Knowledge’ (BIM-K) Framework that will integrate experiential knowledge into BIM implementation for improving decision-making. Input is solicited from various professionals involved with BIM implementation within the UK construction industry. Please be assured that this survey is strictly for research purpose, and individual responses will remain confidential. The data from the research will be used, stored, and disposed of in line with the ethical guidelines of LSBU.(http://www.lsbu.ac.uk/research/governance/ethics)

The questionnaire is expected to take about 20 - 25 minutes to complete. Should you require further details or clarification, you can contact me through the details provided below. If you would like to receive a copy of the research findings, please let me know by sending an email to the email address below.

Thank you for your valuable contribution.

Sikiru A. Ganiyu

Mob. +44(0)7422849120

Emails: ganiyus@lsbu.ac.uk

Page 2: Section 2: General Information

Please mark answers with a **Click** on your option.

Type of your Firm: Which category best describes your firm?

- Architectural or Planning Firm
- BIM Consultancy Firm
- Construction/Contracting Firm
- Engineering Consultancy Firm
- Manufacturing/Installation Firm
- Project/Facility Management Firm

If you selected Other, please specify:

Size of your Firm: Which category describes the size of your firm?

- Micro Firm (1 - 9 employees)
- Small Firm (10 – 49 employees)
- Medium Firm (50 – 249 employees)
- Large Firm (over 250 employees)

Job Title of the Respondent: Which category best describes your job title?

- Architect/Design Manager
- BIM Manager/Director
- BIM Adviser/Consultant
- BIM Technician/Coordinator

- Information/Knowledge Manager
- Project/Construction Manager
- Asset/Facility Manager
- Mechanical /Electrical Engineer
- Civil/Structural Engineer
- Quantity Surveyor/Cost Estimator
- Client Representative
- Other

If you selected Other, please specify:

Years of Experience with BIM Implementation: How long have you been involved with the use of BIM in building projects in the UK?

- Less than 1 year
- 1 - 2 years
- 2 - 5 years
- 5 -10 years
- 10 - 15 years
- More than 15 years

Page 3: Section 3: Knowledge Management Tools for Capturing Experiential Knowledge during BIM Implementation

Working Definition

Knowledge management (KM) refers to the activities and processes through which an organisation manages its body of knowledge. **Experiential knowledge** is the insight learned from direct participation in BIM implementation which resides in peoples head. **BIM implementation** refers to the set of activities undertaken by a project organisation, at the pre-design phase, in preparation for the BIM execution throughout the building lifecycle.

Section 3.1: Experiential knowledge can be **captured** through **KM tools and techniques** for **future reuse and continuous improvement.** This section highlights a list of KM tools and techniques that can be used to capture experiential knowledge related to BIM implementation for improving decision-making. Based on your experience with BIM implementation, within the UK construction industry, please, answer the following questions.

From your experience, how **effective** do you find the following knowledge management tools and techniques in capturing experiential knowledge related to BIM implementation?

	Effectiveness of the tool/technique in capturing experiential knowledge			
	1 = Not effective	2 = Slightly effective	3 = Moderately effective	4 = Highly effective
Communities of Practice (e.g. BIM Hub)	○	○	○	○
Conferences and Seminars on BIM	○	○	○	○
Job Rotation/Experience Swapping/Secondment of BIM Experts	○	○	○	○
Mentoring/Apprenticeship/Training on BIM	○	○	○	○
Collaborative Workspace containing BIM Experts	○	○	○	○
Brainstorming/Group Discussion regarding BIM	○	○	○	○
Storytelling/Oral Narrations about BIM Projects	○	○	○	○
Intranet/Internet/Website on BIM-enabled Projects (e.g. IMRB)	○	○	○	○
Video Conferencing/Audio Conferencing among BIM Experts	○	○	○	○

Expertise Locators of BIM Experts (e.g. Yellow pages)	○	○	○	○
Electronic Chatroom for BIM Expert (e.g Yammer)	○	○	○	○
Social Networking Tools for BIM Experts (e.g. LinkedIn)	○	○	○	○
Interviews of BIM Experts	○	○	○	○
Questionnaire Surveys of BIM Experts	○	○	○	○
Post Project Evaluation of BIM-enabled Project	○	○	○	○

Page 4: Section 4: Experiential Knowledge Required for BIM Implementation

Section 4.1: This section seeks to explore the **experiential knowledge required** for improving decision making during BIM implementation. Based on your experience of BIM-enabled projects, within the UK construction industry, please answer the following questions**.**

Below is a list of sources and activities relating to experiential knowledge for BIM implementation. From your experience, how important do you think are the following sources and activities to improve decision-making during BIM implementation?

