A BIM-based Information Management Schema for Construction Activities Data-Flow Across the Project Life cycle

By

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Abstract

Excellent communication among project participants is critical to successful implementation of construction projects. However, the vast amount and variety of information and the physical dispersion of construction sites obstruct the flow and exchange of this information. Information management across the project life cycle is characterised by a system in which information exchange across projects is underutilise. Thus, threatening project success and productivity. Although BIM was introduced in the Architecture, Engineering, and Construction (AEC) industry to facilitate information sharing and management throughout the construction project life cycle, the existing medium of information transfer and retrieval is inefficient, resulting in numerous challenges in the information handling of construction projects. In addition, BIM within the AEC sector also presents a set of information management challenges, such as interoperability issues, poor information flow, and a failure to integrate design phase data into later construction project phases. To address these information management challenges across the construction project lifecycle, this study aims to develop a BIM-based information management schema for construction activities data-flow across the project life cycle.

The research begins with a review of the literature and employs a phenomenological design that adheres to the interpretive philosophical paradigm and a qualitative research technique. Then, a qualitative data collection strategy was used, which included multiple case studies of four UK construction firms, semi-structured interviews with experts from the selected construction industries, and document analysis. Finally, using NVivo 1.6.2 and thematic analysis, the collected data were qualitatively analysed. The literature review reveals several challenges that include poor pre-planning and design phase information, unspecified information according to each of the project phases, inadequate information needs/requirements. Other challenges are unclear goals for the generated information, interoperability issues and a lack of data standardisation, insufficient quality checks and assurance along the project workflow, among others. These challenges were also confirmed through the interviews and document analysis. Based on these identified challenges, a BIM-based information management schema was developed. The schema was presented in four (4) layers; the information components layer, the information requirements layer, the information flow and exchange layer, and the information delivery layer to address these challenges.

The schema was later validated qualitatively. The validation process evaluated the developed schema to examine its components, quality, suitability, and usefulness for supporting and improving information management processes in construction operations in the UK and beyond. The result of the validation process shows that some information areas must be given top priority in order to have a well-planned BIM information management system. These areas include consideration of soft-landing initiatives, outline of the information components at

each phase of the project life cycle, participation of all parties, including the client and facility manager, from the onset to the completion of the project, and data security, among others. In conclusion, the findings of this study will contribute to knowledge by providing a further understanding of BIM information management across the project life cycle. The proposed techniques could apply to various disciplines in the academic domain, including manufacturing, engineering, project/construction management, or facility management. The study would also benefit industrial practices by offering a direction or focus to those in charge of the construction operations and planning for managing information on construction activities across the project life cycle. In addition, the results and findings from the study could aid policymakers' drive to improve the adoption of BIM and digital twin for information management across the project life cycle.

Declaration

This academic paper is my work and has not been previously submitted to any other institution or organisation for assessment, publication, or other reasons other than the University of the West of England, Bristol, for the Doctor of Philosophy Degree (PhD). All other sources' materials have been appropriately recognised and cited following ethical standards.

Signed: Naimah T. Muhammed-Yakubu

Signature...……… ………………………………

Date…April, 2023………………………………………...

Dedication

This academic paper is dedicated to God Almighty, The Beginning and The End, for His Grace and for providing me with the determination and patience to make the most of the opportunities He has given me in life to begin and complete this research.

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List of Acronyms

10D BIM	10 Dimensions BIM
3D BIM	3 Dimensions BIM
5D BIM	5 Dimensions BIM
6D BIM	6 Dimensions BIM
7D BIM	7 Dimensions BIM
8D BIM	8 Dimensional BIM
9D BIM	9 Dimensional BIM
AEC	Architecture, Engineering and Construction
AIM	Asset Information Model
AIR	Asset Information Requirements
Al	Artificial Intelligence
ANT	Actor-Network Theory
AP	Appointing Party
Aps	Appointed Parties
ASP	Application Service Provider
BEP	BIM Execution Plan
BG	BSRIA Guide
BIFM	British Institute of Facility Management
BIM	Building Information Modelling
BIM GIS	Building Information Modelling- Geographical Information Systems
BIM	PIMF-BIM-Project Information Management Framework
BIMMS	BIM Management Systems
BMS	Building Management System
BLM	Building Lifecycle Management
BoS	Group-BuildofSite group
BS	British Standard
BSI	British Standard Institution
BSIM	Building Services Information Model
BrIM	Bridge Information Model
BSRIA	British Services Research and Information Association
CACP	Computer Assisted Construction Planning
CAD	Computer Aided Design
CAFM	Computer-Aided Facility Management
CALS	Continuous Acquisition and Life-cycle Support
CASE	Computer-Aided System Engineering
CCTP	Cahier des Clauses Techniques Particulières
CDBB	Centre for Digital Built Britain
CDE	Common Data Environment
CDM	Construction, Design and Management
CE	Central Executive
CIA	Construction Information Analysis

CIC	Computer Integrated Construction
CIC BIM	Construction Industry Council Building Information Modelling Protocol
CIC	Computer Integrated Construction
CIOB	Chartered Institute of Building.
CIS	Construction Information Standardisation
CM	Construction Management
CMMS	Computerized Maintenance Management
CMS	Carbon Management Communication
COBie	Construction Operation Building information Exchange
CPA	Construction Products Association
CPI	Construction Project Information
CPIC	Construction Project Information Committee
CPIx	Construction Project Information eXchange
CPRM	Construction Project Reference Model
CSI	Construction Specification Institute
CSs	Cost Savings
DARQ	Distributed ledger technology, Artificial intelligence, extended Reality, & Quantum computing technologies
DB	Design-Build
DCLG	Department for Communities and Local Government
DIs	Direct Impacts
DLT	Distributed Ledger Technology
DnC	Develop and Construct
DoE	Department of the Environment
DPoW	Digital Plan of Work
DTC	Digital Twin Construction
DWG	Drawing
DGN	Design
DIM	Design Intent Model
DXF	Drawing eXchange Format
EDI	Electronic Digital Information
EDMs	Electronic Document Management Systems
EIR	Employer Information Requirements or Exchange Information Model
EPIMS	Electronic Project Information Management System
EB	Episodic Buffer
ESPRIT	European Strategic Programme Research in Information Technology
FCD	Frameworks for Conceptualising web Databases
FM	Facility Management
FTP	File Transfer Protocol
GNSS	Global Navigation Satellite Systems
H&S	Health and Safety
HCA	Home and Community Agency
HVAC	Heating, Ventilation, Air-Conditioning
IAI.	International Alliance for Interoperability

iBIM	Integrated BIM
IBs	Intangible Benefit
ICON	Information for CONstruction
ICT	Information and Communication Technology
IE	Information Exchange
IEM	Information Engineering Method
IEW	Information Exchange Worksheet
IFC	Industry Foundation Classes
IFD	International Framework Dictionaries
IDM	Information Delivery Manual
iBIM	Integrated BIM
IMP	Information Management Process
CPIC	Construction Project Information Committee
AIM	Architectural Information Model
SIM	Structural Information Model
FIM	Facilities Information Model
IM	Information Management
IMP	Information Management Process
IOs	Increase Outputs
IoT	Internet of Things
IPD	Integrated Project Delivery
IPT	Information Processing Theory
ISO	International Standard Organisation
IT	Information Technology
LAP	Lead Appointing Party
LIDAR	Light Detecting and Ranging
LITE	Lifecycle Information Transformation and Exchange
LOD	Level of Development
LODIA	Level of detail, information, and accuracy
LOI	Level of Information
LOM	Level of Model Definition
LTM	Long-Term Memory
MIDP	Master Information Delivery Plan
MDS	Maximum Diversity Sampling
ML	Machine learning
MPDT	Model Production Delivery Table
MPVS	Maximum Phenomena Variation Sampling
MVD	Model View Definitions
NBS	National Building Specification
nD	n Dimensions
NHPAU	National Housing & Planning Unit
O&M	Operation and Maintenance
ODPM	Office of the Deputy Prime Minister
OfC	Offsite Construction

OIR	Organisation Information Requirements
OOD	Object-Oriented Development
PAS	Publicly Available Specification
PDF	Portable Document Format
PL	Phonological Loop
PIM	Project Information Model
PIP	Project Implementation Plan or Project Information Plan
PIR	Project Information Requirements
PMIS	Project Management Information System
POE	Post-Occupancy Evaluations
PPMS	Project Performance Monitoring System
QS	Quantity Surveyor
Qs	Quota sampling
QTO	Quantity Take-Off
RACI	Responsible, Authorising, Contributing, Informed
RIBA	Royal Institute of British Architect
RM	Responsibility Matrix
RQs	Research Questions
RVT	Revit
SL	Soft Landing
SM	Sensory Memory
ST	Structuration Theory
STEM	STandard for the Exchange of product Model data
STMs	Short-Term Memory system
TA	Thematic Analysis
TBs	Tangible Benefit
TIDP	Task Information Delivery Plan
TIM	Task Information Manager
TITS	Total Information Transfer System
TOPS	Total project systems
UI	User Interface
UK	United Kingdom
UML	Unified Modelling Language
Uniclass	Unified Construction Classification
VS	Visuospatial Scratchpad
VCM	Virtual Construction Model
WACM	Web-based Applications in Construction Information Management.
WIs	Wider Impacts
WISPER	Web-based IFC Shared Project EnviRonment
WM	Working Memory
XL	Excel
XML	eXtensible Markup Language
xR	extended Reality

Chapter 1

1 Introduction

1.1 Study Background

An efficient information management system is essential for successfully completing projects in the construction industry (Xun *et al*., 2014; Kahura, 2013). Thousands of pieces of information must be shared and transferred from one project phase to the other. However, as a result of the diversity of project sites, the information quantity and quality, and poor information management systems, information is fragmented, and efficiency is underutilised on construction projects (Lee *et al.,* 2018; Chen & Kamara, 2011; Hu, 2008; Cho, 2002). These problems are compounded by project complexity, industry fragmentation, and the still-in-use traditional information delivery structure for construction activities. Previous research has revealed that construction workers frequently handle and convey information manually throughout the building phases (Anumba *et al.*, 2008). Low productivity, waste, rework, time and budget overruns are the results (Chen & Kamara, 2011; Olawale & Sun, 2010). These issues frequently arise during construction projects, making it more challenging for the sector to function at its highest levels of productivity and effectiveness.

According to other studies, inadequate information management systems cause waste, rework, time, and cost overruns, which are global phenomena that impact every continent (Sheriff *et al*., 2012; Chen & Kamara, 2011). Based on this, a review of earlier studies on information management (IM) from the 1980s to the late 2000s shows that the main emphasis was on electronic digital information (EDI) to digitise the construction industry for construction project effectiveness and comprehensive information management systems. Moving on, information sharing using eXtensible Markup Language (XML) and EDI was common in the early 1990s and late 2000s, and later efforts focused on reviewing the accumulated data and figuring out how to use it effectively (Hajjar & AbouRizk, 2000; Caldas & Soibelman, 2003; Park *et al.,* 2009; Lee, 2009). While it was determined from the analysis of these earlier studies that the measures currently proposed by the construction information management methods are intended for increasing construction activities effectiveness, further investigation is still needed on the management, linking, and using the information generated on projects throughout the construction phases (Lee *et al*., 2018).

Additionally, the accuracy with which individuals prepare the information in authority and inadequate information management constrain the information's use and consistency. Electronic document management systems (EDMs)

(Qady & Kandil, 2010; El-Saboni *et al.*, 2009; Keefe *et al.*, 2009), groupware systems (Duque *et al.*, 2009), knowledge management systems (Khalfan *et al.*, 2010; Rezqui *et al.*, 2010; Dave & Koskela, 2009), web-based project management systems (Ryoo *et al.*, 2010; Senthilkumar *et al.*, 2010), and collaborative systems (El-Gohary & El-Diraby, 2010; Benjoaran, 2009; Zhang *et al.*, 2009) are additional initiatives that concentrate on developmental design and information management practices. This demonstrates how information management practices in the construction industry have undergone a step change over the years. However, these research methods and studies concentrated on a particular facet of information management (Chen & Kamara, 2011). For instance, some parts of the United Kingdom's (UK) construction industry gave information flow a lower priority than risk management and legal compliance. Others prioritise information transfer over workflow-related established processes to improve the final product (Sheriff *et al.*, 2012).

In another research, the construction industry adopted employing digital tools due to the importance of information management, and several studies and methodologies, including Project Management Information System (PMIS), Continuous Acquisition and Life-cycle Support (CALS), and Computer Integrated Construction (CIC), exist for managing information generated during the project phases effectively. But, the results from the research indicate that it is challenging using the data since it is collected as a single data set, such as electronic documents. Besides, they are insufficient for linking the data because they only focus on data presentation (Jung *et al.*, 2013; Jung & Joo, 2011; Jung & Kim, 2011).

Building Information Modelling (BIM) was developed to solve these problems with conventional construction information management techniques (Arayici *et al.*, 2012a). 3D models are used mainly for various assessments and studies, including energy, interference, solar, and viewing area analysis, among others (Lee *et al.*, 2017). However, while it is true that BIM uses three-dimensional parametric modelling to compile data produced throughout the project phase into a database to ensure linking the points of exchange, it is not utilised for managing construction information through consolidation of construction data during a project (Lee *et al.*, 2017; Jung & Woo, 2004). This explains the inability to keep accurate information and the difficulty of maintaining high-quality information in the construction process. A clear information management system is thus essential due to the enormous amount of information generated at every phase of the process. This study is established on this premise, to propose an information management schema for lifecycle information management of construction activities in a BIM setting.

1.2 Problem Statement

Due to its information-intensive nature, the construction sector generates a lot of data from its operations. In a typical construction project, thousands of drawings, specifications documents, letters and quotes, and other materials like meeting minutes, correction reports from the field, and several other vital documents are produced from separate construction operation works (Cha & Lee, 2018). While this information is generated at every phase of the construction process, it is frequently managed via documentation on the construction site (Cha & Lee, 2018; Chen & Kamara, 2011). This information must be consolidated for the project to be completed successfully. Modern construction also necessitates the cooperation of various professionals as a result of project complexity. Since information sharing and management directly affect the success of every project, regular information transfers between the project participants are required during this time.

In addition, ineffective information management and coordination frequently result in delays, cost overruns, and disagreements among parties, among other challenges, during construction projects. Thus, is reported by Egan and Lathan reported in the 1990s. They emphasised how crucial it is for design projects to coordinate information management. Egan (1998), for instance, asserts that the fragmentation of the construction process hampers efficient information management, collaboration, and communication among project stakeholders. He stated that poor information distribution had hampered the potential to comprehensively restructure and simplify the process of project delivery.

Furthermore, since the designing and construction of physical assets is a complicated process comprising a diverse group of parties with different levels of skill (Sage, 2015; Sang *et al.*, 2018), a continual understanding and extensive exchange of information among the various players is required for a successful project (Scheffer *et al.*, 2018; Ahankoob *et al.*, 2020; Al-Ashmori *et al.*, 2020; Dao & Chen, 2021). The immense potential of information technology to improve the management of construction operations phases is lost when information flow is created purely based on drawings. It is a significant problem since the uniformity of the numerous designs can only be verified manually. This manual verification is a significant source of potential problems, especially since the design are frequently generated by professionals from several fields, trades and other businesses. Inconsistencies can happen quickly and sometimes go undetected until late in the construction process, thus suffering high additional costs for ad-hoc site remedies. Design modifications are particularly challenging if they are not regularly recorded and communicated to all relevant parties (Kim & Grobler, 2009).

The insufficient information on paper is also a notable setback of preventing downstream applications from using the building design information directly for any analysis, calculation, or simulation; instead, it must be manually entered, which increases workload and introduces additional human errors (Larsson *et al.*, 2018). Also, for providing information to the client, the client would use significant energy and a lot of time gathering the necessary design documents and information into the FM system. When information is exchanged in this fashion, it is lost at each phase and must be deliberately and thoroughly reconstructed. Furthermore, the documentation from the project site comprises a lot of identical information that is often treated as single documents, making it more challenging to utilise the documents' information comprehensively (Cha & Lee, 2018) by the participating parties. Some of the documented information is generated onsite in paper form, archived as physical papers or as individual documents, and stored in a format determined by the person in charge of document preparation. Thus, requiring a lot of time and energy to use the construction information in these forms, and finding the information required necessitates extensive searching. In this manner, construction teams are unable to offer correct and just-in-time information, resulting in an information insufficiency or deficit and delayed decision-making (Chen & Kamara, 2011; Singhvi *et al*., 2003).

1.3 Gap in Knowledge

Information management (IM) has recently become a significant challenge in the Architecture, Engineering, Construction (AEC) industry. Critical reviewing of previous studies revealed specific inadequacies in information management and handling information about construction projects. One of these studies uses information and communication technology (ICT) to address information management challenges in construction projects. Solutions were proposed for these challenges by developing information management frameworks. These are classified into conceptualised Web Databases for Information Management (Garcia *et al*., 1998; Abudayyeh, 1998; He, 2003; Tam, 1999; and Deng *et al.*, 2001), Electronic Document Management Systems (EDMs) (Bjork, 1993, 2002; Finch *et al.,* 1996; Rezqui & Debras, 2006; Hajjar & AbouRizk, 2000), Construction Information Analysis (Rankin, Froese & Waugh, 1997; Shahid & Froese, 1998; Froese, Rankin, & Yu, 1997), and Web-based applications in construction information management (Aouad *et al.*, 1994; Rezgui *et al*., 1996; Faraj *et al.*, 2000; Abudayyeh *et al*., 2001; Dawood *et al.,* 2002; Mokhtar, 2002).

Even though Conceptualised Web Databases for Information Management included databases for information flow and exchange, the model focused on data transfer and less on information modelling and management, providing a sharable, stable, and organised structure of information requirements. On the other hand, EDMs categorise information management challenges into two groups: 1) difficulties arising from users' re-registration of documents in the database and 2) the systems' inability to comprehend and handle the information existing in the database or supportive documents. The strategy mimics paper-based procedures and the systems' incapacity to provide information accessibility upon project completion. The strategy also failed to address financial and property management challenges. Similarly, Computer Information Analysis developed information management applications to address practical information requirements difficulties in the construction industry, but the systems perform fewer specialised tasks and data processing, thus limiting their usage for information management. In construction information management, web-based applications provide a solution for data sharing among web-based documents. However, rather than aiming to develop a system to manage information, these attempts concentrated on addressing specific demands in the industry. For example, Abudayyeh *et al.* (2001) created a scheme to enable automatic creation of a specific cost estimations and reports, Dawood *et al*. (2002) examined management of drawings, and Mokhtar designed a model of intranet-based information. A comprehensive analysis of these challenges is essential for a dynamic approach to information management research.

Despite the challenges outlined above for IM of construction projects, BIM within the AECO industry also presents its own set of unique information management challenges (Cha & Lee, 2018; Zhang *et al.*, 2018; Olawumi & Cha, 2019; Pishdad-Bozorgi *et al.*, 2018; Dawood *et al.*, 2012). According to some of these studies, BIM IM systems concentrated on the compatibility of information throughout all phases of construction projects, with little effort on the delivery process across all project life phases.

For instance, these challenges can be classified into six (6) broad categories:

- Inability to deploy BIM in the design phase for BIM in the structural or FM data (Liu & Issa, 2012; Dawood *et al.*, 2012; Eastman *et al*., 2010; Caldas *et al*., 2005; and Dawood *et al*., 2003).
- Significant interoperability problems (Ozturk, 2020; Turk, 2020; Jiang *et al*., 2019; Pishdad-Bozorgi *et al*., 2018).
- Poor information flow and management on construction sites (Cha & Lee, 2018).
- Non-integration of design phase information into subsequent phases of the construction project (Volkov, Chelyshkov & Lysenko, 2016; Pandit, Yadav, and Vallabhbhai, 2015; William & Johnson, 2014; Couto, 2012; Takim *et al.*, 2008; 2009; Formoso *et al*., 1998)
- Inadequate information in the construction phase (Hajjar & AbouRizk, 2000; Caldas & Soibelman, 2003; Park *et al*., 2012)
- Unsuccessful linking of graphical and non-graphical data of projects (Chan *et al*., 2005; Caldas *et al*., 2005)

For example, Liu & Issa (2012), Dawood *et al*. (2012), Caldas *et al*. (2005), and Dawood *et al.* (2003) established frameworks for information exchange required to deploy BIM data in the design phase for BIM data in the structural or FM data. They focused on the compatibility of information exchange across all project phases but fell short of actualising a complete information system, generating databases, and combining data for data gathering and management across project phases. These studies exclude information accuracy, distribution format, and pre-construction requirements. According to practitioners, these are particularly significant because they enable standardised methodologies for using information models throughout the project life cycle. They would also allow the project team to make better use of time, resources, and expertise for decision-making throughout the project's development.

Pishdad-Bozorgi *et al.* (2018) investigated data handling challenges during the delivery procedure, from designing, constructing and operating the built asset. The study identified interoperability issues, as well as several inaccuracies in the importing process of Construction Operation Building Information Exchange (COBie). Difficulty in importing and using data generated at the design phase to the operation and maintenance (O&M) phase was also identified. Cavka *et al*. (2017) researched the absence of BIM experience required to determine sufficient BIM needs for management of information throughout the O&M phases. According to these studies, clients are unaware of the information required for operating the asset due to a lack of BIM expertise to analyse prospective information exchanges and an inability to obtain the information.

Cha & Lee (2018) investigated poor unstructured document information management and information flow on construction sites. Three significant challenges were noted in this study: i) a large amount of data hampers a project's completion due to incorrect handling of crucial papers. The information was less valuable due to its limited applicability on the construction site. This is due to the highly detailed information needed during the construction operations. ii) Unconsolidated massive amounts of generated data during the construction phase. Several documents, such as contract documents, drawings, meeting minutes, timetables, estimates, and submittals about the project, are kept informally by the individual who generated them and is often discarded once the project is completed. If additional construction quality problems or the need to double-check construction details occur as a result of a client request, it is almost not possible to locate or obtain the necessary information all over again. As a result, neither an input nor an output protocol, let alone instructions on managing the data, are provided for the various execution phases. Therefore, effectively utilising the information in the documents is challenging; iii) construction projects, being a one-time occurrence, rely substantially on experience and expertise. A specialist abruptly departs a job creates many issues for the project and the construction industry. The lack of a system for managing and organising such a massive amount of data results in an improper preservation of past lessons and the repetition of the same errors, which reduces the competitiveness of the company. Thus, the industry needs to establish, implement, and maintain proper information management systems.

Some studies have also neglected the integration of design phase information into subsequent construction project phases (Volkov, Chelyshkov & Lysenko, 2016; Pandit, Yadav & Vallabhbhai, 2015; William & Johnson, 2014;

Couto, 2012; Takim *et al.,* 2008; 2009; Formoso *et al.,* 1998). The design phase is considered a significant stage in applying BIM information management because it comprises the essential parameters of the other phases' information management model. Thus, non-consolidated information in the design stage limits the effectiveness of information throughout the project life cycle. Several important research projects on the methodology of construction information management have been undertaken by Hajjar and AbouRizk, (2000); Caldas and Soibelman (2003); and Park *et al.* (2012). These studies, however, focused on information aggregation and visualisation for managing construction information on a large-scale, and hands-on approaches for acquiring and utilising site information are lacking (Hajjar & AbouRizk, 2000; Caldas & Soibelman, 2003; and Park *et al*., 2012). Chan *et al.* (2005) and Caldas *et al.* (2005) investigated the linking of graphical and non-graphical data in projects. The studies provided a strategy for linking graphical data with project management data and a methodology for searching for relevant documents using graphical data. However, because the non-graphical data in these studies had a poor input format, it was impossible to correlate the information, so these investigations concentrated less on graphical data.