	Importance of using the knowledge source/activity.			
	1 = Not important	2 = Slightly important	3 = Moderately important	4 = Highly important
Knowledge from creative ideas arising during BIM implementation	○	○	○	○
Knowledge from documented best practices in BIM implementation	○	○	○	○
Knowledge from research, training and skill acquisition in BIM implementation	○	○	○	○
Knowledge from the lessons learned from past mistakes during BIM implementation	○	○	○	○
Knowledge from mentoring and mentorship by experts on BIM implementation	○	○	○	○
Knowledge from brainstorming and group discussion on BIM implementation	○	○	○	○
Knowledge from Communities of Practice on BIM implementation	○	○	○	○

Section 4.2: In practice, how useful is the **experiential knowledge** for improving **decision-making** regarding the following **BIM implementation** tasks and activities which take place during the **pre-design phase**?

BIM Implementation Tasks and Activities (Pre-Design Phase)

	Degree of Usefulness of experiential knowledge for improving decision-making			
	1 = Not useful	2 = Slightly useful	3 = Moderately useful	4 = Very useful
Identifying client business case	○	○	○	○
Developing project goals and objectives	○	○	○	○
Preparing a strategic brief	○	○	○	○
Undertaking feasibility studies	○	○	○	○
Reviewing Site information	○	○	○	○
Deciding the project budget	○	○	○	○
Assembling the project teams	○	○	○	○
Determining BIM competencies project teams	○	○	○	○
Defining the roles and responsibilities of various stakeholders	○	○	○	○
Agreeing on software tools and their interoperability issues	○	○	○	○
Establishing project scope and BIM deliverables	○	○	○	○
Establishing workflow and communication strategies	○	○	○	○
Deciding on a common data environment (CDE) for data operations	○	○	○	○
Defining the BIM tools and their interoperability	○	○	○	○
Preparing handover strategy and risk assessments	○	○	○	○

Section 4.3: Although undertaken at the pre-design phase, **BIM implementation** should consider various **tasks and activities** that would be undertaken during the entire **life-cycle of a building**.

Sub-section 4.3.1: In practice, how important is it to capture and integrate **experiential knowledge** relating to the following **design phase tasks and activities** to improve decision-making during BIM implementation?

Design Phase Tasks and Activities

	Degree of importance of capturing and integrating experiential knowledge relating to design tasks/activities			
	1 = Not important	2 = Slightly important	3 = Moderately important	4 = Very important
Preparing Concept, Developed and Technical Designs	○	○	○	○
Developing the 3D model (Visualisation model)	○	○	○	○
Finalising project brief and design alterations	○	○	○	○
Integrating time schedule into the 3D model (4D)	○	○	○	○
Integrating costs into the 3D model (5D)	○	○	○	○
Preparing materials and components specifications	○	○	○	○
Preparing sustainability analysis	○	○	○	○
Preparing constructability analysis	○	○	○	○
Submitting drawings for building permits	○	○	○	○
Reviewing and updating the Project Execution Plan	○	○	○	○
Discussing and agreeing on the model update	○	○	○	○
Preparing and reviewing construction strategies	○	○	○	○
Developing health and safety strategy	○	○	○	○
Reviewing handover strategies and risk assessment	○	○	○	○

Sub-section 4.3.2: In practice, how important is it to capture and integrate **experiential knowledge** relating to the following **construction phase tasks and activities** to improve decision-making during BIM implementation?

Construction Phase Tasks and Activities

	Degree of importance of capturing and integrating experiential knowledge relating to construction tasks/activities			
	1 = Not important	2 = Slightly important	3 = Moderately important	4 = Very important
Contract administration	○	○	○	○
Preparing onsite and offsite construction programme	○	○	○	○
Prefabricating building components	○	○	○	○
Resolving design queries from site	○	○	○	○
Inspecting site and reviewing work progress	○	○	○	○
Construction quality control	○	○	○	○
Resource planning and procurement method	○	○	○	○
Implementing the handover strategy	○	○	○	○
Preparing the 'As-built model' for handover	○	○	○	○
Implementing and updating construction strategies	○	○	○	○
Updating health and safety strategies	○	○	○	○

Sub-section 4.3.3: In practice, how important is it to capture and integrate **experiential knowledge** relating to the following **post-construction phase tasks and activities** to improve decision-making during BIM implementation?