Thus, from the above points, it is evident that analysing information flow and interactions between different participants across the project life cycle is critical to resolving information management within a BIM setting. According to many industry experts, such a lifecycle information management approach to BIM is vital for producing unique outputs. As a result of the above-identified literature gaps, this study, therefore, emerges with the overall aim of *"developing a BIM-based information management schema" that would facilitate the analysis of information flow and interactions across various stakeholders throughout a construction project's whole lifecycle*. As proposed by Lee *et al. (*2018) and Arayici *et al. (2012*), a robust information schema for BIM deployment has huge potential for better information management of projects in the AECO industry.

1.4 Justification for the Study

In its 2017 construction strategy, the UK government has indicated that adopting digital technology is expected to result in more than £1.6 billion in productivity savings by 2030. (Project and Infrastructure Authority, 2017). Digital information management is expected to promote and transform the delivery of high-quality information flow, storage, use, reuse, and communication processes among stakeholders (Arayici *et al.,* 2012a). However, in addition to the fact that the AECO industry is far less prolific compared to other industries in adopting digital technology, there is also a lack of enough data on construction information management systems (Lee *et al.,* 2018). Furthermore, the UK Government's Transforming Infrastructure Performance: Roadmap to 2030 references information management thirty-seven times (37) to emphasise its importance. The strategy incorporates the Information Management Mandate, which replaces the UK BIM Mandate. This mandate began with the

Government Construction Strategy in 2011. The importance of information management in achieving better results in construction projects is also mentioned in the Construction Playbook. However, despite this acknowledgement, the industry is still far from having an all-encompassing approach to information management. As a result, the proposed BIM-based schema would fill that gap and offer a foundation for the industry to build upon to create a more robust information management platform, particularly within the BIM context.

1.5 Aim and Objectives

The study aims to develop a BIM-based information management schema for construction activities data-flow. across project life cycle. The following objectives help to attain the aim of the study, as presented in *Figure 1.1* below.

a. Investigate the needs for and benefits of information management for construction activities across the project life cycle.

b. Examine the BIM principles and standards guiding information management throughout the construction project life cycle.

c. Use multiple case studies of four construction firms in the UK as data collection strategy.

d. Based on the findings, develop a BIM-based information management schema for construction activity management of projects.

e. Evaluate and validate the developed schema.

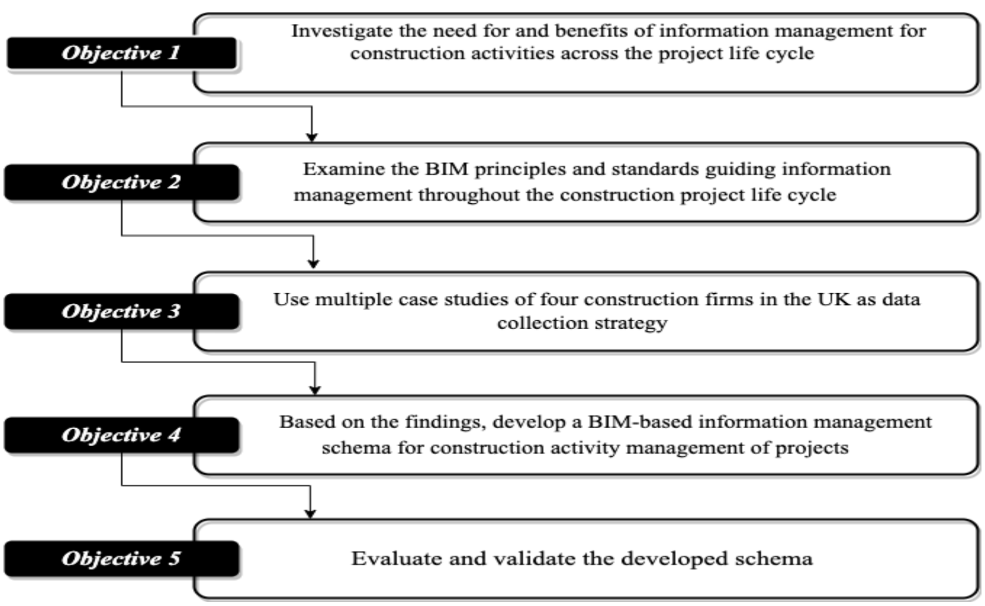


Figure 1. 1: *Research objectives*

1.6 Research Questions (RQs)

The undermentioned research questions (RQs) were developed during the study:

RQ1: What are the needs and benefits of an information management system for construction activities across the project life cycle?

RQ2: What are the existing BIM principles and standards guiding managing information throughout the construction project life?

RQ3: How can a data collection strategy be developed from using multiple case studies of four construction firms in the UK?

RQ4: How can a BIM-based information management schema be developed for construction activity management of projects?

RQ5: How can the developed schema be evaluated and validated?

1.7 Research Methodology and Approach

The proposed study is based on a subjective epistemological background. It investigates the concept of knowledge of reality based on participants' interpretations (Mehrad & Zangeneh, 2019; Cleland, 2015). As a result, the study employed a qualitative methodological approach. The concepts of interpretivism, idealism, and constructivism define qualitative research design. Upon critically reviewing the literature and an appraisal of the paradigms, the study adopts interpretivism, which provides for the active interaction of humans with the phenomenon of research.

The study's focus is to explore the opinions of UK construction industry experts regarding information management in BIM. Therefore, the underlying methodological approach to the study is a Case Study Strategy. As such, multiple case studies of UK construction organisations where BIM has been institutionalised and deployed on projects are selected as real-life contexts for the study. The research starts with a critical review of existing literature, then by semi-structured interviews, case study investigations, as well as documentary analysis. Then, as a case study design, the study examines the research phenomenon in a natural setting and explores the research problems from all aspects. The following is a summary of the research methodology. *Figure 1.2* depicts the research methodological diagram.

i) Reviewing existing literature to highlight the need and benefits of information management systems for construction activities.

ii) Additionally, qualitative methods using a case-study strategy in the form of semi-structured interviews and document analysis were adopted. The interviews were conducted with construction practitioners from the selected case studies, and documents of existing projects of the case study companies were used to throw more light on BIM principles for information management in the construction industry. These techniques facilitate understanding the industries' information handling approaches in BIM projects.

iii) The research focuses its investigations on four (4) case studies from the UK construction industry that are proficient in applying BIM for projects. These companies' consent, and their staff were requested to contribute to the research. The companies selected for the case study were labelled Company ‘A’, Company ‘B’, Company ‘C’, and Company ‘D’.

iv) Two (2) real-life construction projects were selected for validating the developed information management schema.

The following section lists the research instruments used in the research.

I). Critical review of the literature

II). Multiples case studies of four (4) construction companies in the UK

- Semi-structured interviews
- Document analysis

III). Data analysis (thematic analysis)

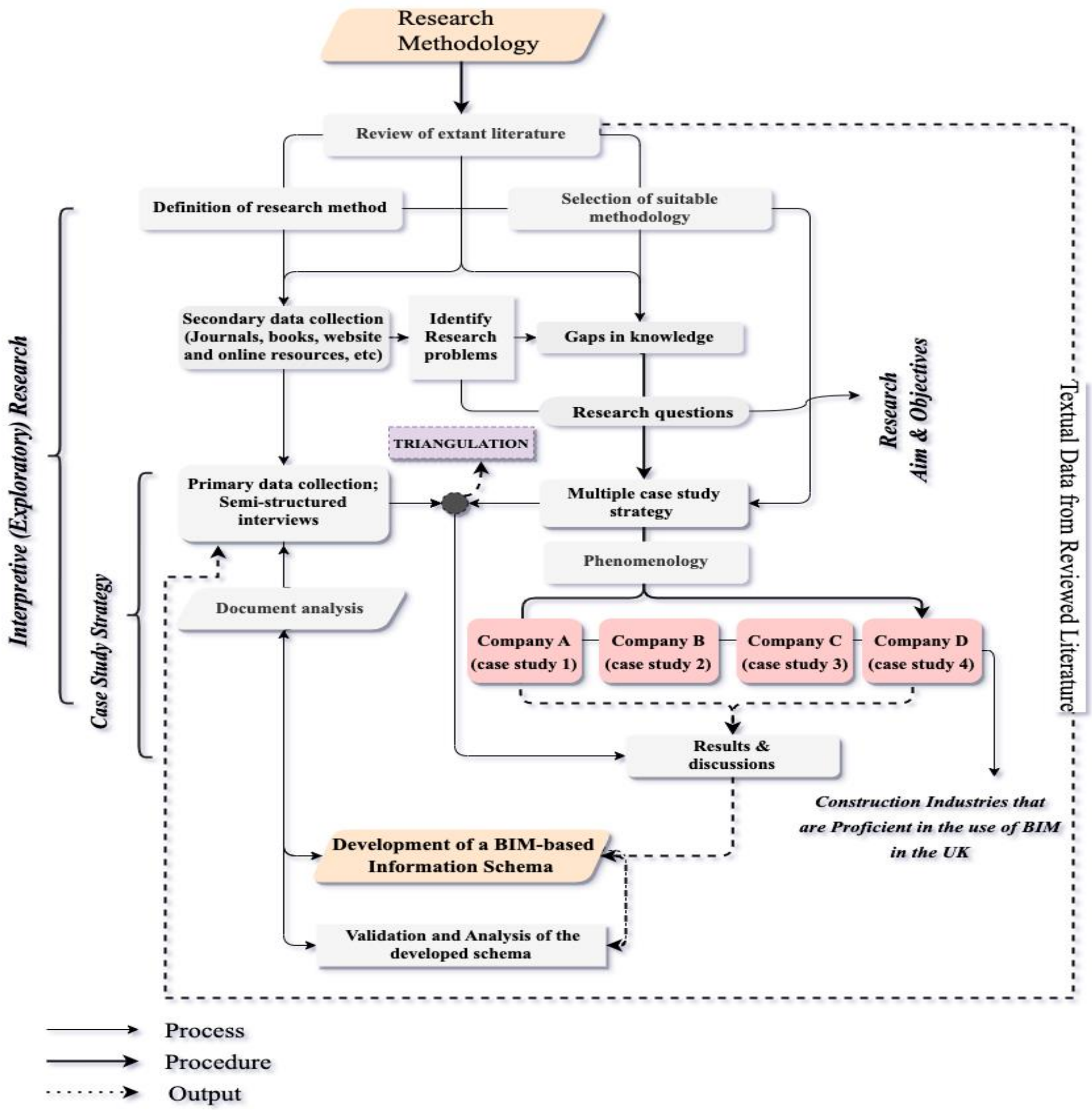
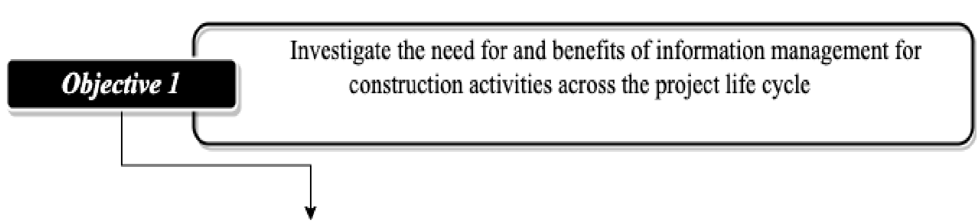


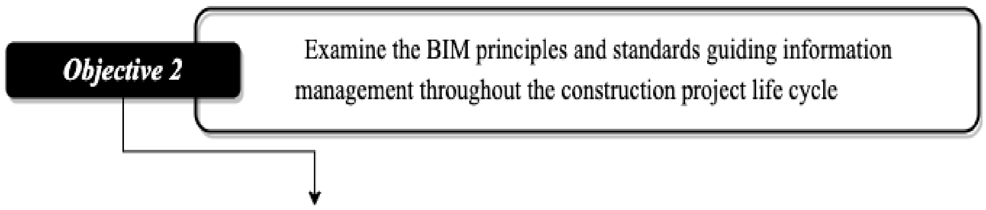
Figure 1. 2: *Research methodological diagram*

1. Methodology for objective 1



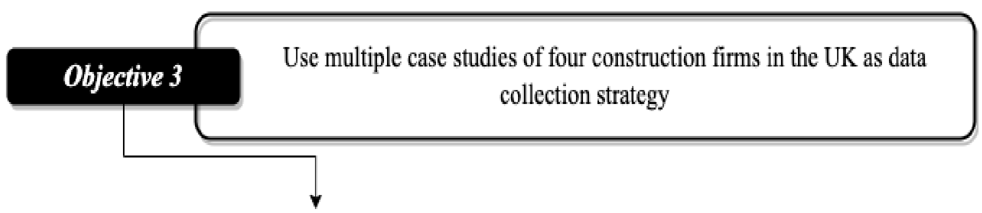
The above objective was achieved by a critical reviewing of the literature. The review aims to identify the need for and benefits of information management systems for construction projects. Peer-reviewed journals were the most reliable sources of information in this study.

2. Methodology for objective 2



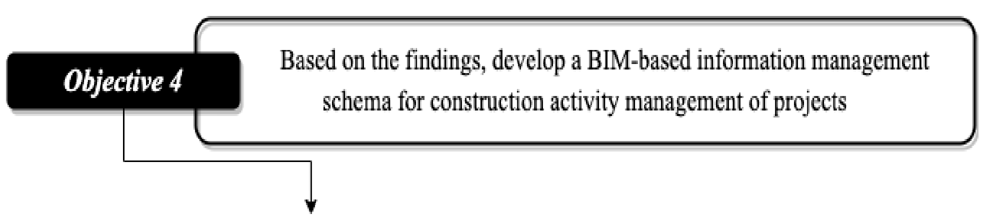
Based on objective 1, document analysis and semi-structured interviews with construction practitioners from the four construction companies were used to justify the needs for information management system. Document analysis enabled the consultation and study of current publications on the concepts and standards of BIM information management. Furthermore, document analysis makes obtaining relevant articles on information management in construction projects easy. Case study research design is another strategy employed to achieve the above goal.

3. Methodology for objective 3



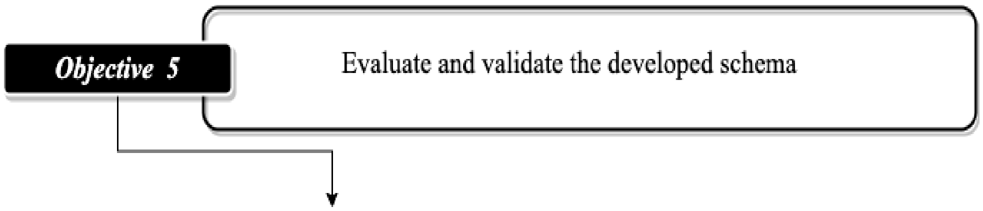
This objective was achieved with a qualitative data collection method involving document analysis and semi-structured interviews with experts from the four selected construction firms used for the study.

4. Methodology for objective 4



The study's research design, which included literature reviews, multiple case studies, document analysis, and semi-structured interviews, was deployed to achieve this objective.

5. Methodology for objective 5



After the development of the schema, two real-life construction projects were used to validate the schema using a qualitative approach. Thus, the developed schema was used to accomplish the above goal.

1.7.1 Sampling techniques

The purposeful, purposive, snowball and sampling techniques were selected for the study because they are suitable, fit and appropriate with the qualitative design approach adopted in the study. Researchers can freely select information-rich subjects (i.e., the interview respondents) using a purposeful sampling approach to grasp the studied phenomena comprehensively (Merriam, 1998; Patton, 1990; Naderifar *et al*., 2017). The snowball sampling strategy relies on referrals from participants who know additional participants willing to participate or take part or who have the necessary skills for what the study entails (Naderifar *et al.,* 2017). The method worked well for this project because it allowed for the recruitment of more participants. As a result of the features of the study's population and the objective (Lopez & Whitehead, 2013), maximum phenomena variation sampling (MPVS) was adopted for the case study. MPVS is a type of purposive sampling. This approach has been utilized in information management studies by (Palinkas *et al.,* 2015; Kalu, 2019), Naderifar *et al.*, 2017, and Shaheen & Pradha, 2019.

1.7.2 Multiple case studies

For this research, four (4) case studies were chosen to represent the population of construction firms using BIM. The selection was based on construction type i.e., BIM construction projects, and the type of project such as housing, infrastructure, office and commercial, and health care projects, among others. The case study allows for a deep investigation of complex topics in real-world contexts. The study adopts multiple cases simultaneously to generate a broader view of BIM information management processes in the selected cases. The sampling strategy adopted for the case study is *maximum phenomena variation sampling (MPVS)* or maximum diversity sampling

(Suri, 2011). This is a type of purposive sampling which aims to get the best representation of respondents in the sample as well as use the sample to represent the entire population to get the whole picture of the population being studied (Lopez & Whitehead, 2013). The researcher also defines the size of the sample for the case study, which is a characteristic of MPVS.

1.7.3 Semi-structured interviews and documentation

The study adopted a semi-structured interviews to gather textual data from UK construction industry experts to acquire a larger perspective of insight from the different construction experts' field and to gain a thorough grasp of the participant's field experience (Hancock *et al.*, 1998). In addition, a semi-structured interview was employed rather than focus group interviews to guarantee that individuals did not influence other participants during the interview process (Van, 2014). For the semi-structured interview in this study, a purposeful sampling technique (Merriam, 1998) and snowball sampling (Naderifar *et al.,* 2017) were used. A purposeful sampling technique was adopted to allow the researcher to freely select information-rich subjects to understand the phenomenon under investigation thoroughly.

Furthermore, snowballing was adopted as potential participants were invited to the study by participants who knew other participants. Thus, thirty-six (36) participants were recruited for the interview using purposeful and snowball sampling techniques. Stakeholders in the construction industry are the study's target demographic. Therefore, the job description of the participants, which falls under the role of an architect, civil/structural engineer, contractor, subcontractor, construction/project manager, site instructor/manager, BIM manager, BIM demonstrator or information manager, is one of the selection criteria for the interviews. Another consideration is the participants' years of experience. The adoption of document analysis as a qualitative research design was used in the study. The procedure entails assessing electronic and paper documents to evaluate, comprehend, and build upon the information they contain about BIM information management. The adoption of this strategy helps ensure triangulation in the study for added robustness and reliability.

1.7.4 Research approach

The research approach provides a comprehensive technique of data collection, interpretation, and analysis, along with steps for making general assumptions. However, it is based on the particular research problem. It is divided into two parts: the methodology for gathering data and the evaluation of that data. An inductive approach is required for qualitative data, and as such was adopted for this study.

1.7.4.1 Data collection and analysis

Data was collected and analysed qualitatively in the study. The existing literature, documentary reports, and semi-structured interviews with construction experts was analysis using thematic analysis achieved by NVivo 1.6.2 qualitative analysis software. The recorded conversation was translated through thematic analysis into written scripts, which were subsequently analysed to obtain the participants' views on information management on construction sites. Important themes were identified after the transcripts were read and coded rigorously and thoroughly to allow the main themes to emerge. Sections of interview text were thus categorised to establish themes' linkages and identify themes that were important to the study.

1.8 Unit of Analysis

Wepundi *et al.* (2012) asserts that, the unit of analysis of a study is the occurrence about which research generalisations are to be developed. It is considered the research's focus because it is what would be conveyed after the study. However, depending on the study setting, a unit of analysis could be an individual, team, project, artefact, organisation, or industry. A research project might include several analytical units, as in the case of this study. An artefact and an individual are the study’s units of analysis. To provide improved guidance for developing a robust schema, the BIM information management systems of construction activities and the many stages involved in the systems were evaluated using case studies of construction organisations or enterprises.

As a result, the schema to be developed is derived from a BIM solution, i.e., by analysing BIM to develop an information process to demonstrate that the schema being developed is valid and generalisable enough to be tested against a real-life example of construction operations. The unit of analysis is what has been studied in order to develop the BIM schema with the existing inadequacies in information management. The project is researching BIM and how a BIM-based information management schema for onsite building activities can emerge from the research. As a unit of analysis, individuals also contribute to the study by sharing their industry experience to inform the study's conclusion.

1.9 Contribution to Knowledge

There are various areas where contributions to knowledge could be viewed in academic work. Either through the theoretical framework or lenses through which others viewed the study or through the theories or methods used in the studies and the research questions. Nonetheless, contribution to knowledge refers to creating new knowledge based on research on previous studies to arrive at new knowledge. It involves doing extensive and rigorous research across the different areas of the subject under study. However, in this study, the following are the areas in which the study contributes to knowledge.

i. Contribution to academic knowledge

The study would contribute to the academic community by providing additional knowledge about BIM IM across the academic domain. The proposed techniques in this study could apply to various disciplines in the academic domain, including manufacturing, engineering, project/construction management, or facility management. The outcomes of the study would provide technical expertise in the administration of different projects requiring construction IM and assembly as well as academic insight, strengthening upcoming research in the subject area. Furthermore, the study provides academics, scholars, and practitioners with a comprehensive knowledge of construction information management, its enablers, and its effects on the success and performance of projects across the life cycle in construction firms.

ii. Contribution to practice

This research would also benefit industrial practices by offering a direction or focus for those in charge of the construction operations and planning for information management of construction activities across the project life cycle. Enterprises seeking a robust modelling framework for effective construction activity information management systems could leverage the findings. The proposed schema could also guarantee that the construction team or practitioners are appropriately informed about decisions that would improve project information management, increase productivity, and eliminate information-related or construction-related problems. The results of this study can also aid developers, builders, and construction companies in completing projects more quickly, successfully, efficiently, and effectively. In addition, the study will contribute to developing a BIM-based information management schema for construction activities data-flow across the project life cycle.

iii. Contribution to policy makers

Since the construction industry is highly fragmented and governed by strict regulations, the government's drive to adopt BIM is vital. This government's drive to adopt BIM in the construction industry applies to the UK and to all other countries, including the United States, Finland, Singapore, and Australia. In these countries, the government and its subsidiary authorities have played a key role in demanding and encouraging the adoption of BIM, although through different approaches, strategies, and initiatives. In the UK, BIM policies range from a firm mandate of Level 2 BIM, which corresponds to '3D collaborative BIM' from 2016 onwards in all publicly procured projects, to other encouragements and support initiatives via legislation changes. As a result of this action by the UK government, the adoption of BIM in the construction industry has been accelerated in the past few years, and this goal is heading towards being met. To further drive this initiative, policymakers have continued to improve on the previous BIM protocols to develop improved guidelines and new protocols/mandates. As this study is established on BIM information management across the project life cycle, the study will contribute to policymakers in various ways. The study suggests the involvement of the client and all other parties such as experts at the pre-design stage through to the project's inception to its completion, with quality checks and verification at various points along the project workflow. Thus, this study contributes to the understanding of these parties of an improved BIM IM process, the role of technology in the process, and a comprehensive understanding of the impact of the policy. In addition, the study will contribute to the government's initiatives towards digitalising the construction sector and its transition to net-zero carbon by the inclusion of project carbon information to the developed schema.

1.10 Scope and Limitation of the study

According to Creswell (2009), the extant review of similar studies in a particular area of research assists in determining how the scope of the research can be limited to a specific area of investigation or inquiry. As a result, a thorough search and review were conducted to determine the scope of this study. The study efforts were based on improving information management systems in the UK construction industry (big, medium, and small). Thus, the scope of the study is narrowed down to UK construction projects. In 2017, the UK government calculated that up to 345,000 housing were required in England each year, considering new household formation and the existing requirement for acceptable accommodation (HCA, 2018). The nation's expanding housing needs result from several factors, including overcrowding, serious affordability issues, a large number of young people staying with their parents for extended periods, and higher rates of homelessness. As such, efforts therefore need to be made to support the construction industry in the delivery of the required number of housing units.