Post-Construction Phase Tasks and Activities

	Degree of importance of capturing and integrating experiential knowledge relating to post-construction tasks/activities			
	1 = Not important	2 = Slightly important	3 = Moderately important	4 = Very important
Concluding the contract administration	○	○	○	○

Handing over the building to the client	○	○	○	○
Carrying out activities listed in the handover strategy	○	○	○	○
Maintaining and repairing the building as scheduled	○	○	○	○
Evaluating performance and providing feedback for future use	○	○	○	○
Updating 'As-built' model with feedback information as required	○	○	○	○

Page 5: Section 5: Decision-making Process for BIM Implementation

Section 5. 1: This section highlights the **decision-making process** for BIM implementation and the different **phases** of **building life-cycle** that need to be considered during BIM implementation**.** Based on your experience of BIM implementation, within the UK construction industry, please answer the following questions.

In practice, to what extent do you consider different phases of building life-cycle when engaging in the following decision-making activities regarding BIM implementation? Please indicate your response on scale 1 to 4, where 1 = Never considered, 2 = Rarely considered, 3 = Sometimes considered, 4 = Always considered

	Pre-Design Phase				Design Phase				Construction Phase				Operation Phase			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Identifying the problem to be addressed through BIM implementation																
Establishing the goals and objectives for BIM implementation																
Gathering relevant data and information regarding BIM solutions to the problem																
Determining the criteria to evaluate the alternative BIM solutions																

Developing possible alternative BIM solutions to the problem	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Analysing all the alternative solutions based on the goals for BIM implementation	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Selecting the most suitable alternative solution within the context of BIM implementation	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Implementing the selected solution in line with the BIM implementation goals	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Reviewing and evaluating the effectiveness of the selected solution	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Capturing the lessons learned and best practices for future reuse.	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Page 6: Section 6: Factors Impacting on Integrating Experiential Knowledge into BIM Implementation

This section highlights **categories of factors** that could **impact** on the **effective integration** of **experiential knowledge** into **BIM implementation**. Based on your experience with BIM implementation, within the UK construction industry, please answer the following questions.

Section 6.1: From your experience, to what extent do the following ***Individual-related Factors*** impact on effective integration of experiential knowledge into BIM implementation?

	Extent of Impact			
	1 = Not impactful	2 = Less impactful	3 = Moderately impactful	4 = Highly impactful
Level of face-to-face interaction among individual colleagues	○	○	○	○
Willingness and ability of individuals to freely share experiential knowledge	○	○	○	○
Level of involvement and participation of individuals in decision making	○	○	○	○
Rewards and incentives for individuals involved in integrating experiential knowledge	○	○	○	○
Effective and honest communication among individual colleagues	○	○	○	○
Level of training, education and apprenticeship available to individuals	○	○	○	○
Level of trust among individuals involved in integrating experiential knowledge	○	○	○	○
Individual's level of creativity	○	○	○	○

Section 6.2: From your experience, to what extent do the following ***Project-related Factors*** impact on effective integration of experiential knowledge into BIM implementation?

	Extent of Impact			
	1 = Not impactful	2 = Less impactful	3 = Moderately impactful	4 = Highly impactful

Open and collaborative discussions among project team members	○	○	○	○
Availability of adequate time for activities to integrate experiential knowledge among project team	○	○	○	○
A knowledge-oriented culture among the project teams that encourages creative and innovative ideas	○	○	○	○
Availability of appropriate knowledge management tools for integrating experiential knowledge among project team	○	○	○	○
Early composition of project team members and their continuity on the project	○	○	○	○
Well defined knowledge management processes for integrating experiential knowledge among the project team.	○	○	○	○
Level of commitment to knowledge integration activities among the project team.	○	○	○	○
Level of mutual understanding and trust among project team	○	○	○	○
Project team motivation, and presence of motivational aids	○	○	○	○
Level of complexity of the projects	○	○	○	○

Section 6.3: From your experience, to what extent do the following ***Organisational-related Factors*** impact on effective integration of experiential knowledge into BIM implementation?

	Extent of Impact			
	1 = Not impactful	2 = Less impactful	3 = Moderately impactful	4 = Highly impactful
Organisation’s leadership support for, and commitment to activities relating to the integration of experiential knowledge	○	○	○	○
Organisational culture (beliefs and values) that encourages activities relating to the integration of experiential knowledge (e.g. experimentation)	○	○	○	○
Organisation’s efficiency at leveraging experiential knowledge to improve decision making	○	○	○	○

Flexible organisational structure that encourages activities for integrating experiential knowledge through lateral communication	○	○	○	○
Organisational reward systems that incentivise activities for integrating experiential knowledge	○	○	○	○
Organisational infrastructural systems that support the integration of experiential knowledge (e.g. open workspace)	○	○	○	○
The size of the organisation (e.g. small, medium or large)	○	○	○	○
Organisational transparency and openness	○	○	○	○

Page 7: Section 7: Skills and Knowledge Inventory (SKI) of Decision-makers in BIM implementation

Section 7.1: This section highlights a set of **skills and knowledge** that are considered to be important for **key decision makers** in **BIM implementation,** now and in the future. Please, indicate your answers about the degree of importance of these skills/knowledge.

As one of the key decision-makers in BIM implementation, please, indicate the degree of importance of the following skills/knowledge to you, now and in the future (next 5years) as a BIM implementation decision-maker. Please, also indicate the degree of training/education needed to develop the skills/knowledge over the next 5 years? Kindly indicate your response on a scale of 1 to 4. (where 1 = Not important, 2 = Slightly important, 3 = moderately important, 4 = Highly important)

	Degree of importance (now)				Degree of Importance (future - next 5 years)				Degree of Training/Education needed (now)			
	1	2	3	4	1	2	3	4	1	2	3	4
Strategic planning (defining and planning the strategic goals and objectives to be achieved from implementing BIM)	○	○	○	○	○	○	○	○	○	○	○	○
Leadership (generating overall mission statement for BIM implementation and leading others through the whole processes of implementing BIM)	○	○	○	○	○	○	○	○	○	○	○	○
Scope and schedule management (identifying and defining the level of information and development required for BIM implementation)	○	○	○	○	○	○	○	○	○	○	○	○
Communication (communicating the goals, objectives and benefits for BIM implementation among all stakeholders effectively)	○	○	○	○	○	○	○	○	○	○	○	○

Human resource management (identifying and managing roles, responsibilities and expectations of all stakeholders involved in BIM implementation)	○	○	○	○	○	○	○	○	○	○	○	○
Procurement and material resource management (identifying and managing all material resources required to implement BIM)	○	○	○	○	○	○	○	○	○	○	○	○
Time management (managing personal and project time, processes and workflow in line with BIM execution plan)	○	○	○	○	○	○	○	○	○	○	○	○
Conflict management (resolving conflicts arising from workflows and among project stakeholder during BIM implementation)	○	○	○	○	○	○	○	○	○	○	○	○
Change management (identifying and adapting to changes in project workflows and technology relating to BIM implementation)	○	○	○	○	○	○	○	○	○	○	○	○
Financial management (establishing financial management strategy for project delivery during BIM implementation)	○	○	○	○	○	○	○	○	○	○	○	○
Risk management (identifying and clarifying areas of risks and likely obstacles to achieving the goals of BIM implementation)	○	○	○	○	○	○	○	○	○	○	○	○
Project management (understanding and managing the project lifecycle and environmental context for BIM implementation)	○	○	○	○	○	○	○	○	○	○	○	○

Quality management (developing policies to ensure quality project delivery during BIM implementation)												
Teamwork/collaboration (working collaboratively as a team with other stakeholders during BIM implementation)												
Negotiation (negotiating the use of resources, budgets and other BIM requirements and deliverables with all the project stakeholders)												
Multi-tasking and organisation (effectively managing two or more tasks relating to BIM implementation in an organised way)												
Software management (proficiency with use of common and state-of-the-art software tools to support decision-making)												
Motivation (motivating and inspiring all stakeholders to develop a robust project execution plan during BIM implementation)												
Critical thinking and Analysing (weighing the pros and cons of every possible solution to problems relating to BIM implementation)												
Policy knowledge (adequate knowledge and understanding of policies and protocols relating to BIM implementation)												

Page 8: Appreciation

Thank you very much for taking part in this survey. I anticipate that, with your help, the results will assist in improving the decision-making process through the effective integration of experiential knowledge into BIM implementation.

If you would like a copy of the results of the research, free of charge, please contact me using the contact details provided below:

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