The focus of this study is thus on residential structures in the UK. The lack of dwellings or housing is not a new topic in any country, including the United Kingdom. The UK government is concerned about a lack of suitable housing for the country's expanding and ageing population (Smith, 2013; DCLG, 2014). The Sustainable Communities and Baker's study of housing supply by the Deputy Prime Minister's office (DPM) in 2003 and 2004 brought the attention of the UK government to the scarcity of house creation compared to housing requirement estimates. In 2007, the National Audit Office emphasised the UK government's inability to meet the demand for new dwellings. The ODPM stated in 2005 that expanding housing and residential supply is a national priority that requires immediate attention (ODPM, 2005). As a result, a number of government and non-government initiatives added up to an annual housing output to address the UK's housing shortage. As a result, the study focuses on residential dwellings in the UK to contribute to the government's efforts in meeting the target of housing demand. *Table 1.1* summarises some of the findings on housing needs in the UK. Thus, the study focuses on residential dwellings in the UK to contribute to the government efforts in providing the required housing units.

Table 1. 1: *Yearly housing demand estimates in the United Kingdom by government and non-government organisations (Adapted from Heath, 2014)*

Bodies	***Requirement***	***Unit***
DCLG, 2007	240,000	2016
NHPAU, 2007	270,000	2016
BoS Group, 2013	230,000-333,000	2020
CIOB, 2014	243,000	2031

DCLG*: Department for Communities and Local Government;* ***NHPAU:*** *National Housing & Planning Unit;* ***BoS Group****: BuildofSite group;* ***CIOB****: Chartered Institute of Building.*

1.11 Dissertation Structure

The dissertation is divided into ten chapters. Chapters one and two introduced the study and background information. They explained the study's background and justification, including the need for and advantages of information management. The third chapter examines information management concepts and principles, including reviews of IM topics fundamental to the creation of the study, primarily BIM IM, standards, information requirements, interoperability and exchange formats, and information management approach principles. Chapters four and five discuss the study's theoretical and methodological approaches, including data collection and analytical methodologies for qualitative research. In chapter six, the research design and choices, including ethical considerations, were discussed. Chapters seven, eight, and nine covers the results, analysis and discussions of the findings from the adopted qualitative research design, the creation of the information management schema, and the validation procedure, respectively. Chapter ten concluded the study, discussing the limitations of the research, practical applications and implementations, and future directions, as shown in *Figure 1.3 below.* The ten chapters are depicted in this diagram, with each chapter outlining a portion of the topics discussed.

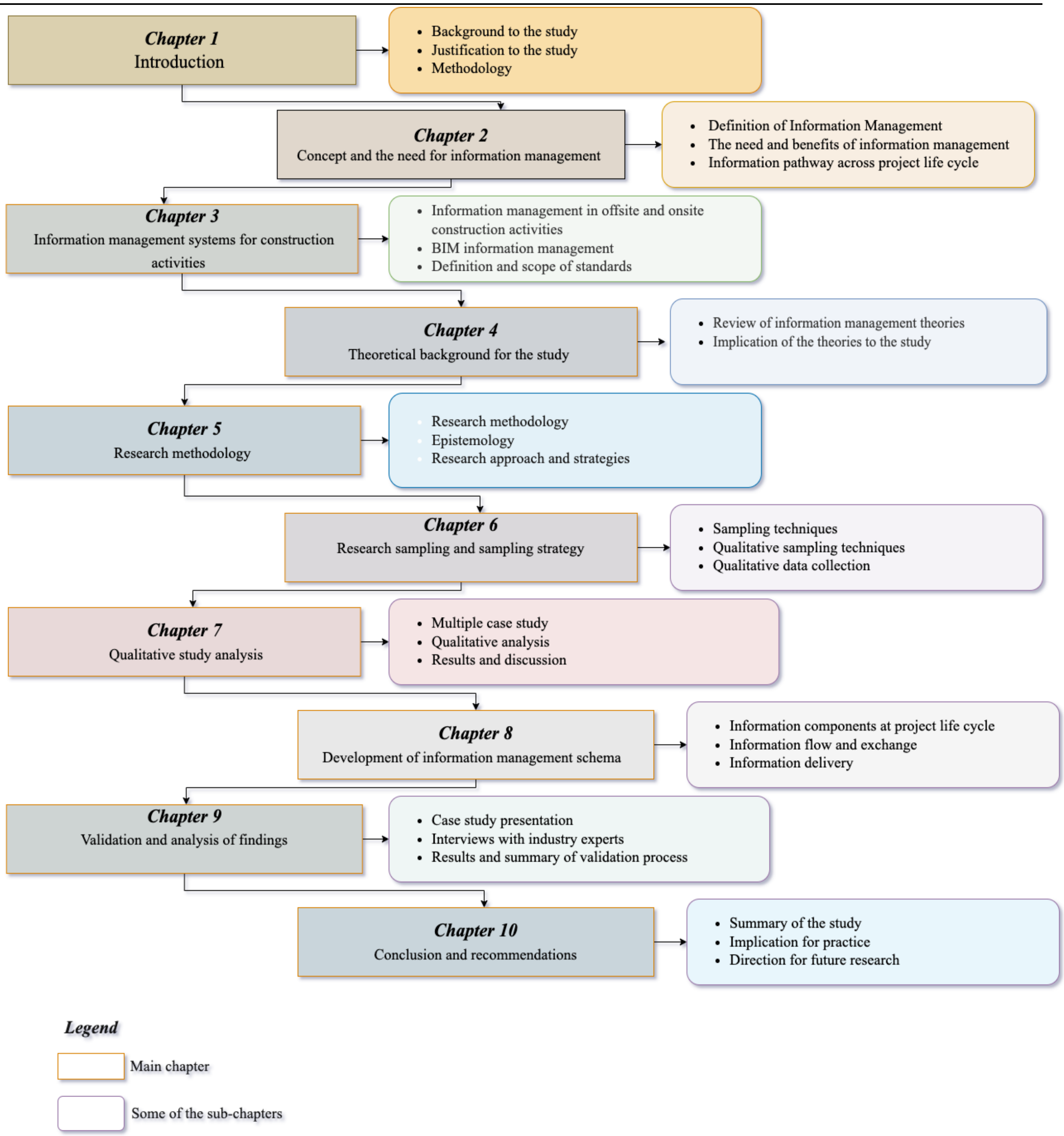


***Figure 1. 3**: Dissertation structure*

Chapter 2

2 Concept and the need for Information Management Systems across Project Life cycle

2.1 Chapter Overview

Massive volumes of information are created, managed, and used throughout a construction's project. Based on this knowledge, information management (IM) must improve the quality, availability, and timely transmission of information generated or created during construction and facilitate more efficient decision-making. As a result, this section establishes the meaning, necessity, and advantages of IM in the construction industry. Additionally, this chapter systematically lays out the information procedures from designing to constructing to operating and maintaining stages of the built asset to better understand information across the project phases for effective management. The chapter comprehensively discusses the primary topics that comprise information management during the design, construction, operations, and maintenance phases. It delves into the component RIBA plan of work and its BIM equivalent requirements during these stages. Furthermore, some features of BIM, such as project life cycles, levels of BIM, and dimensions of BIM, were also explored.

2.2 Need for Information Management across Project Life cycle

IM is essential for better decision-making, efficiency, and effectiveness, as well as for raising the quality, standard, accessibility, and prompt delivery of created or collected data. Information management has been defined in several ways, including *"life cycle management, information flow, organisation management, and information and communication technology"* (Nonato & Aganette, 2022), "*tasks and processes used to verify the quality and integrity of data input, processing, and generation*." (PAS 1192-2:2013), "*method of delivering timely and relevant information to decision-makers"* (Davis, 1997), and "*an organisation's systems and processes for creating and utilising high-quality basic data"* (Robertson, 2005). IM has been equated to information technology management from the viewpoint of information systems (Davis, 1997), which aims to communicate the relevant information to the user at the appropriate time, and for the right purpose (Robertson, 2005). According to Davis (1997), the terms "information management" and "management information systems" relate to both the organisation's function to design, build, and manage the system as well as its method of applying information technology to provide information and communication services (Davis, 1997). As a result, IM is an important enabler of digital transformation.

According to the literature, information is crucial in developing any industry that must be carefully managed for optimum efficiency. Gyampoh-Vidogah *et al*. (2003) states that, documentation was the first technique used for information management on sites. Then, it was thought to be the most effective means of communication and information creation among construction stakeholders. However, the current management of information is still characterised by cumbersome and slow paper-based information exchange, in addition to other factors like information silos, with each department managing and maintaining its own information or data, the lack of an exchangeable link for information accessibility, and the effect of information technology (IT) on information transfer (Gyampoh-Vidogah *et al*., 2003).

Construction organisations need to focus more on managing soft knowledge, such as tacit knowledge, judgement, and intuitive skills, to accomplish effective IM (Anand *et al.,* 1998). As a result, all implicit knowledge, judgement, and intuition systems are included in IM. Expertise, which is built on tacit knowledge, is used to create, integrate, and support decision-making in any organisation (Nonaka *et al.*, 1994). 90% of knowledge is embedded and synthesised in tacit form, and it is the basis of competitive advantage and crucial to the daily management of generated information and data (Nonaka *et al*., 1994). Hands-on skills, employee experiences (which vary depending on projects), special or technological expertise, instructions on dealing with complex challenges, best practices of team members, project leaders' expressions of opinions, and feedback from clients or project managers on projects are all examples of tacit knowledge in the AEC industry. Individual judgement is premised on the ability to make the best option possible regarding tacit information and reach a reasonable and sensible conclusion in decision-making (Nonaka *et al*., 1994; Woo *et al*., 2004).

Without direct evidence or reasoning, humans are born with the instincts to know, comprehend, or do many things. While intuitive skills are closely tied to tacit knowledge, they are a significant strategic resource that aids in completing a task (Woo *et al.,* 2004). Consequently, effective use of tacit knowledge, judgement, and intuitive talents is required to successfully apply IM. IM is critical for solving problems, innovating, and making sound decisions. In the traditional technique of managing information, vital information or knowledge is frequently lost because it is not passed on to others or appropriately managed. This technique creates an irreplaceable, costly, and time-consuming knowledge gap. As a result, industries and organisations require approaches or methods for gathering, managing, and storing information/knowledge from experts and employees to benefit the organisation or industry's future development.

2.2.1 Benefits of information management across project life cycle

The benefits of information management can affect every business or sector directly and significantly. While the wider impacts (WIs) result from utilising IM for beneficiaries other than organisations or participating teams, the direct impacts (DIs) result from the advantages of using IM for the organisation or participating parties (CDBB, 2018). The advantages of IM as applied to the construction domain is examined in this paper. As shown below in *Figure 2.1*, the benefits are in the form of cost savings (CSs), increased outputs (IOs), and tangible-TBs/intangible benefits (IBs).

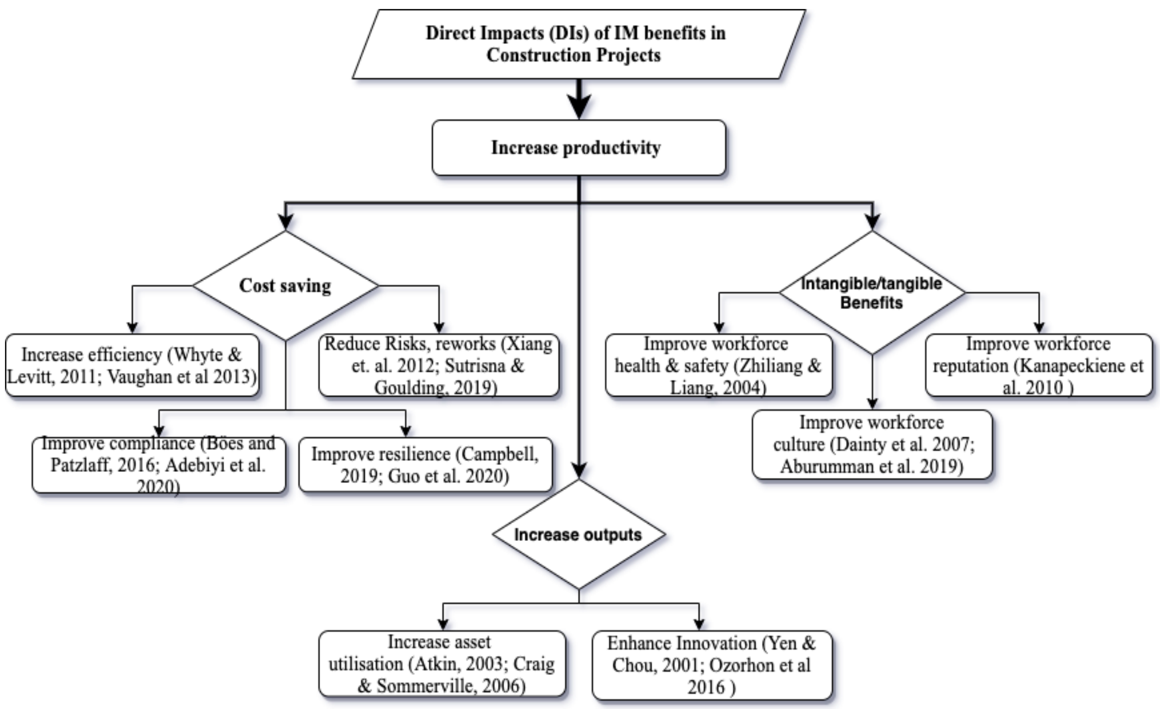


Figure 2. 1: *Impacts of information management systems on construction projects across its life cycle (Adapted from CDBB, 2018)*

2.2.2 Information pathway across project life cycle

All project stakeholders generate information throughout the project that must be shared. The transmission of information must be carefully planned to manage it effectively (Fontana, 2020). However, the principal objective of each phase is to make sure that all the data needed for a client’s signing off a project stage is appropriately captured inside a collection of documents at the conclusion of the stage (RIBA, 2020; Watkins *et al.,* 2020). The objective is twofold: (i) the information generated at the end of each phase reflects the client's diverse choices, which will influence how the next stage develops; and (ii) the information generated at the completion of each phase informs the project teams about the relevant information to start and use in the following construction phase.

These two objectives lead to the agreement on the procurement strategy and the establishment of the particular project's information requirements. This agreement is based on choices made by the engaged teams or external parties during project or design reviews (RIBA, 2020). The information at the end of one stage must be linked to the information required at the next stage and the methodology used to determine the information to create continuity. Information exchange begins at stage 0 in the Royal Institute of British Architects Plan of Work (RIBA plan of work), with the decision to begin the construction of the project and concludes at stage 7 with the information necessary for the project to be used throughout its life cycle (Nguyen *et al.*, 2020; Foxell, 2020). There are eight (8) information exchange stages during the life cycle of a project, as depicted in *Figure 2.2* below.

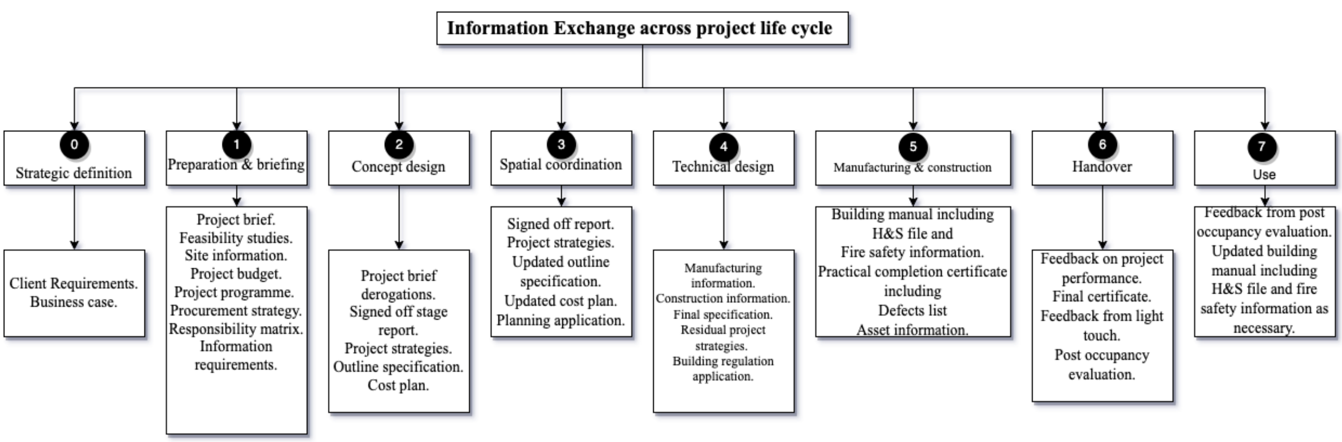


***Figure 2. 2**: RIBA plan of work for the information exchange across project life cycle (Adapted from RIBA, 2020)*

The objective of stage 0 is strategic, and the data acquired here specify the most effective strategy to satisfy the client's objectives (Watkins *et al.*, 2020; Ojo & Pye, 2020; Asare *et al.*, 2020). It outlines and develops the business case and selects the appropriate team to deal with strategic issues. stage 0 outputs are passed on to stage 1, which establishes the project and the several skills that will be required (Adedotun & Pye, 2020; Asare *et al.*, 2020). At this point, much of the information is focused on the project requirements, and the information requirements for each stage are also established. stage 2 introduces the design concept and ensures that the tasks are carried out in accordance with the stage objectives (Asare *et al.*, 2020). However, providing too much information at stage 2 could distract the design team from determining the optimum project approach, and providing too little information could render stage 3 ineffective (RIBA, 2020). Information is particularly crucial at this stage because it influences the overall project's path as well as the skills of the collaborating teams in developing the information requirements for stage 3.

stage 3 aligns the design physically and precisely outlines the demands for production and construction before stage 4. At this stage, the project's design team and specialised subcontractors provide most of the information needed in stage 4. stage 3 information must be appropriately integrated to ensure that the planning for the building's construction in Stage 4 is based on up-to-date information (RIBA, 2020; Cartlidge, 2020). Most of stage 5's content relates to the building's production and construction, as well as any associated inspections, reporting, and site query resolution (RIBA, 2020). Information from stages 4 and 5 is typically shared simultaneously in projects. For the building to function as intended, those establishing the information needs in stage 5 must determine what information is necessary for the structure's effective use for it to perform as planned (Cartlidge, 2020). stage 6 information focuses on the construction/project team resolving any issues and completing the tasks necessary to complete the building contract in preparation for stage 7, during which the building is in use until it reaches the end of its life cycle (Cartlidge, 2020).

2.2.3 Challenges of information management

The inadequacy of an IM system frequently leads to information loss since it is not correctly managed, denying others who might want to use the information the chance to do so, as finding the information in a conventional way requires time. Teams of specialists are frequently a clearly defined characteristic of the information produced on the site. As construction information management is structured and organised into efficient project teams, the information must be accessible to all the specialists participating in the construction project. The information is frequently based on the differing opinions of the professionals employed in the various functional areas of the construction project, and the interchange is conducted similarly to how it was done in previous decades. Also, after the computer creates the data, it requires reformatting before it can be imported and reused, frequently leading to mistakes, misinterpretations, and the loss of important data. As a result, for a better construction project, coordination of this information flow is required.

For example, some of the challenges identified in prior literature are issues with construction stakeholders implementing change (Deng *et al.,* 2001), technological malfunctions and other structural issues (Tam, 1999), and significant data transfer issues (Garcia *et al.*, 1998; He, 2003). Other challenges, as identified in other recent studies, include inaccurate information (Cha & Lee, 2018), unclear definitions of the roles and responsibilities of project teams, contractual obligations, and liability (Graham, Chow & Fai, 2018; Maleeva, Selyutina, and Frolova, 2019), and difficulties with information transfer and management of projects on the construction site.

As such, the construction industry needs to develop a better information strategy given the easily accessible and rapidly evolving information technology (IT). However, although the technology is readily available, it presents a challenge in meeting the evolving requirements and points of view of the information and data exchange systems of the many professionals involved in the construction process (Dawood & Akinsola, 2002). Thus, the answer to these problems must incorporate the qualities that define data and information quality requirements, namely correctness, consistency and reliability, and accessibility (Rojas & Songer, 1999). When information is exchanged, it is accurate if it retains its genuine value for the particular situation of information objectives and is consistent when it retains its significance after being exchanged.

2.2.4 Analysis of the literature review

The review of literature in the study presents an overall view of various analyses of BIM information management systems and provides the research background and guidelines. The literature analysis revealed various information challenges that are grouped into three. They are (1) Challenges with previous information management approaches, (2) Deferred on-site decision-making and (3) BIM information management challenges. These issues were reported at various project life cycle stages. Based on this understanding, the literature referred to several issues discussed and summarised in *Table 2.1* below.

Table 2. 1: *Some identified information management challenges from the literature*

S/n	Challenging Features of Information Management	References from the literature
1.	***Challenges with previous information management approaches***	
	EDMs	El-saboni *et al*, 2009; Keefe *et al.*, 2009; Khalfan *et al.*, 2010
	Groupware Systems	Duque, *et al.*, 2009, Froese *et al.*, (1997); Shahid & Froese, (1998)
	Knowledge Management System	Dave & Koskela, 2009; Khalfan *et al.*, 2009; Rezgui *et al.*, 2010
	Web-based Management Systems	Ryoo *et al.*, 2010; Senthikumar *et al.*, 2010
	Collaborative System	Benjaoran, 2009; El-Gohary *et al.*, 2010; Zhang *et al.*, 2009
2.	***Deferred onsite decision making***	
	Inefficient information exchange	Singhvi & Terk, 2003
	Ineffective on-site inquiries and interactions	Chen & Kamara, 2011
3.	***BIM information management challenges***	
	Undefined organisational structure	Davenport, 2000; Sheriff *et al.*, 2012.
	Lack of expertise in information management strategy	Davenport, 2000
	Insufficient information needs/requirements	Matarneh *et al.*, 2019, Cavka *et al.*, 2017, Lee *et al.*, 2013; Kelly *et al.*, 2013.
	Inaccurate or incomplete information along the project workflow	Cavka *et al.*, 2017; Gao & Pishdad-Bozongi, 2019
	Unclear pre-planning and design phase information	Daluwatte & Ranasinghe, 2020
	Insufficient information in the construction phase	Xu *et al.*, 2014), Monteiro & Poças Martins, (2013)
	Inability to access essential information for operation, maintenance and handover phase	Cavka *et al.*, 2017, Lu *et al.*, 2018, Pishdad-Bozorgi *et al.*, 2018 Kang & Choi, 2015; Rail Baltica, 2019
	Interoperability issues and lack of data standardisation	Gao & Pishdad-Bozorgi, 2019; Pishdad-Bozorgi *et al.*, 2018; BIFM, 2013

2.2.4.1 Challenges with previous information management approaches

Various approaches to information management, including Electronic Document Management systems (EDMs) (Khalfan *et al.*, 2010; El-saboni *et al.*, 2009; Keefe *et al.*, 2009;); Groupware Systems (Duque *et al.*, 2009), Knowledge Management Systems (Rezgui *et al.*, 2010; Dave & Koskela, 2009; Khalfan *et al.*, 2009), Web-based Project Management Systems (Ryoo *et al.*, 2010; Senthilkumar & Varghese, 2010), and Collaborative Systems (Benjaoran, 2009; El-Gohary *et al*., 2010; Zhang *et al*., 2009) were mentioned in the literature. Particularly about some of the ineffectiveness of these approaches. For instance, according to Björk *et al*. (1993), EDM techniques focused on managing documents in digital format rather than the information contained inside those documents. Froese *et al*. (1997) and Shahid and Froese (1998) reported on web-based systems that they have not resulted in the creation of IM applications to meet the real-world needs of the construction industry despite being vital for developing construction information management systems. Other approaches, like groupware systems, knowledge management systems, and collaborative systems, also attempted to develop a system to manage information, but these initiatives are concentrated on meeting particular demands in the construction industry.

2.2.4.2 Deferred on-site decision making

Inefficient information exchange on construction sites can result in disregarding critical concerns that call for an immediate reaction, which may delay making the right judgments (Singhvi & Terk, 2003). According to Chen & Kamara (2011), ineffective on-site inquiries and interactions between project participants lead to delays in decision-making, resource waste, cost overruns, and schedule overruns.

2.2.4.3 BIM information management challenges

Some of the principal challenges emphasised in the literature are discussed below. This is fully represented later in the chapter.

(a) Undefined organisational structure

Since projects are the central objective of construction industry organisations, a pure developmental understanding or assessment does not adequately capture the overall information generated, exchange, and managed/maintained in the organisations. It also does not allow industries engaged in many projects to adequately manage information across projects. Furthermore, the internal industry-specific information management issues brought on by the rising digitisation of information assets are not considered, as mentioned by Davenport (2000) and Sheriff *et al.* (2012).

(b) Lack of expertise in information management strategy

Information managers are essential to the administration of BIM information management. However, most information managers are unaware of the broader issue regarding information management profession in the construction sector or have only a hazy understanding of it (Davenport, 2000).

(c) Insufficient information needs/requirements

Several studies, including those by Matarneh *et al.* (2019), Cavka *et al.* (2017), Lee *et al*. (2013), and Kelly *et al.* (2013), commented on the difficulties in establishing information requirements in the BIM model. For instance, Matarneh et al. (2019) stated that, while BIM can streamline information flow among project teams throughout the asset lifecycle and facilitate information model handover and close-out to operation and facility management teams, the information flow is neither seamless nor automated, and there are numerous technical issues to contend with.

(d) Inaccurate or incomplete information along the project workflow

Another critical point in the literature is the information's accuracy and significance. Cavka *et al*. (2017) noted that great attention must be accorded to the amount of information incorporated into the model because information overload might occur and end up in a massive amount of unused information. Gao and Pishdad-Bozongi, 2019, also stated that human errors need to be considered when assessing data accuracy because they are unavoidable when users enter information into the asset model or the COBie excel sheet.

(e) Unclear pre-planning and design phase information

Daluwatte and Ranasinghe (2020) reported information management challenges during the design phase. According to him, pre-construction planning helps gather knowledge, expertise, consistency, and dependability over a project. Unfortunately, risks from insufficient site investigation, relationships between professional staff during the planning stage, a delay in obtaining designers for information, and an extension of the bid validity period significantly contribute to the failure to obtain the significant/necessary information needed for use in the project phases (Daluwatte & Ranasinghe, 2020). Xu *et al.* (2014) also reported that because building designs have become more sophisticated, managers in the project find it extremely challenging to precisely calculate the time of construction planning and scheduling.

(f) Insufficient information in the construction phase

Getting the building in preparation for use is implemented during the construction phase. According to Xu *et al.* (2014), the phrase creates the majority of the information for a project. He insisted that the project's implementation management is the most crucial task to be accomplished all through the construction stage. As such, when there are insufficient descriptions/definitions of the model development and uses at this stage, each entity involved in a BIM project creates its model to meet its needs. Basically, to meet the requirements for a cost estimate and quantity take-off. This lack of information management between designers and contractors due to the siloed information may compel the contractor to redesign the project from the initial concept (Xu *et al*., 2014; Monteiro & Poças Martins, 2013). Hence, jeopardising the effective use of the information, resulting in reworks, unnecessary costs, and waste of time and human resources.

(g) Inability to access essential information for operation, maintenance and handover phase

Information from the design and construction phase is frequently insufficient and arrives in an inappropriate format for the operation and maintenance phase (Cavka *et al*., 2017). The material, they continued, is not organised correctly and has too many inconsistencies to be put to good use. They emphasised that incompleteness of the information leads to errors and information loss in another study by Lu *et al.* (2018). Additionally, the manual entering of information into operation and facility management systems is frequently required (Lu *et al*., 2018). In another study, the facility manager receives much information on paper that need to be entered into the operation and facility manager systems instead of the automated format (Pishdad-Bozorgi *et al.* (2018) and Gao & Pishdad-Bozorgi 2019). Kang & Choi, (2015) also added that as a result of the medium of transfer, the facility management spend much time searching for the needed information for the asset operations. Data loss during the flow and delivery process is also evident when data is transferred from the construction to the operation phases, necessitating the need to recreate the database for the operation phases (Rail Baltica, 2019). In the lifecycle of an asset, the handover phase of the BIM information management process (soft landing) is crucial. However, problems with the handover phase or non-inclusion of soft-landing initiates have been documented in several pieces of literature, as well as a lack of involvement of facility managers or its equivalent experts at the design and construction stages, frequently resulting in problems during the commissioning (Lu *et al.*, 2018).

(h) Interoperability issues and lack of data standardisation

A notable setback to construction information management is the lack of data standardisation. The identification of this issue has prompted the creation of several standards for standardising product models. Such standards include the IFCs by the AIA and STEP by the ISO. Nevertheless, despite these efforts, interoperability concerns among the model and the operation and facility management system have been reported (Gao & Pishdad-Bozorgi, 2019; Pishdad-Bozorgi *et al.,* 2018). For instance, Pishdad-Bozorgi *et al.* (2018) complained about their difficulty attempting to import a COBie spreadsheet into a Revit model. They pointed out that despite interoperability being considered from the beginning of the project, the error nevertheless happened. In addition, the method of exchanging data in the BIM model and operation and facility systems was noted by BIFM (2013) as not an easy process/procedure. For example, the incorporation/integration of BIM and CAFM has been chastised for its lack of data interoperability, especially its inability to effectively transfer facility and logical operation information (BIFM, 2013). Others challenges with BIM IM include no clear information strategy, unavailable resources for managing information, low-quality information and data security.

2.3 An Overview of BIM

The acronym BIM is a comprehensive expression that specifies, produces, and manages information digitally about a constructed asset such as residential dwellings/housing, highway, tunnel, or bridge. BIM according to ISO 19650:2019 is defined as "using a shared digital representation of a built asset to facilitate the design, construction, operation and maintenance processes and provide a reliable basis for decisions." In addition, transforming infrastructure performance: Roadmap to 2030, published by the Infrastructure and Projects Authority on September 13, 2021, defines BIM as "*...a combination of process, standards, and technology that enables the generation, visualisation, exchange, assurance, and the subsequent usage and re-usage of information, including data, to form a trustworthy foundation for decision-making to the benefit of all those involved in any part of lifecycle of a project.*" This life cycle covers the projects' inception, procurement and delivery, asset and facility management, maintenance, refurbishment, and asset's end of life or disposal or re-use.

The advantages of BIM in projects have added value to the lifecycle of construction project. For example, it improves the quality of the design, prefabrication, the effective simulations of construction schedule and the transfer of crucial information to the asset owner (Messner *et al.*, 2019). Additionally, BIM offers early collaboration among various stakeholders, earlier project visualisation, earlier detection and correction of errors and omissions in the design, and accurate retrieval of quantities for cost projections (Sacks *et al.*, 2018).

2.3.1 BIM Uptake in the UK

The mandate for BIM adoption in publicly procured projects has resulted in an increase in its uptake, with the UK currently ranking among Singapore, the United States, and Scandinavia in BIM usage. Architects and larger contractors in the UK ranged the highest in using BIM, whereas service engineers, facilities managers, and smaller contractors use it less. According to the 2011 NBS BIM study, 13% of respondents used BIM. By the

2020 survey, this figure had risen to 73%, as shown below in *Figure 2.3.* Although only 20% of clients requested BIM Level 2 on all projects, according to construction manager (CM) BIM survey (2017), 49% of clients did not required BIM on their projects. Another survey of 173 manufacturers conducted in November 2017 by National Building Specification (NBS) in partnership with the Construction Products Association (CPA) found that about half of the manufacturers believed the BIM mandate had had a lot of setbacks due to non-strict enforcement.

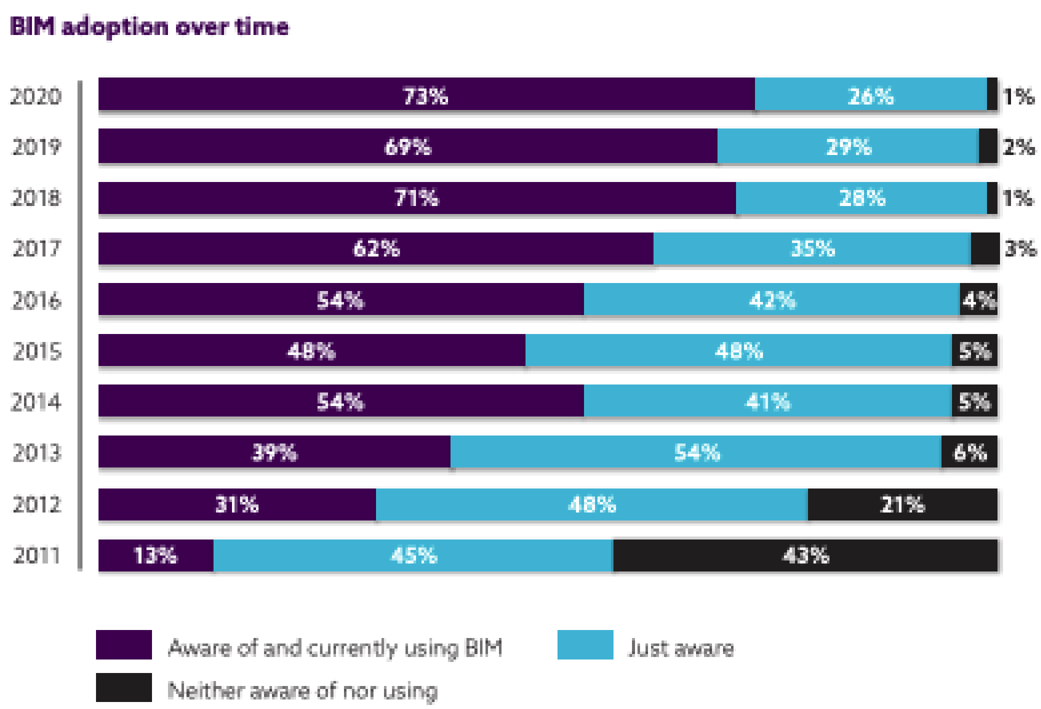


Figure 2. 3: *NBS survey on BIM awareness and 'use' 2011 vs 2020 (NBS report, 2019)*

In addition, the NBS 2018 National BIM Report, published in May 2018, stated that 62% of respondents did not believe the government had enforced the BIM mandate. However, the NBS National BIM Report in 2019, 69% of the survey respondents are aware of and are using BIM. Also, the analysis revealed that a dynamic industry was growing, coupled with a drop in awareness of government operations. Furthermore, with the NBS's years of conducting surveys with architects, engineers, technologists, contractors, and manufacturers, it has become evident that correctly deploying BIM is a huge task. It requires investing time and energy in it. Workflows and processes need to be modified. While BIM adoption is challenging, it provides benefits to firms that use it. Most (71%) of the individuals who have used BIM say it has increased their productivity. Over half (57%) of those who have yet to implement BIM agree as well, and 40% see the same result if they embrace it. Thus, the vast majority of users and non-users agree that BIM improves the coordination of construction documentation (85% and 76%, respectively). Likewise, it minimises the probability of problems emerging, according to 72% of BIM users and 64% of non-users of BIM, as depicted in *Figure 2.4.* All of these are favourable consequences for the construction companies as well as the clients who hire them. However, there is a divide between those who have implemented BIM and those who have not. Only slightly more than a third of non-users believe that clients force them to use BIM (NBS Report, 2020).

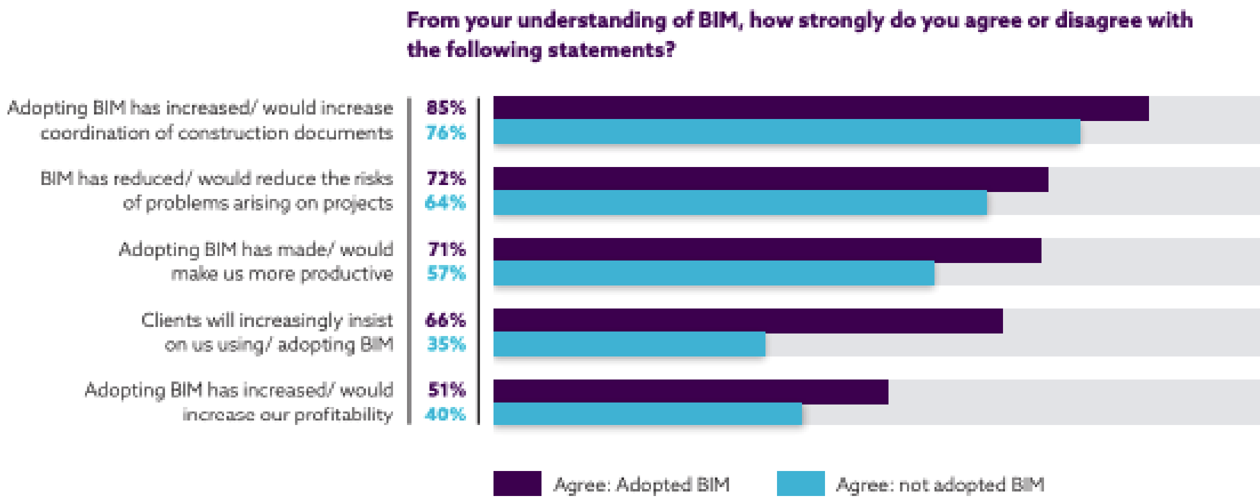


Figure 2. 4: *NBS survey on Benefit of BIM to the construction industry (NBS report, 2019)*

From the NBS survey, it was also believed that BIM and effective information management serves as a basis for adopting new digital technologies and methods of operation. These technologies work with BIM to increase design visualisation for clients, technical data exchange with other participating project team members, and link multiple types of data across the project and within an asset. The majority of individuals currently use cloud computing (42%) and immersive technologies like augmented, virtual and mixed reality (38%), as represented in *Figure 2.5.* However, the benefits of technologies like Internet of Things (IoT)/sensors, Analytics and Big Data technologies, DARQ technologies; 3D printing, and drones, are yet to be fully recognised in their adoption with BIM in the industry (NBS report, 2019).

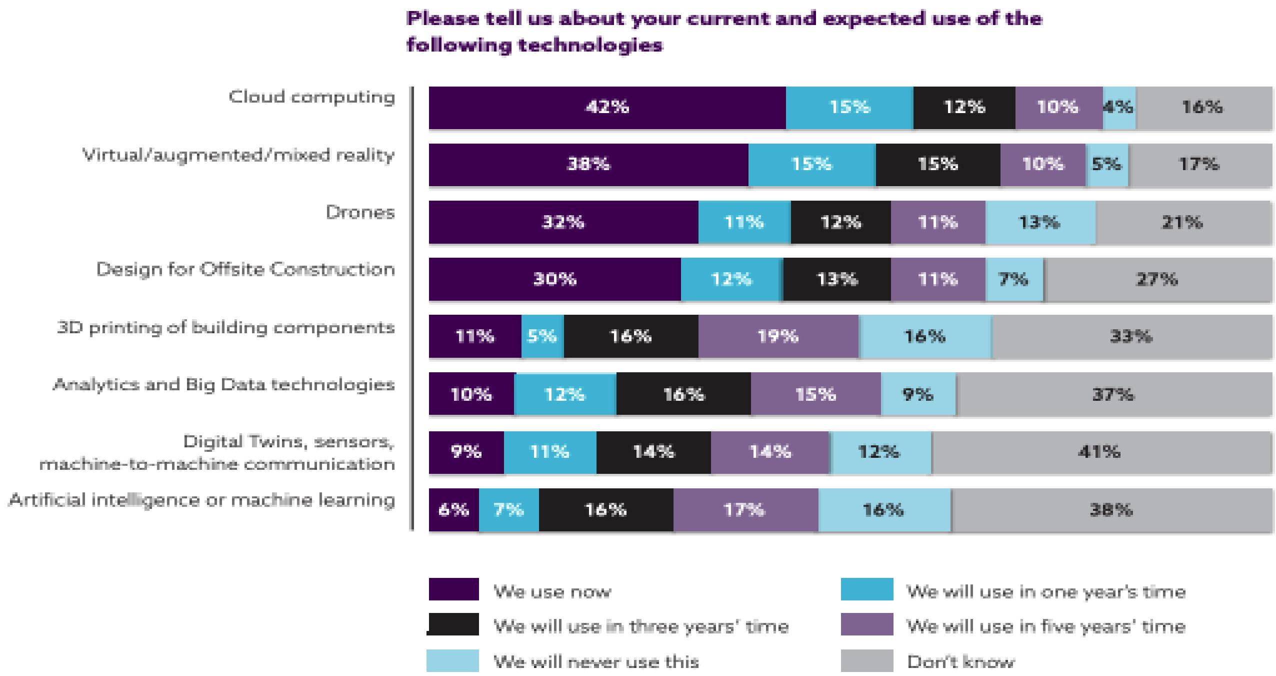


Figure 2. 5*: NBS survey on the use of digital technology with BIM (NBS report, 2019)*

2.4 Procurement Methods

Several procurement approaches have been suggested as more suitable for BIM implementation. Concurrently, BIM implementation has an impact on project coordination. Several approaches to the implementation of BIM have considered integrated project delivery (IPD) method, though according to different sectors (Aibinu & Papadonikolaki, 2016). Procurement is frequently used as a fundamental component in several organisational forms to handle increasing demands and the distribution of responsibilities, tasks, and hazards (Patil & Laishram, 2016). Numerous papers or documents, and design representations, make up construction agreements or contracts. In addition, procurement specifies the scope of work that is necessary to improve BIM information management in the built environments for operational efficiencies (Kuiper & Holzer, 2013; McAdam, 2010). According to Hamdi *et al*. (2013), while different types of contracts is a significant step in addressing certain legal difficulties, determining the allocation of risks and obligations is a substantial difficulty with a BIM project's contract development cycle.

Several studies have established that the integrated approach, or IPD, can demonstrate innovative digital information exchange among all project actors. IPD involves collective procurement and includes fair benefits and deficiencies for project participants (Abd Jamil & Fathi, 2018). In IPD, the exchange of information is regarded as transparent by all parties involved. Thus, it was determined that IPD is the best-fit contract strategy when using BIM (Abd Jamil & Fathi, 2018; Sacks *et al.*, 2018). In the other forms of contract, like Design-Build (DB), Design-Bid-Build (DBB), Develop and Construct (DnC) or Design and Construct, and Construction Management at Risk (CMR), for instance, in Design-Build, the client has an agreement with a design and build contractor, where the contractor oversees the design and the construction. According to Hale *et al.'s* (2009) analysis of similar projects, DB performed better in time and cost compared with DBB. When using Design-Bid-Build (DBB) method, the designer and the contractor have separate contracts with the client. It is also referred to as the traditional procurement method. The design is specified, developed and delivered based on the need of the client for the project. The client then chooses a contractor to build the project as designed (Hale *et al.*, 2009). Design-Bid-Build considered the UK's most common and preferred procurement method (Rahmani, Maqsood & Khalfan, 2017).

Likewise, in the NBS (2018) survey, traditional procurement, i.e., DBB, is still the generally accepted approach in the construction industry, about 46% industry professionals rate it as their preferred approached, to be followed by DB (41%). Develop and Construct (DnC) is a variation on DB, in which most of the design is completed before the contractor is appointed. This avoids some of the potential problems of DB but also misses some of the opportunities. A variation or variation order (VO) in the construction industry is a revision or an addition, substitute, or omission from the initial specification/scope of work indicated in the agreement. Almost every project deviate from the initial concept, scope, or specifications at some point during construction. Variations may occur due to technical advancement, changes in the client's needs, statutory variations or enforcement, variations in site or work or workmanship conditions, geological differences, inadequacy or unavailability of materials, or merely because the contracted work continues to evolve following the expiration of the contract. The DnC procurement route is commonly used in relatively large and large-scale construction projects because the clearly defined data flow allows the professionals to monitor their resulting BIM models when used by other specialists (Holzer, 2015). Construction management at risk (CMR) provides the client with distinct contracts with the architect and builder. According to Mohsini *et al*. (1995), some difficulties are created by CMR in the traditional construction operations while others are solved by it. This is as a result of significant variation and complexity of the involved parties (Mohsini *et al.*, 1995). Conversely, when compared to DBB, CMR, and DB, IPD provides statistically significant result in terms of quality, cost, and services (El Asmar *et al*., 2013).

Mesa *et al*. (2016) described integrated approach as an innovative delivery technique that has the possibilities to increase project quality through improved integration of the supply chain. A multiparty contract is signed by the client, designer, and contractor. One advantage that IPD have over the other procurement route is the involvement of all parties early in the project (AIA, 2007). As a result of this involvement, all stakeholders' competencies contribute to better choice, management and project outcome. The knowledge from all stakeholders would be included in the stage where it will have the most impact. Owners can also analyse project possibilities that meet their business objectives, builders can collaborate and share their opinions on construction knowledge to improve project performance, and the design team can benefit from this involvement early in the project to generate better project outcomes (AIA, 2007).

Although IPD has not been tied to any technology, BIM has been mentioned as one of the appropriate technologies for IPD. BIM offers the necessary collaboration and integration for an integrated procurement route (AIA, 2014). It also a key enabler of IPD. Due to BIM's interoperability and data exchange features, models generated in the earlier phases (i.e., pre-design and design) integrate information for subsequent project development and operation processes (Sacks et al., 2018). Interoperability is critical to enabling collaboration and integration in the BIM setting. According to Cestari *et al.*, 2014 and ISO 25964-2: 2013, "...interoperability is the capacity of disparate software platforms to share data over a common set of agreed-upon formats while maintaining data integrity" (Cestari *et al.*, 2014; ISO 25964-2:2013). Chapter three delves into greater detail about interoperability.

2.5 BIM as a Delivery Vehicle for Information Management Systems

The collaborative use of rich 3D digital building information models at all phases of the project life cycle is proposed to facilitate and enable an integrated project information flow, exchange, and delivery approach. BIM utilises object-oriented ideas to improve information management efficiency throughout the construction life stages. Generally, BIM ensures relevant information is generated adequately and appropriately, allowing better decision-making. The use of BIM for information management is about more than just creating a 3D model. It goes beyond the planning and design phases to extend through the project's entire life cycle, including occupancy and end-of-life, as depicted in *Figure 2.6* below.

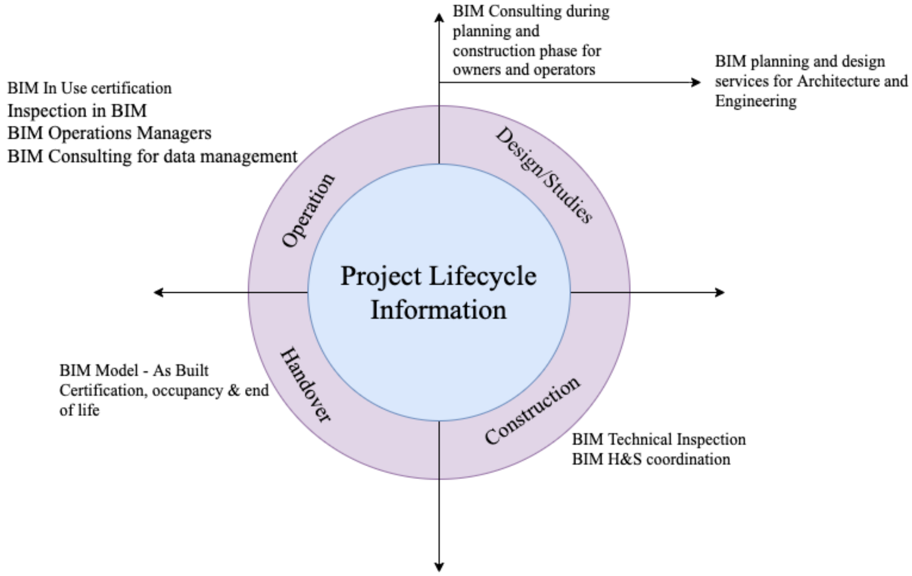


Figure 2. 6: *BIM Project Life cycle*

As a result, the concept of BIM facilitates the analysis and integration of 3D information modelling from project inception to operations and maintenance, repairs, and end-of-life (Lee *et al.,* 2018). In this regard, some benefits of BIM technology include the capacity to accumulate construction information through the model data for easy standardisation and administration of knowledge transfer and sharing and enabling the accumulation of data and 3D model management. Thus, ensuring the distribution of information among all construction parties, procuring supplies, encouraging collaboration, and supporting an effective information management process (Lee *et al.,* 2018). Furthermore, BIM technology creates a digital environment for managing information, reducing the resources required for drawing preparation, quantity calculations and estimates, and other areas of information management. However, the literature review conducted in this study revealed some challenges in BIM IM. These challenges are discussed in the next chapter to provide a direction to achieve the objectives of this study.

2.6 BIM information components throughout the project life cycle vs the RIBA Plan of Work

The project life cycle entails the core design stages, which begin at stage 0 for strategic consideration at the beginning of the project and end at stage 7, which reflects the overall life span of a construction project (RIBA, 2020). BIM influenced the plan of work in 2013 through the involvement of stage 0 (to highlight the significance of preparation and client interaction) and stage 7 (to emphasise the value of handover and post-occupation work) and by including BIM in the information management systems. It was later updated again in 2020 to include sustainability guidance to reflect the commitment of the UK government to be Net-Zero carbon come 2050 and soft-landing initiatives as represented in *Figure 2.7* below

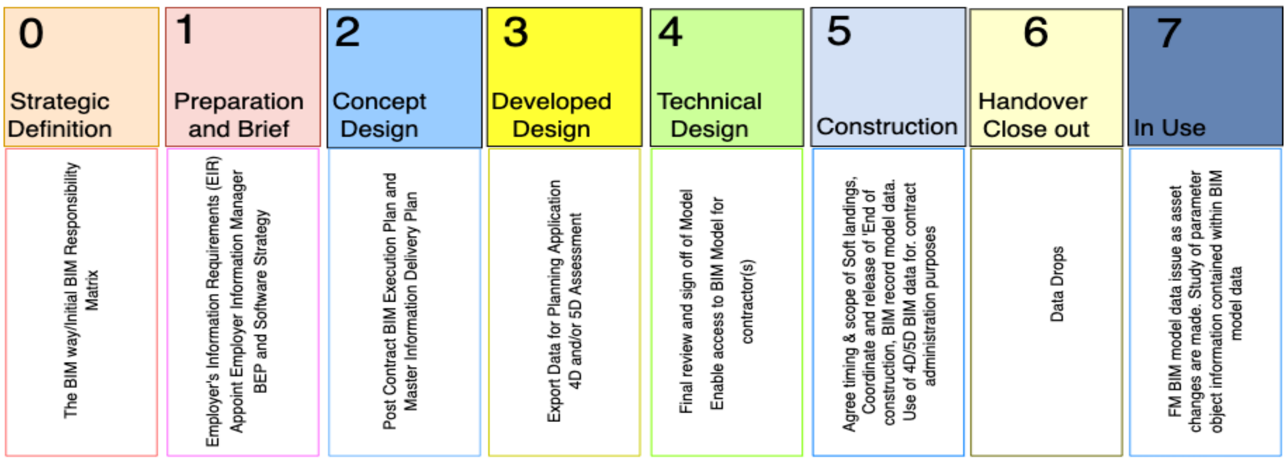


Figure 2. 7: *BIM Vs RIBA Work Stages (Adapted from RIBA, 2020)*

So, alongside a large proportion of the UK construction industry, RIBA targeted 2030 to achieve this and concluded that to successful achieve this, the construction industry must commence its implementation immediately (RIBA, 2020). This target poses a lot of challenges to the design teams who now focus their design to reflect sustainability measures from the beginning of the project. This inclusion of sustainability and the targets are defined and established with the project owner in stage 1, quality-check during the design and construction process, and then verified in the later stages i.e., stages 6 and 7 during operation and maintenance, and post-occupancy evaluation. *Table 2.1* below lists the BIM uses or applications for each RIBA stage throughout the project life phases. The project teams must provide information that will enable BIM usage in the project. The information in the table below also outlines how the BIM model is used at each RIBA stage and specific directions for the project teams.

Table 2. 2: *BIM Uses for each RIBA Stage (Adapted from Ralhp & Jhon, 2013)*

BIM Use	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Creation of the design	√	√	√	√	√		
Evaluation of design		√	√	√	√		
3D coordination		√	√	√	√		
Clash Detection		√	√	√	√		
Digital Fabrication				√	√		
Facility Management						√	√

4D Sequencing				√	√		
Quantity extraction	√	√	√	√	√	√	√
2D Drawing Production		√	√	√	√		
Existing Conditions modelling	√						
Visualisations		√	√	√	√	√	

2.7 RIBA Information Requirements

Due to various changes in how projects are proposed, developed, constructed, maintained, and operated, determining the information needs for a project is becoming increasingly challenging. According to RIBA (2020), the required information for each stage serves two significant purposes i) They enable the client to examine and approve the project developmental work accomplished during the particular stage, emphasising the need of documenting the key decisions made; and ii) the information generated after one stage informs the actions to take in the next (RIBA, 2020). As a result, these information requirements must take into account not just the outcomes of the current stage production, but also how well to deliver the outcomes for succeeding stages. For instance, a poor project brief in stage 1 could lead to a poor architectural design in the second stage, i.e., stage 2, or insufficient information in stage 4 could cause delays and obstruct the project's progression on the site in stage 5.

2.7.1 Strategic definition (stage 0)

The information requirements for this stage are focused on accurately addressing the client's requirements and creating the business case using the data acquired from the client. The successful output at this level defines the start of the information required for the next stage. *Figure 2.8* below highlights what should be expected at and after stage 0, and it divides the information into four phases: the stage result (outcome) at the end of the stage, the main tasks (core), during the stage, the core statutory processes during the stage, the procurement route, as well as the information exchanges at the end of the stage (RIBA, 2020).

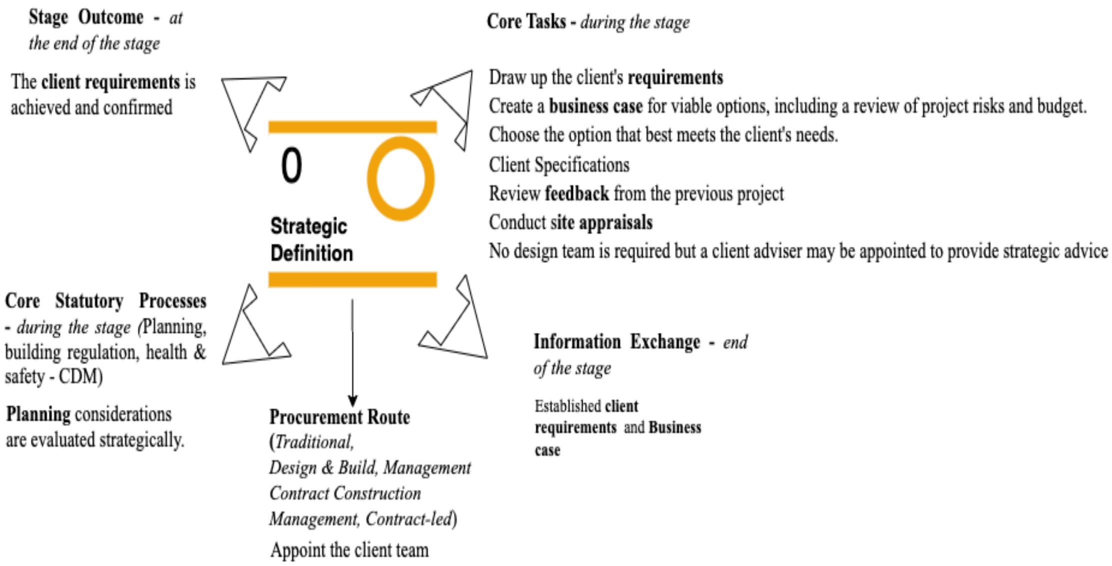


Figure 2. 8: *Information requirements at stage 0 (Adapted from RIBA, 2020)*

2.7.2 Preparation and briefing (stage 1)

Stage 0 consideration Information requirements are necessary for all stages from 2 to 5. This consideration is because specialised services agreements and building contracts need to stipulate the type of information the designers and the contracting team must deliver at the stages' completion. Who produces the relevant information may not change depending on the procurement and planning method adopted, but timing and the contractual chain of duty may. Therefore, establishing the information needs is vital in stage 1, irrespective of the project's size and complexity. However, as illustrated in *Figure 2.9* below, determining precisely what data is required takes time and effort.

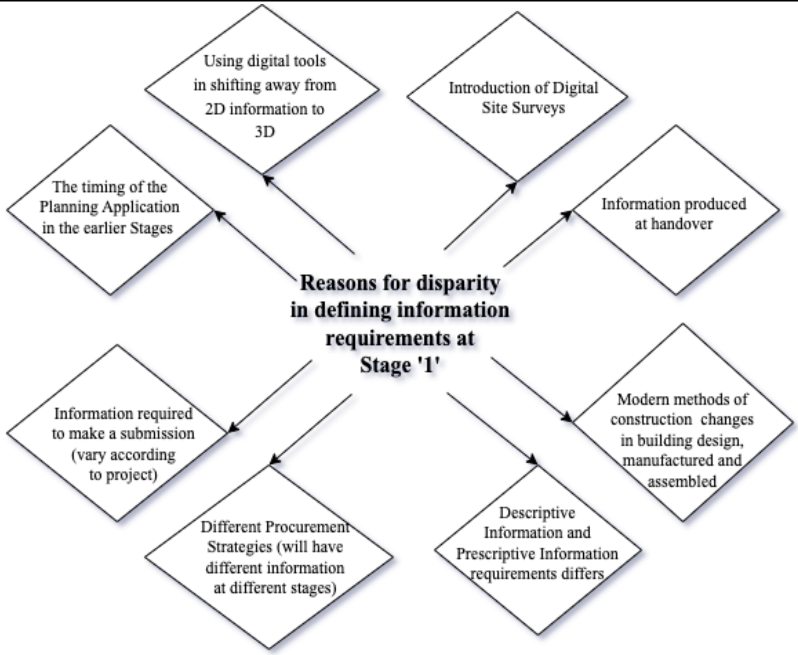


Figure 2. 9: *Reasons for information requirements disparity in stage 1 (Adapted from RIBA, 2020)*

The information requirements must be decided upon with the client at the outset (i.e., at stage 0), which depend on the project's complexity and the widening range of information possibilities. For instance, the client team may need the help of an information manager to establish the information requirements for larger projects. However, for fairly larger projects, project owners rely on their professional opinions to recommend information that will increase the value of the design and construction process, like a virtual reality model to assist the client to better grasp the conceptual design. At this point, the client often decides whether to embrace the BIM approach or defer to the design team and, if the BIM approach is selected, what required activities need to be outlined. Since the BIM approach will be considered for this study, a summary of BIM work will be reflected in the discussion on information requirements, including the development of the Responsibility Matrix (RM) or Model Production Delivery Table (MPDT). Additionally, stage 1 requirements are outlined below in *Figure 2.10*.

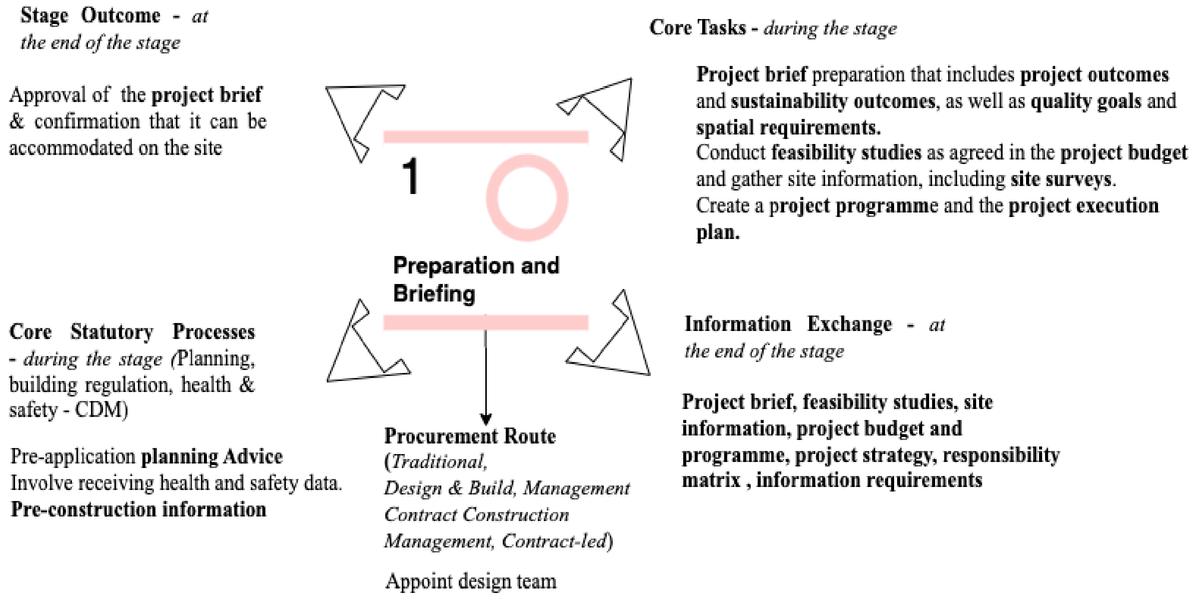


Figure 2. 10: *Information requirements at stage 1 (Adapted from RIBA, 2020)*

2.7.3 Concept design (stage 2)

The project team determines what information is required at this level. This differs and depends on the size and complexity of the project, the site’s as well as brief’s challenges, the client team's opinions, and the information that best proves the fulfilment of the stage. Stage 2 information challenges determine the contents of the stage report. The stage report documents all pertinent decisions made throughout the stage for the future. The stage report outlines the decisions taken regarding the project design and developmental strategies, why they were made, who participated when the decisions were taken, and why a note of options was considered and why one was not. If the confirmation process includes a formal design assessment, the stage report might have a section that records any complaints, objections or agreements made and the designer's comments during the assessment, allowing all comments to be recorded in a single-one document. Undertaking Design Reviews is a critical responsibility at stage 2. As indicated in *Figure 2.11* below, all project stakeholders must be included in these for their comments to be incorporated into the stage’s report.

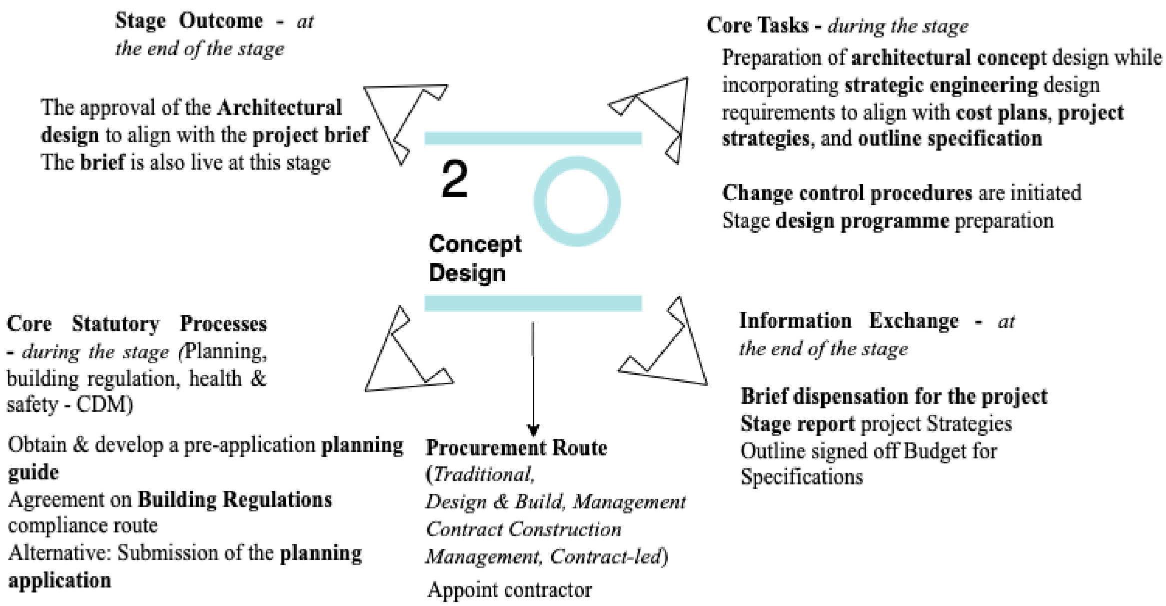


Figure 2. 11: *Information requirements at stage 2 (Adapted from RIBA, 2020)*

To accompany the stage report in the format agreed upon by all stakeholders, a set of preliminary designs (drawings, sections, as well as elevational views of the project at an appropriate scale) would typically be generated. With BIM, an innovative method is used to develop stage Reports that combine 2D views to show how space requirements are met with 3D views (with 3D visualisations), sequences, and BIM model extracts to illustrate design choices. On the other hand, the stage Report can be used to record the decisions that have affected this information and reflect on everyone's work. At this level, information is supported by the data and tasks of the collaborating teams. If some stage 2 actions are not done well, stage 3 may be more difficult. Taking on a lot tasks (that are simple to achieve) may cause effort to be diverted from reaching stage outcomes. The RM or MPDT developed in stage 1 should be clear about the actions required in stage 2 to meet the information requirements. These actions ensures that the conceptual design meets the requirement and matches the budget proposal. A RM as shown below in *Figure 2.12* determines who is responsible for the numerous tasks that must be done at each step. It can identify who on the project team ought to lead the task and who ought to assist.

Activities	*BIM*	*PM*	*Architecture*	*Civil Engineer*	*Structural Engineer*	*MEP*	*Site Manager*	*Principal Contractor*	*Q & S*	*H & S*	*Client Representative*	*Information Manager*
BIM Management Deliverables /Team A												
Manage BIM 360	AR	A	I	I	I	I	I	I	I	I	I	I
BIM Execution Plan	AR	A	C	I	C	C	C	I	C	C	C	I
Project Management Deliverables /Team B												
Assigning Roles	I	AR	I	I	I	I	I	I	I	I	I	I
Construction Schedule	I	AR	C	C	C	C	C	I	C	I	C	I
RACI Matrix	I	AR	I	I	I	I	I	I	I	I	I	I
Minimal Cost	I	AR	C	I	I	I	I	I	I	I	C	I
Architecture Deliverables (Within 3D Model) / Team C												
Location	I	A	R	I	C	C	I	I	I	I	C	I
Design Proposal	I	A	R	I	C	C	I	I	I	I	C	I
Advising Client	I	A	R	I	C	C	I	I	I	I	C	I
Detailed Drawing	I	A	R	I	C	C	I	I	I	I	C	I
Work Coordination With Contractor	I	A	R	I	I	I	I	C	I	I	I	I
Clash Detection	I	A	R	I	C	C	I	I	I	I	I	I
Risk Register	I	A	R	I	I	I	I	I	I	I	I	I
Civil Engineer Deliverables /Team D												
Execution As Per Design And Drawing	I	A	C	R	C	C	I	A	C	C	I	I
Maintain And Improve Physical Environment	I	A	I	R	I	I	I	C	I	C	I	I
Coordinate With Sub-Contractors	I	A	I	R	I	I	I	C	I	I	I	I
Coordinate With Vendors	I	A	I	R	I	I	I	C	I	I	I	I
Evaluation Of Payment Certificate	I	A	I	R	I	I	I	C	A	I	I	I
Planning And Budgeting	I	A	I	R	I	I	I	C	C	I	C	I
Monitor Due Material Quality Standards	I	A	I	R	I	I	I	C	C	I	I	I
Safety Inspection	I	A	I	R	I	I	A	C	I	A	I	I
Structural Engineer Deliverables/ Team E												
Cut And Fill Calculation	I	A	C	C	R	I	I	I	I	I	I	I
Risk Register	I	A	I	I	R	I	I	I	I	I	I	I
Structure Design	I	A	C	I	R	C	I	I	I	I	I	I
Coordinate With Contractor On Further Structural Design	I	A	I	I	R	I	I	C	I	I	I	I
Clash Detection	I	A	I	I	R	I	I	I	I	I	I	I
MEP Deliverables/Team F												
Propose MEP System	I	A	C	I	I	R	I	I	I	I	I	I
Propose Sustainable Elements	I	A	C	I	I	R	I	I	I	I	I	I
Drainage	I	A	C	I	I	R	I	I	I	I	I	I
Lighting And Fittings	I	A	C	I	I	R	I	I	I	I	I	I
Solar	I	A	C	I	I	R	I	I	I	I	I	I
Clash Detection	I	A	I	I	I	R	I	I	I	I	I	I
Site Manager Deliverables /Team G												
Traffic Management	I	A	I	I	I	I	R	I	I	I	I	I
Ensure Site Safety	I	A	I	I	I	I	R	C	I	C	I	I
Providing Machines Use On Site	I	A	I	I	I	I	R	C	I	I	I	I
3D Logistic Plan	I	A	I	I	I	I	R	I	I	I	I	I
Reviewing Progress Of Work	I	A	I	I	I	I	R	C	I	I	I	I
Principal Contractor Deliverables/Team H												
Liaise With Client And Designer	I	A	C	I	I	I	I	R	I	I	I	I
Review Plan And Model	I	A	C	I	I	I	I	R	I	I	I	I
Manage, Monitor And Coordinate Construction	I	A	I	C	I	I	I	R	I	I	I	I
Ensure Suitable Site Induction Are Provided	I	A	I	C	I	I	C	R	I	I	I	I
Provide Welfare Facilities For Workers	I	A	I	I	I	I	C	R	I	C	I	I
Q & S Deliverables/Team I												
Costing Plan	I	A	I	I	I	I	I	I	R	I	C	I
Whole Life Costing	I	A	I	I	I	I	I	I	R	I	C	I
4D Simulation	I	A	I	I	I	I	I	I	R	I	I	I
Risk Register	I	A	I	I	I	I	I	I	R	I	I	I
H & S Deliverables /Team J												
CDM Regulations	I	A	I	I	I	I	I	I	I	R	I	I
H & S Guidelines	I	A	I	I	I	I	I	I	I	R	I	I
Risk Assessment	I	A	I	I	I	I	I	I	I	R	I	I
Rendering	I	A	I	I	I	I	I	I	I	R	I	I
Client Representative Deliverables/Team K												
Represent Client	I	A	I	I	I	I	I	I	I	I	R	I
EIR (Employer Information Requirement)	I	A	I	I	I	I	I	I	I	I	R	I
Pre-construction Management	C	A	C	C	C	C	C	C	C	C	R	I
Follow-up with Contractor	I	A	I	I	I	I	I	A	I	I	R	I
Monitor Due Budget	I	A	I	I	I	I	I	I	A	I	R	I
Monitor Construction Quality	I	A	I	A	I	I	I	A	I	I	R	I
Information Management Deliverables/Team L												
Minutes Of Meeting	I	AR	I	I	I	I	I	I	I	I	I	R
Handling Mode Of Communication	I	AR	I	I	I	I	I	I	I	I	I	R
Manage Project Information	I	AR	I	I	I	I	I	I	I	I	I	R

Key Responsibilities:

Responsible: Those who do the work to achieve the task. There is at least one role with a participation type of *responsible* , although others can be delegated to assist in the work required.

Accountable: The one ultimately unanswerable for the correct and thorough completion of the delivarable or task, and the one who delegates the work to those *responsible* . In other words, an accountable must sign-off (approve) on work that *resposible* provides. There must be only one *accountable* specified for east task or deliverable.

Consulted: Those whose opinions are sought, typically subject matter experts and with whom there is two-way communication.

Informed: Those who are kept up-to-date on progress, only on completion of the task or deliverable; and with whom there is just a one-way communicaton. It s generally recommended that each role in the project or process for each task receive, at most, just one of the participation types. where more than one participation type is shown, this generally implies the participation has not yet been fully resolved, which can indicate role corruption.

R	Responsible
A	Accountable
C	Consulted
I	Informed

Figure 2. 12: *Sample of a responsibility matrix*

The MPDT or RM *(Figure 2.12)*, is tightly linked to the information requirements and is defined by the construction system. It is one of the core BIM processes incorporated into the RIBA plan of work. It is designed conceptually at stage 1 and adjust according to the architectural concepts when stage 2 is completed to make sure that no project plan duty uncertainties or omissions in subsequent stages i.e., stage 3 and 4. The RM is a strong ad vital strategic document as it guarantees that everyone understands what needs to be done and when it has to be done.

2.7.4 Spatial coordination (stage 3)

Following the client's approval of the stage 2 information requirements, the focus shifts to engineering analysis, which includes strategic developments, additional assessment of the cost plan, and refining all architectural proposal's specifics through design studies. The column and beam measurements or ductwork sizes, are the main engineering output at this stage, as such no detailed designs are required. The project planning application is typically completed at this stage following the information requirements established by the building or planning authority. A planning application is a request to the building/planning authority to request approval to construct a certain structure on a particular site. According to the RIBA works stages, the Application are to be submitted at the completion of stage 3. However, as illustrated in *Figure 2.13*, one of the vital information concerns in stage 3 is the timeliness of the planning application, particularly where the application is made (i.e., by the local authority).

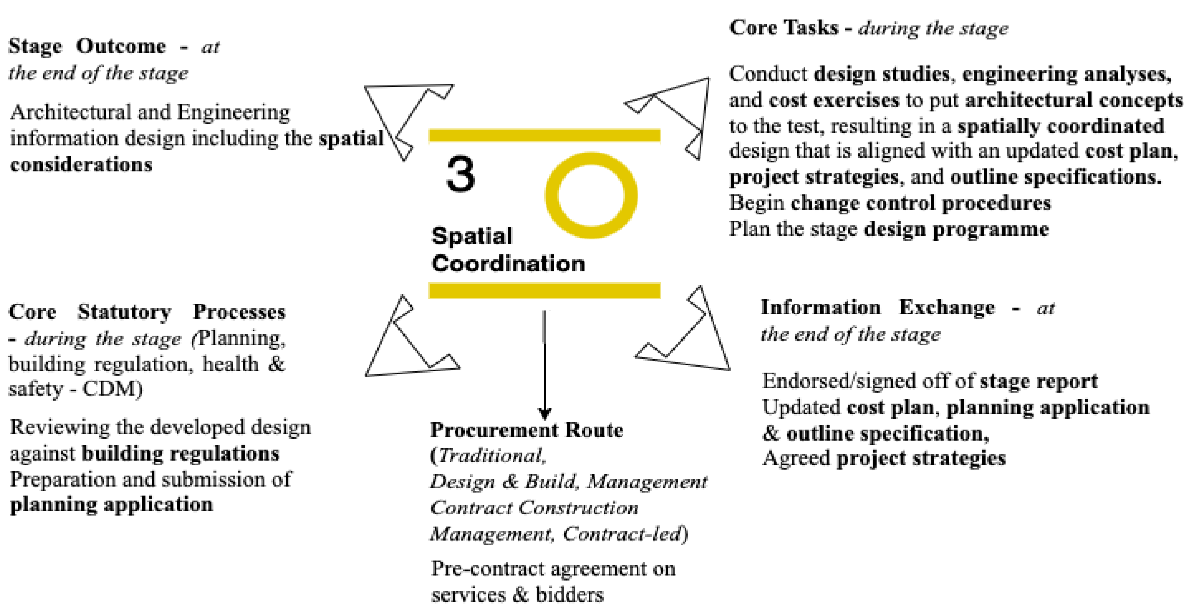


Figure 2. 13: *Information requirements at stage 3 (Adapted from RIBA, 2020)*

2.7.5 Technical design (stage 4)

At the technical design stage, the design information required to manufacture and complete the project's construction is provided. Several aspects are considered during the development of stage 4. They include:

i) *What kind of information—descriptive information or prescriptive information—will the design team produce?*

ii) *What innovative techniques will be adopted?*

iii) *How will the required information be affected by the digital design?*

iv) *How will the procurement approach affect the design plan?*

As the project progresses, prescriptive information emerges at stage 4. The designers creates either descriptive information to be used by the specialised subcontractors in the design, production, or construction of the building systems or prescriptive information for onsite construction. At this level, the appropriate organisations also produce guidelines on information requirements for structural engineering, as depicted in *Figure 2.14* below.

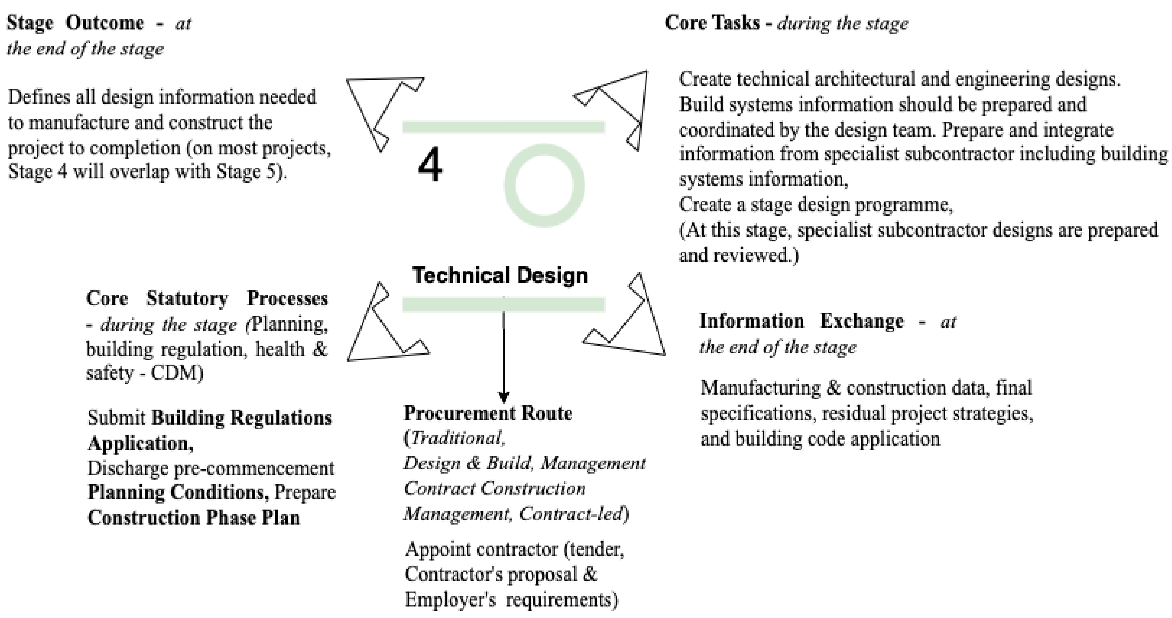


Figure 2. 14: *Information requirements at stage 4 (Adapted from RIBA, 2020)*

2.7.6 Manufacturing and construction (stage 5)

Some improvement brought about by BIM level 2 in the RIBA work stages is illustrated in this 5, as shown in *Figure 2.15* below, which describes the ability to extract data from Manufacturing Information and Construction Information for use in asset maintenance and operation stages.

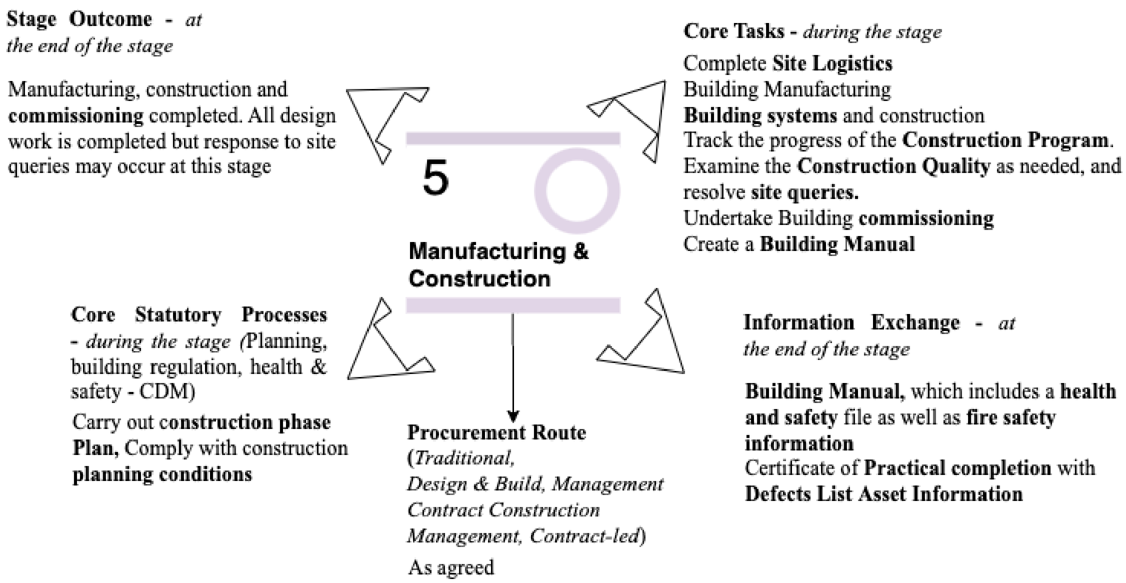


Figure 2. 15: *Information requirements at stage 5 (Adapted from RIBA, 2020)*

The main source of this information is the COBie schema. It defines the data characteristics or qualities for each construction stage. Building owners and operators can specify what data is required to run the facility in the COBie specification (Schwabe *et al.*, 2018). In stage 5, In stage 5, team members decide on the asset information needed for handover. Information deliverables are determined from the start to adequately describe this component in terms of those receiving and sending information. Describing the deliverables from the start allows the required information to be developed incrementally as the project and the recipient of such information progress (RIBA, 2020). The knowledge gathered at the completion of the design and construction stages delivers huge advantages all through the life of the structure. However, to achieve the intended results, the distribution criteria for asset information must be appropriately stated and specifically at this point.

2.7.6.1 Soft landing (SL) initiatives

Soft landing initiatives are an essential aspect of BIM in the construction process prior to handover and close-out. It was first released in 2017 and has since been modified and updated. The updated version aligned with the RIBA 2014 work stages and was included in the updated 2020 RIBA work plan. *Soft landing* is described as the UK government's initiative with the aim of making the changeover or transition from the construction to the operation phase of the "as-built model" as straightforward as possible, as well as to address issues that post-occupancy evaluations (POE) reveal throughout the performance of the built asset. Soft landings help in the improvement of operational performance (Gana, Giridharan, and Watkins, 2018). The transition is considered all through the life cycle or development of the project. The client generally agrees to implement the soft-landing plan early so that a reasonable budget may be set aside and appointment agreements and briefing documents can be included in the requirements. These early plans would include a consensus among the teams to deliver the required information for handover and commissioning, training, facility management, and BIM information requirements. The fundamental concepts of the SL initiative, as described by BSRIA, 2014a, can be grouped into three categories, as shown in *Figure 2.16*.

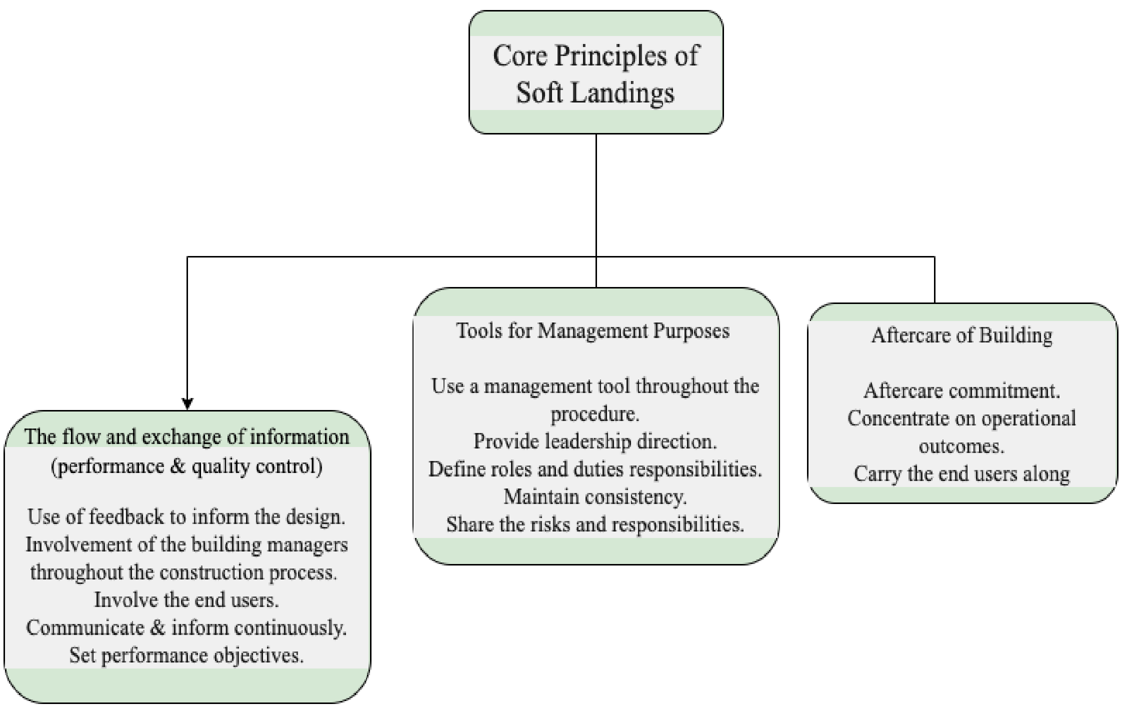


Figure 2. 16: *Soft landings core principles (Adapted from BSRIA (BG/54), 2018)*

2.7.7 Handover (stage 6)

The built asset is ready for use in Stage 6 as shown below in *Figure 2.17*, and the project team's attention will now be on correcting any deficiencies and executing the procedures required to finish the contract. Since the construction is nearing completion stage, the construction team becomes dedicated to completing the components of the project and verifying practical completion to finish Stage 5 at the expense of handover operations that guarantee the client can make the best use of the building.

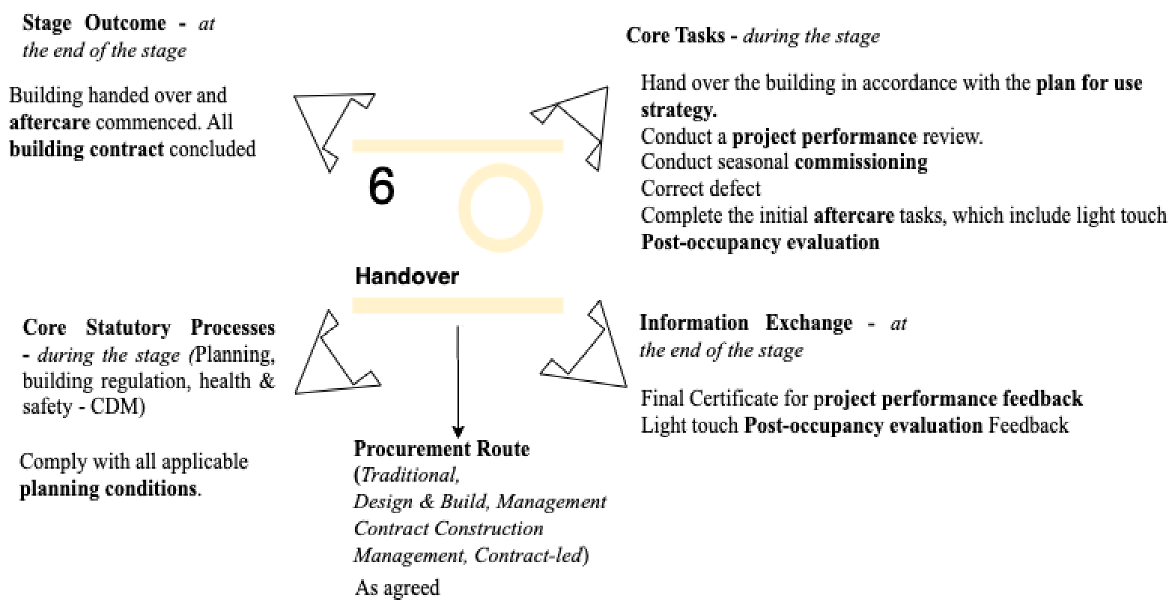


Figure 2. 17: *Information requirements at stage 6 (Adapted from RIBA, 2020)*

The Practical Completion certificate, or the time when the building is legally ready for occupancy, is still used to identify the completion of Stage 5. However, it is agreed that the need for information regarding handover activities must begin prior to and last after this date. These consist of the requirements for information to assist the client with moving in, such as the creation of a building manual, ensuring that the built asset is operating as expected following occupancy, and post-occupancy evaluation.

2.7.8 In use (stage 7)

Stage 6 marks the completion of the information requirements for planning, designing, producing, and constructing the building. The project team's work is complete when the building contract is closed out. Tasks that need to be completed beyond stage 6 must be clearly outlined in separate professional services contracts. stage 7 requirements as represented in *Figure 2.18* consists of scheduling appointments to complete aftercare tasks like thorough post-occupancy evaluations or longer-term client counselling. There are several opinions, nevertheless, on how an asset's end of life fits into the circular procedures of the RIBA Plan of Work. A project stage beyond stage 7 is justified in some industries when the work needed to finish an asset's life is vast and prolonged.

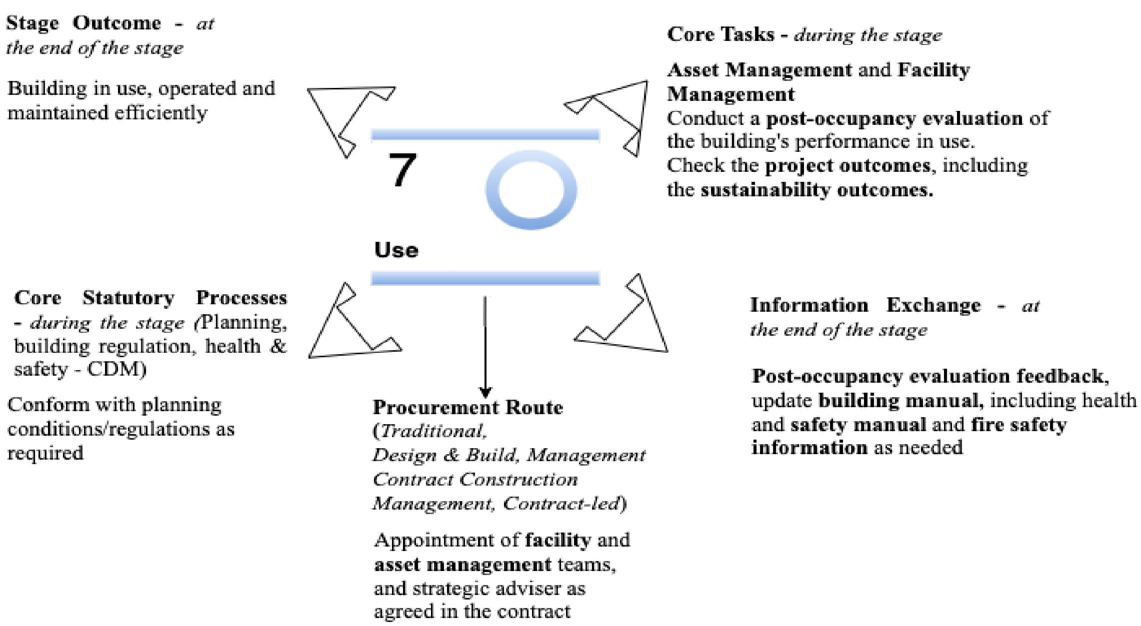


Figure 2. 18: *Information requirements at stage 7 (Adapted from RIBA, 2020)*

When clients consider what to do when a facility no longer serves their needs or is not usable again, they are essentially initiating a new procedure from stage 0. For instance, the client may decide to either refurbish, reuse, or extend the structure; if not, the structure will be demolished and its constituent elements repurposed, reused, or recycled. With the outcome of stage 7 in mind, sometimes clients may add substantial considerations in the project brief. The design team, for example, can suggest that test fittings be created for new potential applications or that the construction strategy at stage 2 explicitly defines how to demolish the building. However, it is believed that as circular economy principles spread throughout the construction sector, it is expected that the information requirements for these jobs will become more clearly defined.

2.7.9 BIM levels of maturity

Different aspects of BIM can be reached for various project types. These aspects of BIM are called BIM levels. Each level denotes a separate set of features that represent a specific level of "maturity" (development). These levels are important in this study because they are used to determine how efficiently or how much information is communicated and kept throughout the procedure. It simply refers to the level of shared collaboration that transpire across the various stages of a construction project development. The levels are briefly described, along with the prerequisites for each stage. A BIM level diagram is used to depict all of the different BIM levels -"levels of BIM maturity" or the "UK BIM maturity model". The diagram is widely known as the "wedge" due to its shape, and it is an important component of the UK's national BIM policy, as shown in *Figure 2.19* below. At the same time, the diagram's simplicity makes it an excellent example of the various levels of BIM and their corresponding information. Some models just depict the predicted minimal level of BIM integration, whereas some include additional standards and processes.

Level 0 describes unstructured computer-aided design (CAD), while Level 1 describes structured CAD in two and three dimensions. Building information is created in a collaborative 3D setting with data connected but, in several field models such as architecture and design information models, mechanical/structural information models, operations (facilities) information models, bridge information models, building services information models, among others. BIM level 2 is currently the minimum requirement for publicly-funded projects in the UK, but BIM level 3 is not yet specified but is planned to incorporate a standard, collaborative production and operations model that includes additional information on cost, construction sequencing, and lifecycle management.

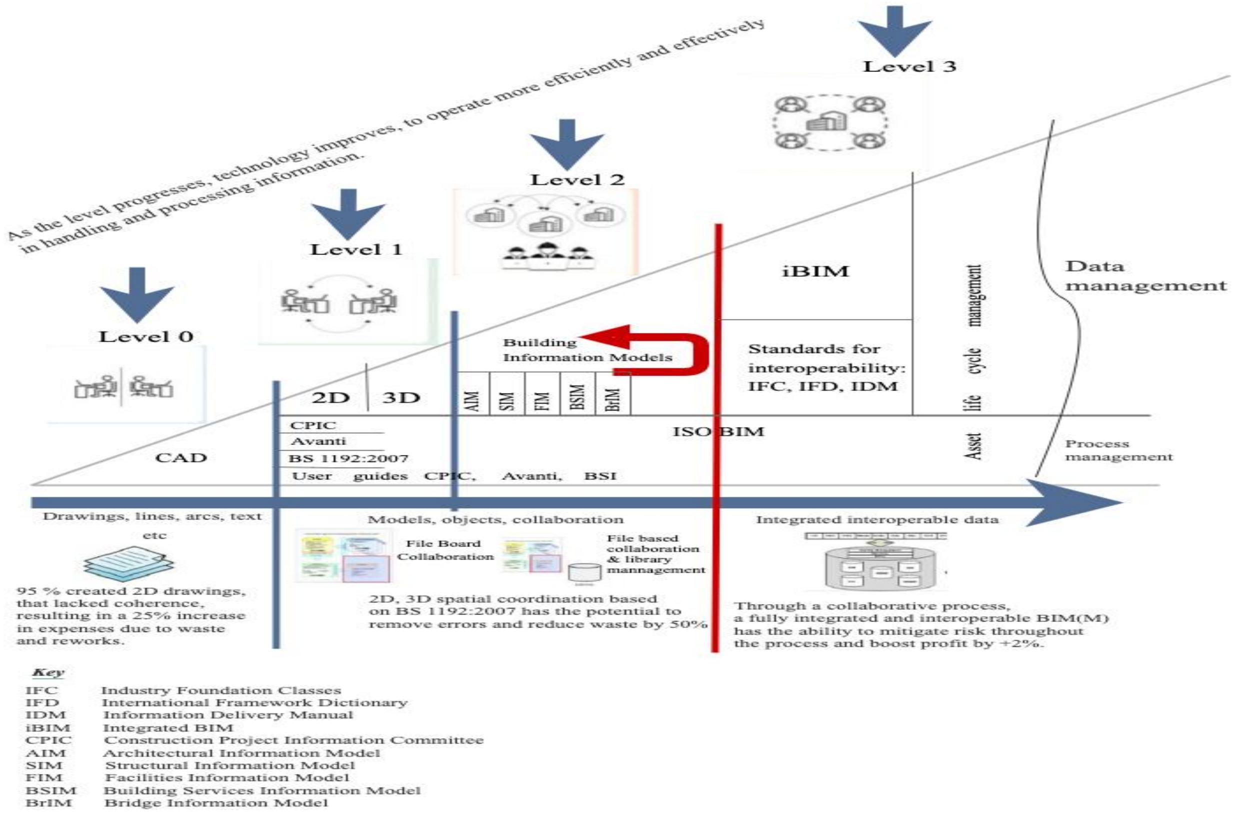


Figure 2. 19: *Levels of BIM Explained: the wedge diagram showing BIM maturity levels and the information required at each level (Adapted from Bew and Richards, 2008).*

2.7.10 BIM Dimensions

The method by which specific pieces of information or data are connected or linked to the BIM model is described in BIM dimensions. The most common BIM dimensions contain specific information, ranging from concept design (1D) to industrialised construction (10D). *1D* is a concept design that develops into a 2D CAD drawing dimension. 3D BIM includes the creation of graphical and non-graphical information as well as its sharing in a Common Data Environment (CDE). This information develops as the project progresses throughout its life cycle, and at the end of construction, the it is handed over to the client or user. Construction sequencing or scheduling, often known as planning in some literature, is the fourth (4D) BIM dimension that add time to the model. Given that it allows for a better construction schedule with fewer conflicts, 4D BIM is considered the best method for construction management and optimisation (Dakhil *et al.*, 2016; Habib *et al.*, 2020; Shilton *et al.*, 2018; Papadonikolaki *et al.*, 2018).

The 5D BIM adds a cost component to the model to extract precise project cost information. The information/data model at 5D contains some types of quantities, namely: i) quantities established on actual model components, including visible features that are to be studied on the model; ii) quantities obtained from model elements that are not readily visible (such as mouldings around windows); and non-displayed amounts (temporary work, construction joints) (Charef *et al.,* 2018; Charef, 2022). Except the production stage is shown, the resulting design model would clearly represent design quantities but not construction quantities (Vigneault *et al.*, 2020; Charef, 2022). The 6D BIM model uses concepts such as lifecycle information of the project, sustainability, operation and maintenance management, and integrated BIM (iBIM) (Mesáro *et al.,* 2019; Kushwaha, 2016). In addition, 6D BIM includes information to improve life cycle management and operations of the project, leading to improved construction results (Malla *et al.,* 2022).

This information could contain the manufacturer, installation date, needed maintenance, specifications on configuring and maintaining the asset for maximum performance, and life expectancy and decommissioning information. Facilities managers can use this technique to create spending profiles across the life of a built asset as well as schedule maintenance actions up to several years in advance, allowing them to determine when repairs are no longer financially feasible or if current systems are inefficient. 6D BIM enables realistic energy consumption projections while also assisting stakeholders in constructing sustainable and energy-efficient structures (Kaewunruen, Sresakoolchai, and Zhou, 2020).

Although there is less consensus on other levels of BIM, namely, 7D-nD, the idea of the 7D is that of the information coming from the construction (Charef, Alaka and Emmit, 2018). While the 6D specifies the purpose of the created asset, the 7D is information from sensors and analytics that are increasingly assisting in the asset's commissioning and operation (Mesáro *et al.,* 2019). 8D BIM is a BIM dimension that includes the model's safety information at the design and implementation phases (Charef, 2022; Smith, 2014). When working with 8D BIM, construction professionals can spot risks early in the project stage (Koutamanis, 2020; Darko et al., 2020). Building security and emergency plans are incorporated into 8D BIM (Charef, 2022). One way of dealing with the hazards is to eradicate them at their source by avoiding design flaws with this BIM Dimension.

Incorporating lean construction specification into 8D BIM results into 9D BIM (Schiavi *et al.*, 2022; Kulkami *et al.,* 2018). Another dimension of BIM is 10D BIM that attempts to leverage industrialised construction while also incorporating plans for disaster management (Ershadi *et al.,* 2021; Botelho *et al.*, 2021; Evan & Farrell, 2020). As a result, AEC professionals use BIM dimensions to establish information requirements for construction project deliverables. BIM 3D–10D Dimensions aid in assessing project requirements, understanding information requirements, and identifying who is liable for generating the model's information (Piaseckien, 2022; Charef, 2022; Sidani *et al.,* 2021; Charef & Emmitt, 2021). In particular, the idea of nD BIM (multiple dimension building information) describes the extensive hierarchies of building information in more detail (Koutamanis, 2020; GhaffarianHoseini *et al.*, 2017).

2.8 BIM and Information and Communication Technology (ICT)

A lot of information is created and managed on construction sites, and a range of approaches within information and communication technologies have been employed for effective information management. Production (construction) information has been combined with computer/information and communication technologies to improve construction task productivity and management efficiency. Earlier information technology attempts aimed to create a system integrating all construction phases on site. These earlier attempts focused on integrating project life cycle elements, construction system integration, and information and technology deployment (Cha & Lee, 2018). These studies, however, primarily concentrate on data collection and visualisation for construction management at a substantial measure, while a lack of practical procedures exists for gathering and applying data from the site, where data generation and management mostly occur.

In 1995, the Department of the Environment (DoE) in the UK developed a three-part information technology strategy specifically for the construction industry. These include i) encouraging more excellent information sharing through the use of linked project databases. ii) developing an industry-wide knowledge base to promote information exchange and team collaboration, and iii) employing information technology (IT) to improve project operations. As a result of the DoE initiative, consulting firms began to recognise the importance of information management in terms of information production, gathering, and archiving on construction sites. In addition, many public sectors eventually began to promote the adoption of information management systems to improve information transfer procedures White, 2015), thus increasing the use of information management. As a result, project stakeholders were able to request design information more intelligently, receive instructions more quickly, receive and retrieve information when needed, avoid information overload, and improve general information administration within construction projects (Adekunle *et al.*, 2022).

Meanwhile, while considering the utilisation of information technologies in the construction industry, the BIM technology cannot be overlooked. The primary emphasis of the study was BIM modelling. Data management and BIM documentation have gained centre stage over the last ten years (Oraee *et al.*, 2017). Modern BIM research efforts are centred on establishing a database and form based on obtained information in the construction process, rather than leveraging knowledge through modelling (Teng *et al.*, 2022). Since continuous information management via a link between graphic and non-graphic information is a fundamental principle in BIM technology, the research trend in BIM is rapidly evolving in the direction of data documentation and management (Saad, Ajayi and Alaka, 2022).

2.9 Chapter Summary

Construction activity has recently grown increasingly industrialised, necessitating using highly automated systems for maintaining information regarding construction activities. Consequently, the complexity of the methods strategies and activities used to manage this information in a typical construction environment, coordination, communication, and collaboration are extremely difficult. This necessitates a better information management system and end-to-end information flow to highlight and reap the benefits of an effective information management system. This chapter highlights several of these benefits, including some challenges with information management in the construction industry. Different work plans and guides are available worldwide to guide stakeholders across the lifecycle of a project. Each of these texts covers the construction life cycle in a unique way, dividing the project into distinct stages of design, construction, operation, and maintenance. When using BIM, it is critical to establish defined goals for the facility's entire lifecycle use from the start of the project. It is also critical to consider how all parties will use BIM.

Chapter 3

3 Information Management for construction activities

3.1 Chapter Overview

Projects are becoming increasingly complex as technology continues to revolutionise the building industry. As a result, a significant amount of information must be exchanged, coordinated, and transferred during the construction process, from offsite construction locations to onsite activities. Unfortunately, the conventional construction approach and current platforms for information management are inefficient and time-consuming since information is spread and lost frequently during the many construction processes before reaching its intended consumers. The chapter explains how information is processed in detail throughout offsite and onsite construction activities, how BIM helps narrow the information gap, how BIM systems are employed as a tool for managing information, and its challenges from existing literature.

3.2 Information Management Systems for Construction Activities

Hundreds of data pieces must be transported and shared from one project phase to the next on construction sites, as lots of material exists. Most of these are lost or disconnected due to the site's various improvement cycles (Cho, 2002; Lee *et al.*, 2018). This way, information in documents cannot be used in a consolidated manner (Lee *et al.*, 2018). Some of this documentation is prepared onsite in paper form and archived as physical papers, whilst other documentation is created as individual documents and saved in a format chosen by actor of the document preparation. If stored in this format, it requires a lot of effort and time to use construction data in these forms, and it requires searching through lots of data to discover what is needed. Construction professionals cannot deliver correct and just-in-time information due to the present information documentation formats on site, resulting in an information deficit or insufficiency and delaying decision-making on site and throughout the project (Singhvi *et al.*, 2003; Chen & Kamara, 2011). Thus, insufficient information and poor information requests, queries, collaboration, and interactions among construction site personnel result in reworks, waste, delays, and cost overruns (Chen & Kamara, 2011).

As a result, a review of earlier studies on information management between the 1980s to the 1990s reveals that the primary emphasis was fundamentally on Electronic Digital Information (EDI) to digitise the construction industry for the efficiency of construction work or industry and to manage information (Lee *et al.*, 2018) thoroughly.

Before the emphasis changed to data analysis and efficient data consumption, information sharing via XML and EDI was common in the early and late 2000s (Hajjar & AbouRizk, 2000; Caldas & Soibelman, 2003; Park *et al.*, 2009; Lee, 2009). Although the analyses of previous studies revealed that current construction information management systems offer techniques to enhance the efficiency of construction processes on the work site, there is still a shortage of studies on how to manage and use the information generated on the job site. Other initiatives focusing on the project design, construction, and information management systems include groupware systems, collaborative systems, electronic document management systems (EDMs), knowledge management systems and web-based project management systems, (El-Saboni *et al.*, 2009; Keefe *et al.*, 2009; Qady & Kandil, 2010; Benjoaran, 2009; Zhang *et al.*, 2009; El-Gohary & El-Diraby, 2010). As a result, over the last ten years, the construction industry's information management has undergone a drastic change. Examples of these earliest studies are discussed in subsequent sections.

3.2.1 Previous studies on information management

Using ICT for improving the efficiency of information management in construction processes is the focus of the earliest studies on managing information in the construction industry. This information is confirmed through the review of various studies in the field. A review of these studies revealed some ICT topics pertinent to information management. These are mentioned and represented below in *Tables 3.1, 3.2, 3.3, 3.4,* and *3.5.*

3.2.1.1 Frameworks for conceptualising web databases (FCD).

Information exchange is thought to benefit significantly from the information management developmental systems that integrate database and web technologies. For instance, Deng *et al. (2001)* and Tam (1999) both address the conceptual underpinning of such systems. These two studies created the Total Information Transfer System (TITS), (a scheme based on internet system) that uses Telnet and File Transfer Protocol (FTP) as its primary data exchange protocols. The system has six main components: a search engine, a live video camera, an email system, enhanced internet chat with on-screen graphics, data sharing, and remote log-in. The technology, however, was more focused on data transfer than information modelling. *Table 3.1* below provides examples of similar studies.

Table 3. 1: *Conceptualised web databases for information management*

S/n	References	Focus of the study	Method	Results	Comments
1.	Garcia *et al.*, 1998	Internet solutions of information management	Database for information exchange	Combined databases for information management	Directed the bulk of the project to data transfer i.e., specific to a particular area of construction.

2.	Abudayyeh, 1998	Internet-based information exchange	Internet-based project control system	Enhanced performance of construction projects	So, it does not solve the issue of information transfer.
3.	He, 2003	Internet-based systems for information management	based on Internet information communication and management-establishes the project information portal	Improved project and data exchange	Not directed to information modelling
4.	Tam, 1999	Internet-based Data exchange (global internet) for information management on construction sites	Total information transfer system (TITS), employing File Transfer Protocol (FTP), internet chat, video cam	Improved Information efficiency and accuracy, information exchange,	Low adoption of technology by the construction staff is evident in its use. Technology malfunctions and other structural problems are evident.
5.	Deng *et al.*, 2001	Internet-based project management for construction projects	Total Information Transfer System (TITS), employing File Transfer Protocol (FTP)	Information efficiency and accuracy, information exchange,	Problems with implementing change

3.2.1.2 Electronic document management systems (EDMs)

EDMs provide storage, versioning, metadata, security, indexing, and retrieval features in addition to tracking and storing electronic documents. In other words, information carried on paper is transferred, stored, and handled for a particular purpose (Löwnertz, 1998). Electronic document management systems (EDMs) are believed to offer some degree of control over the flow of information throughout the construction operation, regardless of the format in which the information is presented i.e., whether hard copy documents or electronic. However, other studies have found that two main factors that affect how well EDM systems perform. For instance, Finch, Flanagan, and Marsh (1996) cited two major barriers to the performance of EDMs in the industry: i) the desire for the user to re-enter information to register upcoming documents into a database, thus mimicking paper-based methods; and ii) the inability of the system to analyse and modify the information contained in the document or accompanying the document. Some of the earlier research on EDMs for information management is represented in *Table 3.2.*

Table 3. 2: *EDMs for information management*

S/n	References	Focus of the study	Method (s)	Result(s)	Comment(s)
1.	Bjork *et al.*, 1993 Bjork *et al*., 2002	Integrated system for managing documents for construction project The influence of electronic document on information management	Integrated management of documents Project webs (for big projects), Literature review, Case study	Managing documents in digital form Monetary benefits such as reduced cost of construction projects & reduced of travelling for project meetings; quantifiable benefits such as reduction in project delivery time and qualitative benefits like ease of using the electronic site diary and support for distance working	No clear direction on the management of the information Barriers to EDMs' use for information management are classified as *technical, behavioural, cost-related, organisational (using the new technology & long-term reliability of third-party services; ASP)* and *legal*. No scope for standardisation (IBB, 1999).
2.	Finch *et al.*, 1996	Bar coding mechanism of designed drawings to improve the functionality of EDM	Bar coding of hard-copy drawing to electronically transfer documents from the designer to the contractor.	Information on drawing documents is electronically transferred from the designer to the contractor. Only provide confined benefits	The technique aims to enhance the performance of EDM systems where physical copy documents are prevalent. However, the fragmentation of the industry hampered the success of the technique.
3.	Rezgui & Debras, 2006	Two problems were proposed to be solved: (i) a methodological strategy for computer-aided compilation of project documentation (ii) an organised method for every participant in the construction project to access the information included in project paperwork and regulations	Construction project data model is used to generate computer-aided project documents. The system used the construction project reference model (CPRM) and a document reference model, from which the Cahier des Clauses Techniques Particulières (CCTP) document type models were created.	Offers pragmatic solutions to the issues of document-based information's integrity and consistency while also providing a comprehensive description of a building's lifecycle through conceptual modelling approach (i) and for (ii), creating and using hypertext references to allow users to move between documentary items (internal or external to the document)	Enabling internal or external document navigation from one documented item to another while practical challenges in implementing the suggested strategy were imminent
5.	Hajjar & AbouRizk, 2000	Document management is integrated with project and company data.	The concept used is based on specialised construction data models in a steel fabricating company.	The approach takes care of validation in projects. Employee & project material information are easily accessible. Furthermore, any changes to the document, project, or company information are automatically reflected in all the client systems.	It was clear that the document design process was difficult for inexperienced users. Employee opposition to the approach's implementation. New kinds of documents are constantly needed, resulting to the company and product data models' structures change. Excessive setup expenses as well as additional maintenance expenditures.
6.	Hayes *et al.*, 1998	Information technology-enabled BRP in the construction industry: a case study of the European Strategic Programme Research in Information Technology (ESPRIT) Condor project	Model-based approach. To bridge the gap between the proposed (model-based) techniques and the conventional document-centred approaches to project information organisation and representation.	Document management practices of the Condor project end-users.	Challenges in accessing information on the completion of the project, including issues of software compatibility, security, financial & property management systems, network communication problems and EDMs lacking user-friendliness.

3.2.1.3 Construction information analysis (CIA)

Database systems require careful analysis of the data collected and transferred during construction. For example, Rankin, Froese, and Waugh (1997) described a computer-assisted construction planning (CACP) approach to facilitate plans that include work schedules, cost estimates, work methods, and organisational structure. Also, in Shahid and Froese's (1998) studied of information flows in construction projects, they plotted various information categories against the documents that commonly contain useful information, as well as the construction performance management that offer and access this information. On the other hand, Froese *et al.* (1997, outlined the conceptual stage of computer tools that enable construction information management and provided a provisional listing of construction documents and operational classifications for project management. Although these approaches are necessary for developing construction information management systems, these information management analysis efforts have yet to develop information management applications to meet the practical needs of the construction industry (Chassiakos & Sakellaropoulos, 2008). *Table 3.3* below indicates some examples in this category.

Table 3. 3: *Construction information analysis (CIA)*

S/n	References	Focus of the study	Method	Result(s)	Comment(s)
1.	Rankin, Froese & Waugh, 1997	Construction planning using computers in the context of total project systems	Adopted computer-assisted construction planning (CACP) to suggest plan for (i) integrated Construction management systems - Total project systems (TOPS) (ii) development standard information system and (iii) distinct perspectives on project information at different levels of concept	The focus is on emerging information technology and integrated construction management systems, which enables a comprehensive, "richer," adaptable plan with any project	The system is partially developed.
2.	Shahid and Froese, 1998	Information control systems for project management	The comprehensive project information systems approach is a computer system approach to supporting the task of project information management.	The system was designed to enhance and establish project information understanding as a contribution to a broader collection of research on integrated information data systems and standards for the construction industry, rather than to improve on commercially available construction information and verification tools.	They performed far less intricate calculations and data processing useful for information management
3.	Froese, Rankin, & Yu 1997	Total project management application models and computer-assisted construction planning	Project Application Models; Total Project Systems	Partially completed computer tools that support construction management	Incomplete table of project papers and project management functional types.

3.2.1.4 Web-based Applications in construction information management (WACIM).

Aouad *et al.* (2003) and Rezgui *et al.* (1996) proposed an information engineering method (IEM) and object-oriented development (OOD) with computer-aided system engineering (CASE) to create integrated databases and models as shown below in *Table 3.4*. Other examples in this category include the collaborative computer system of Faraj *et al.* (2000), which suggested an IFC for the communication of dispersed applications, including creating conceptual design, 3D visualisation, cost estimating, project planning and specifications, and other construction information supplies. Using an intranet-based cost estimating control system, Abudayyeh *et al.* (2001) developed an automated system to create a particular cost report. Focusing on drawing management, Dawood *et al.* (2002). Dawood *et al.* (2002) designed a commercial retail information management system. Mokhtar (2002) designed an intranet-based information model to address incompatibility mistakes in drawings. A conceptual model of a data information system established on metadata sharing among web-based construction project management documents was presented by Chan & Leung (2004). Instead of designing a system to manage information, these initiatives focus on addressing specific demands in the construction industry (Chassiakos and Sakellaropoulos).

Table 3. 4: *Web-based application in construction information management (WACIM)*

S/n	*References*	*Problem/Focus of the study*	*Method(s)*	*Result(s)*	*Comment(s)*
1.	Aouad *et al.*, 1994; Rezgui *et al.*, 1996	The integration of Information for CONstruction (ICON) projects in the UK	Information engineering method (IEM) and object-oriented development (OOD), with computer-aided system engineering (CASE) to create integrated databases and models	It was investigated whether developing a framework for integrating information systems in the construction industry was possible.	Limited to construction procurement techniques
2.	Faraj *et al.*, 2000	Web-based collaborative construction computer environment based on Industry Foundation Classes (IFC).	Adopted a Web-based IFC Shared Project EnviRonment (WISPER)	Project information sharing via a distributed computer integrated environment based on the Web and Industry Foundation Classes (IFC)	The process-based model, procurement system, and roles and responsibilities of the design team are not supported.
3.	Abudayyeh *et al*., 2001	An intranet-based cost control system	An intranet-based cost control system as a mechanism for utilising project control data and information	A database management system that serves as the core repository and processing engine for data and information on the Web, where cost control systems are created.	The system focused on a particular aspect of construction phase i.e., costing
4.	Dawood *et al.*, 2002	Using internet technology, an automated communication system was used to manage site information (web-technology)	IT-based site document management tool	A system to facilitate and improve sharing of information and communication within the construction team. And offers a fully automated environment for the construction project team to communicate, retrieve, store, and distribute project documents.	This study was still in progress and the recent copy is unavailable. So, no comment was gathered
5.	Mokhtar, 2002	Internet-based coordination and customisation of design information	Information model to customise and coordinate design information	An information model that aims to use the Internet technology to coordinate information of the multidisciplinary team in the design environment	Geometrical data such as dimensions is not supported by the created model.
6.	Chan & Leung, 2004	Metadata-based information system model	eXtensible Markup Language (XML) technology	Created a prototype model for construction project management that employs a Unified Modelling Language (UML) for data exchange between several web-based documents.	Does not support web-based collaboration for automatic information exchange and integrated representation.
7.	Cheung *et al.*, 2004	Web-based Project Performance Monitoring System (PPMS).	Construction Project Performance Monitoring System approach	Monitoring and evaluating performance of the project from data input to aid project managers in exercising construction project control.	PPMS relies heavily on database system and the internet for smooth functioning, constant monitoring and good security
8.	Zhiliang *et al.*, 2004	XML information exchange support in construction projects	Electronic Project Information Management System, (EPIMS) approach for information exchange in construction projects	XML was used to manage the exchange of information in construction projects.	Possibility of the approach not to support current practices

3.2.1.5 Application service provider (ASP)

Several commercial web-based applications for information management have been developed specifically for the construction industry by technology companies. These application developers either lease these systems as services or make them available as web-enabled software managed by the construction firm. Some examples of these applications are depicted below *Table 3.5* below. Some advantages of ASP include minimal implementation costs, the absence of complex IT needs, and accessible platform upgrades. However, its major drawback is that a third party manages the data. As a result, data protection or security, data accessibility, and quality of the service are significant issues. Extremely large businesses sometimes use bespoke solutions since they can customise the software to fit their unique business needs and brand. The obvious limitations include the high investment, extensive outsourcing, and prolonged development cycle (Chan & Leung, 2004).

Table 3. 5: *Information management application providers*

S/n	*Application Service Provider (ASP)*	*Application/ Software*	*Method*	*Results*	*Comments*
1.	Bentley https://www.bentley.com/en/project profiles/2019/scdot seamless information sharing	ProjectWise	Global information sharing hub	Information retrieval applications, with a central information hub to speeds up project delivery.	The connected data environment offered a method for assembling data from all sources, acting as a trustworthy and secure centre for exchanging and integrating data. However, quite a number of people do not have access to it.
2.	Autodesk https://www.autodesk.com/bim-360/construction-document-management-software/	BIM 360 Docs	Cloud-based storage solution	Team management and document control, access to project information, manage construction drawings, documents and models.	Digitally transforms project delivery, improve project outcomes. Not budget friendly, and ownership issues
3.	TeamFlow https://www.teamflow.com/	Teamflow	Universal data model-Repository for process documentation	Building of documents directly from process flow	Can only be use for specific projects
4.	Meridian Project Systems https://www.crunchbase.com/organization/meridian-project-systems	Project Mark	Portfolio-driven network	Management of industry content online	Focused mainly on cost information management
5.	Primavera P6 - Oracle Smart Construction Platform https://docs.oracle.com/cd/E97085_01/TPMhelp/en/Europe/10308296.html	Prime Contract	Cloud	Intelligent for project teams	Project planning operations & construction payment management, Third party involvement. As such, data is not secured.
6.	e-Builder Enterprise (Trimble Construction One: Cloud for Owners) https://e-builder.net/product/project-lifecycle/	e-Builder	Cloud-based Software-as-a-Service (SaaS)	BIM collaboration, program, cost & assets management	Manage information from the planning phase to completion and operational. Third party involvement, as such no security.

3.2.1.6 Construction information standardisation (CIS)

Computer-integrated building research initiatives have faced significant challenges due to the absence of data standardisation. The ongoing creation of such standards results from the acknowledgement of this issue. The International Organization for Standards (ISO), Standard for the Exchange of Product Model Data (STEP) and the International Alliance for Interoperability's Industry Foundation Classes (IFCs) are the main initiatives for product model standardisation by the international alliance for interoperability (IAI). The ISO-STEP 10303 standard's goal is to provide a neutral mechanism for describing product data throughout the project life cycle, regardless of system or software.

3.3 Information management of offsite and onsite construction activities

Offsite construction (OfC) is a term for manufacturing products in a controlled factory setting (Hou *et al.,* 2020). Many studies have examined offsite construction under different headings, such as prefabrication (Zhong *et al*., 2017; Hou *et al.,* 2020), offsite manufacturing (Abanda *et al.,* 2017), modern methods of construction (Ross, 2005), offsite production (Zhai *et al.,* 2014), industrialised building systems (Babič *et al*., 2010; Zhai *et al.,* 2014), modularisation (Oesterreich & Teueberg, 2016; Isaac *et al.,* 2016) and a host of others. There are minor differences in the use of these names. According to Svajlenka & Kozlonvska (2017), offsite construction can minimise the shortcomings of traditional IM in construction activities relating to productivity quality, efficiency, safety, and sustainability. Nonetheless, there are notable barriers to the use of OfC worldwide compared to traditional construction (Choi *et al.,* 2019). It is believed that digital technologies can effectively solve these barriers to streamline and improve the way project information is collected, analysed, used, and reused (Choi *et al.,* 2019). Making effective supply chain management and quality control in OfC processes possible (Zhong *et al.,* 2017) and understanding the rationale behind information management in OfC (Hou *et al.,* 2020).

Onsite construction on the other hand focuses on the successful delivery of the project in conjunction with clients' goals for quality, schedule, cost, and safety (Arayici *et al.,* 2011; Azhar, 2011). Thus, everything at the onsite stage constitutes onsite construction which include different tasks connected to the design and the construction phase (Chen & Kamara, 2011). Digital technologies have been widely adopted at various levels of information management on offsite and onsite construction sites. Equally, the execution of construction projects is mostly carried out on both construction sites where project members have difficulties accessing conventional computer systems for information delivery and use (Zhang *et al.,* 2017). In addition, principal personnel often go from site to site or from the site offices to the construction sites to pass information. Furthermore, it can be challenging to move bulky drawings and documents around construction sites, which often impedes the quality, timing, and quantity of information that can help a project succeed during the project life stages (Chen & Kamara, 2011).

The transition of information between offsite and onsite working environments is evident in OfC workmanship (Hou *et al.*, 2020). To effectively meet these transition needs, it is critical to comprehend the digital transformation underpinned by technological advancements and related to asset and equipment operation, waste, quality, safety, and management issues (Hou *et al.*, 2020). In 2016, Ramaji & Memari established a BIM-based information management system that advices on various cost potential benefits and options for modified building elements based on client demands. Ramaji (2017) also presented a manual for digital information delivery outlining specific BIM execution processes, technical challenges, and solutions to aid OfC's information management. OfC management is a knowledge and information-intensive process that heavily relies on domain-specific data. Since OfC asset management is knowledge, ontologies represent the body of knowledge in the different domains. As a result, BIM supported by ontology and concepts emerges as a promising strategy for effective and efficient information management approaches in OfC projects, including definition of project problem diagnosis, and preventive and corrective decision-making plan (Ramaji, 2017).

Construction information can be obtained, analysed, gathered, utilised, transferred, and reused digitally on job sites with the help of digital technologies, and automatic information management of activities is also made possible. The emergence of BIM technologies can potentially enhance the boundaries of information systems from construction sites offices to actual job sites, and make sure real-time transmission of data is possible to and from construction sites (Chen & Kamara, 2011). Using an efficient information system in an integrated and comprehensive manner is necessary because the industry is unique in its own right and with unique features, such as the participation of various project partners, the diverse site offices and work sites, and the movement of construction personnel from office to site. First, however, it is essential to assess how BIM technologies can be used to address issues with information across construction stages and to identify any possible areas where other technologies could be used to make improvements.

3.4 BIM Information Management

Information and information management in the BIM process are the key concepts in this section. Every stage of a project generates information that need to be efficiently managed for success of the project. BIM appears to be a cutting-edge method for managing project information shared amongst all parties, ensuring its quality and boosting confidence in its veracity (EFCA, 2019). Information, according to PAS 1192-2:2013, is a formal representation of data that can be used by people or computer programs for communication, interpretation, or processing. This information includes geometric models, timetable databases, documents, video clips, or sound recordings. To provide participants with information about the project (project information model-PIM), the BIM model stores graphical (data transmitted using shapes and arrangement in space), non-graphical (data employing alphanumeric characters to convey data), and project-related documents.

According to the UK BIM Framework (2020), information management is a process that makes certain specific information developed for a predetermined purpose to be delivered appropriately to the right location and people at the appropriate time. The PMI (2017) states that several elements that may impact this process should be considered when determining how this information is stored, accessed, and communicated. For example, it is essential to comprehend who requires each piece of information, who has access to it, when it is needed, and where to obtain it. The information format, how to access it, and potential obstacles, such as cultural differences, are other crucial issues because of the increased project complexity and the collaboration of different professionals. As a result, there is evidence to indicate that the construction sector is about managing information as well as people, materials, and equipment. Unfortunately, poor information management and coordination often cause many problems in construction project practices.

To address these issues, BIM was introduced in the AEC industry. The BIM method allows a more extensive utilisation of computer technology for the design, engineering developments, construction, and operation of built facilities. Rather than storing, trying to maintain, and transferring data in designs, BIM stores, maintains, and communicates data through complete digital representations known as building information models (Eastman *et al.*, 2011; Costain *et al.*, 2018; Li *et al.*, 2019). This method significantly improves the collaboration of design processes, simulation integration, construction project setup and control, and building information handover to the operator. In addition, by reducing the manual re-entry of data to a minimum and facilitating the ability to re-use digital information, labour - intensive and mistake work is avoided, resulting in an increase in productivity and quality in construction projects (Eastman *et al.*, 2011; Abanda *et al.*, 2015; Costain *et al.*, 2018; Li *et al.*, 2019).

BIM adoption provides solutions to the numerous challenges encountered across the design and construction phases. It is a defined collaboration when using BIM at different construction stages. Building design models created at the design process would include all of the information required for use and retrieval during subsequent phases, i.e., during construction and operation phases. Abanda (2015) portrayed BIM as a global technology and an information repository (Xu *et al.,* 2014) capable of easing the construction process, facilitating collaboration, and improving the effective transmission of information on construction sites. BIM was also regarded as a cutting-edge technology capable of facilitating project activities across the project's lifecycle (Sampaio, 2015; Eastman *et al.*, 2008), to provide series of techniques for information transfer, creating, and evaluating building models. Similarly, Demian & Walters (2014) emphasised the critical role BIM plays in managing project information and how its use has helped solve several construction industries challenges. However, despite the broad use of BIM for various construction process, using BIM for IM has been uncoordinated and poorly handled across the lifecycle of a construction project (Xu *et al.*, 2014). Several challenges with BIM information management have been addressed in the literature. Some of these are summarised in *Table 3.6* below.

Table 3. 6: *Challenges associated with BIM information management*

S/n	Author/date	Problem/focus of the study	Method(s)	Result(s)	Comment(s)
1.	Cha and Lee, 2018	Information flow of unstructured documents	Document management framework	A construction project information management system for archiving and searching documents	Lack of standardisation for the spatial breakdown and information breakdown structures (SBS & IBS)
2.	Ozturk, 2020	Interoperability issues in BIM information management	Interoperability analysis, scientometric mapping, and bibliographic search	The study employs bibliometric/scientometric analysis and mapping to address interoperability in BIM for the AEC/FM industry.	The scope of the research was constrained since bibliometric analysis could not uncover global studies on BIM interoperability.
3.	Zhang *et al.*, 2018	BIM model Geotechnical information	Obtaining and incorporating information from archived geotechnical data in the form of geological sections and geotechnical investigation reports	A geotechnical data management strategy that realises full life cycle management of geotechnical data by integrating geotechnical data into the project BIM model.	The challenge of articulating the distributed pattern of geotechnical space is made more difficult by the fact that data is typically restricted to two-dimensional and static space.
4.	Alsafouri and Ayer, 2018	Examining ICT adoption to improve communication between virtual models and building locations	Literature review of journal articles between 2005 and 2015	A methodical way to identifying information communication trends revealed in recent papers by distinguishing information flow modalities	The mode of information flow was not considered.
5.	Alreshidi, Mourshed and Rezgui, 2017	Collaborative environment for effective communication and make sure it is well supported during the project life cycle	Questionnaire and formal interviews.	BIM governance framework (G-BIM) was created with cloud computing/technologies, together with the identification of efficiency criteria that ensure successful collaboration	The collaborative BIM framework established primarily prioritised the technical aspect without taking into account the socio-organisational or legal process.
6.	Jiang *et al.*, 2019	Information interchange between various software platforms and disciplines	Systematic analysis of OpenBIM philosophy and practice to achieve interoperability in information exchange	Information organisation, information query processing, information exchanging, information advancement, and interoperability in terms of OpenBIM analysis.	Mismatched geometric information and a single capacity server's restriction on information exchange led to semantic feature loss and inaccurate BIM-GIS data integration.
7.	Graham, Chow and Fai, 2018	Level of information, detail, and accuracy of existing heritage buildings in BIM	Critical evaluation of existence and development of BIM guidelines to quantify the quantity and quality of information in a particular model and to create new benchmarks distinctive to current heritage buildings	Based on the level of information, detail, and accurate designs from the evaluation, a new benchmark for current and heritage structures was created called LODIA (Level of detail, information, and accuracy)	Incomplete sets of information for the study as a result of BIM reliance on diverse – and sometimes unavailable information
8.	Olawumi and Chan, 2019	Framework for project information management and BIM in construction	Explanatory case study technique with four BIM construction projects	Improves the functional information, management of project and proposed a BIM-project information management framework (BIM-PIMF) and associated assessment model for construction projects	The framework developed is indefinable for use by industry practitioners
9.	Volkov, Chelyshkov, and Lysenko, 2016	BIM Information management in the construction	Normative documentation and technical literature	The number of concurrent functions and the participating team in the construction process are two examples of the many variables that influence the requirements for BIM in IM.	The study did not appropriately determine the flow of information in the construction process to allocate in separate stages

10.	Maleeva, Selyutina, and Frolova, 2019	Use of modern technology and information modelling in capital construction object life cycle management	Not mentioned	The study demonstrates that information modelling technologies, which serve as the basis for digital construction, enable an integrated informational space in a single location and inseparable in time of use, as well as collecting and organising all object data and streamlining the information management process.	Uncertainty in the definition of roles, responsibilities, contractual obligations, and liability frameworks; challenges in the interoperability of BIM and FM operations; and a lack of clearly defined information need for the practical application of BIM in FM all contribute to the field of FM's inflexibility toward new technologies.
11.	Lee, Park & Song, 2018	Construction information management framework based on BIM for site information management	The database model for structural and non-structural information categorising system for organising the information generated.	A construction information database system is built on BIM technology to allow for the comprehensive management of site data generated throughout the project period.	Created challenges with direct application at the actual construction site
12.	Sheriff *et al.*, 2012	Information management drivers, limiting factors, and barriers in UK construction sector	Interviews with construction industry experts in the United Kingdom	The research offered a realistic perspective on the difficulties of information management within a multidisciplinary organisational framework, and it added that the nature of information management is shaped by existing dependent elements in accordance with the unique requirements of each organisation.	The research identified three barriers to the effective use of IM in the UK construction industries. They are: Constraining factors (the specific characteristics of the IM strategy developed within the organisation, such as project factors & services, company strategy, etc.); Drivers (the primary motivation for developing a holistic approach to IM, such as improved process & product, transfer of learning, etc.); and Barriers (impact on a comprehensive IM strategy in construction organisations e.g., content & technological barriers, organisational barriers etc)
13.	Succar & Poirier, 2020	Information flows throughout the lifecycle of an asset	Using Design Science research as a foundation, the Lifecycle Information Transformation and Exchange (LITE) framework was developed	The delivery of a digital, open-access IM platform for the project's asset lifecycle	The LITE framework focuses on how information flows across Milestones and transforms across developed framework rather than the product and production of the information system.
14.	Nepal & Staub-French, 2016	BIM's support for knowledge-intensive construction management tasks	Critical evaluation of the synthesised literature, use of retrospective analysis, and knowledge engineering and other information gathering and knowledge acquisition methodologies	The study identifies a subset of construction management (CM) knowledge pertinent to various building component design conditions.	As a result of the discrete and fragmented information flow, detailed design conditions were not captured.
15.	Sacks *et al.*, 2020	digital twin information systems in construction	The study was based on established ideas for BIM, a lean project approach and digitally collecting data from the construction environment.	Workflow of the Digital Twin Construction (DTC) information system, which includes data repositories, information processing capabilities, and monitoring tools.	DTC is seen as a new method of handling information rather than as an extension of BIM technologies information strategy
16.	Cavka, Staub-French, & Poirier, 2017	Owner data requirements for project implementation and asset management using BIM	Review, documentation, and case study were used.	The study produced a conceptual framework to support the formalisation process that would link physical and digital productions to client needs and organisational set-up.	The complexity in defining and establishing the information requirements to facilitate model-based construction process delivery and facility management is a key obstacle to

					BIM adoption for owners.
17.	Xu, Ma & Ding, 2014	BIM-enabled construction project life cycle information management	Framework for managing life cycle information in BIM	The developed framework provides a unified platform for maintaining data integrity and managing information.	The authors come to the conclusion that despite the fact that many scholars have researched information management, BIM's potential in life-cycle management has not been fully explored.
18.	Chen & Kamara, 2011	Adopting mobile computing to manage information on construction sites	Adopted a review and case study technique, a framework consisting of a conceptual framework, an application model, and a technical model was developed.	The framework functions to implement mobile computing for construction site information management.	The research depended on previous research to determine which areas could be improved by implementing mobile computing through the development of sub-models, so the study's scope is limited.

3.4.1 Definition and scope for industry standards for BIM information management

Data capture, exchange, utilisation, and administration throughout the information lifespan (planning and design, production/construction, operations and maintenance (O&M), and renewal or project's end of life) is one of the barriers to BIM information management. To manage BIM information, which involves the flow of data through the design, construction, O&M phase, it is necessary to explore standards linked to data interoperability. The British Standard Institution (BSI) and the International Standard Organisation (ISO) have created the most comprehensive standards. They concentrate on BIM and information management procedures throughout a project life cycle. While some standards for the O&M phase concentrate on transferring information and geometry from the design through construction to the O&M phase, they did not focus on asset information management using BIM. The significant proportion of the standards are concerned with the design and construction phases. The ISO 19650 standard is an international standard for managing information throughout the life cycle of a project in the BIM process. (Sadrinooshabadi *et al.*, 2020; Alhoz, 2021). The standard details the required procedures of the UK BIM framework and is aligned with the UK 1192 standards (Dadmehr & Coates, 2019; Peter & Mathews, 2019; Alhoz, 2021).

The first document in the standard series on BIM for IM is ISO 19650-1 outlining the principles, guiding ideas, as well as suggestions for project information management. ISO 19650 is based on BS 1192:2007+A2:2016 and PAS 1192-2:2013. These two standards replace the BS EN ISO 19650-2 (Bower *et al.*, 2021; Puthiyaveetil, 2020; Chunli, 2019). For information management at a point of maturity, it is referred to as information building modelling. ISO 19650-1 provides concepts and principles, and preliminary planning, conceptual designs, detailed designs, engineering designs, development, documentation, and construction, together with ongoing operations and maintenance, refurbishment/repair, and end-of-life. In addition, the application of the ISO standard helps to remove barriers to cross-border and competitive tendering.

The part 2 of the ISO standard-19650-2 provides information management standards for the delivery phase of construction project. Part 3 (ISO 19650-3) deals with asset management during the operational phase (Çekin & Seyis, 2020; Junior *et al.*, 2020), while Part 5 (ISO 19650-5) deals with security-conscious information of developed building models, digital format of the built environments, and smart/intelligent asset management as added in 2020. In August 2019, the UK BIM Alliance, CDBB, and BSI produced guidance to offer assistance to people and organisations across the UK to grasp the basic ideas of BIM as outlined in parts 1 and 2 of the ISO 19650 standards. (UK BIM Alliance, 2019). Additionally, the ISO standard technical subcommittee chair provided insight into how the ISO standards for improved cooperation for efficient information management were created in the excerpt provided below.

"The *International Standardisation Organisation 19650 standard was established based on a series of tried-and-tested BS 1192 and the PAS 1192-2. These standards have been shown to provide assistance to users, such as saving up to 22% in construction costs, said* the chairman of the established ISO standard technical subgroup. "*Taking this to a global scale will not only allow for a more operational and efficient collaboration on large-scale projects worldwide, but it will also allow design and contractor teams on all types of construction projects to clearly and efficiently manage information."*
_Chair of the ISO technical subcommittee).

The above quotations further highlight the significance of the improved ISO standards. Part 1 (ISO 19650-1, 2018a) specifies the conceptions and principles of the information delivery cycle from the viewpoints of all stakeholders and design cooperation. Conversely, part 2 (ISO 19650-2, 2018b) outlines the delivery process of the information and splits it into several phases, as explained below in *Table 3.7.*

Table 3. 7: *Definition of the information delivery process (Adapted from ISO 19650-2:2018)*

S/N	Definition of the information	Explanations
1.	Requirement and assessment	All information management rules, duties, and actions are defined as well as applicable standards, specifications, and requirements.
2.	Tender invitation	Documentations of all information and requirements concerning information flow and management are defined and summarised in tender documents in order for the public or private market to be aware of the project's bidding/tender process.
3.	Response to tender	The tendering/bidding company would create tender documents following the selection of project team and competence assessment (ISO, 2018b; Holzer, 2016).
4.	Consultation and appointment	At this stage, the validation of the winning bidder's pre-contractual BEP is established by the contractor while a post-contractual BEP that including BIM workflow standards (ISO, 2018b; Holzer, 2016) are prepared
5.	Mobilisation of parties	The contractor tests all pre-established project procedures and developments, rules, and technology in the provided BIM Execution Plan (ISO, 2018b).
6.	Information production	This stage is established by the collaborative working of the involved parties for production following the modelling process, with interoperability of a robust BIM tool and extensive professional participation. (ISO, 2018b).
7.	Model delivery	Consolidation of all project deliverables, including documentation, BIM models, and all data generated. During this phase, the contractor conducts a final review of the project model, finishing with its acceptance or rejection.
8.	Project handover and close-out	Archiving the CDE and compiling any lessons learnt for future projects, which will be incorporated into future PEB adaptations.

Basically, the BS standard (BS EN ISO 19650) series aims to establish consistent even practices for the digitisation journeys of the involved project parties, notably in terms of digitisation of information management features (Winfield *et al.*, 2019). According to UK BIM Alliance (2019a), standard guidance Part 1concept (BS EN ISO 19650) is a best practice standard that defines information management standards and guidelines in the context of digital transition. As a result, digitalisation has a lot to do with how digital data, or information, is collected and managed.

According to Shillcock & Winfield (2019a), The ISO 19650 standards provide a global acknowledged framework for digital information management processes. The standard aims to decrease and regulate the project's quality, time, and costs not like the previous 1192 standards. The 19650 standards provide a comprehensive and cohesive record of activities for distribution between the parties, for the purpose of a smooth execution of projects from beginning to end (Shillcock & Winfield, 2019a). According to their study, inability to properly assign activities may result in those activities not being completed at all or completely. Assigning all essential roles is unique to the information management process. For example, ISO 19650 part 2 of the series (BS EN ISO 19650-2:2018) requirements (handling the design and construction phases) expect the 'appointing party' to receive all project-related information required at key decision points, enabling the appointing party to make necessary and accurate decisions.

On the other hand, failure to have or follow such a requirement could make it difficult for clients or employers to make crucial project decisions or force them to base these decisions on incomplete information, resulting in possible cost and time implications. Also, the ISO standard includes particular, unbiased terminology that differs from UK standard wording in some circumstances. The client or employer, for instance, is the appointing party; the lead appointed party is the contractor or equivalent entity, and the appointed parties are the other members of the supply chain employed by the lead appointed party. Additionally, the 19650 standards guarantee the understanding of the parties to have the knowledge of the project information and outcomes the appointing party require, as well as the procedures and techniques that will be employed by the various supply chain parties (Shillcock & Winfield, 2019b).

3.4.2 BSI Standards

The British Standard Institution (BSI) created a detailed set of BIM standards focusing on certain lifecycle stages, such as design, construction, and O&M. The BSI BIM standards outlined the BIM IM procedures in the way information are defined, gathered, exchanged, saved, utilised, and disposed of (BSI, 2013). Although, BIM is commonly used in the design and construction phases, it is less widely used in the operations and maintenance phases because of varied or complicated asset management issues, as well as the asset management framework's integration with BIM IM processes. *Table 3.8* below gave a summary of the basic BIM standards and specifications during the project life cycle stages.

Table 3. 8: *Established BIM standards for information management and exchange (Adapted from Guillen et al., 2016)*

Standard type	***Standard title***	***Focus area***
Collaborative production of AEC information standards	BS 1192	Production construction information. of architectural, engineering -Code of practice.
Collaborative production of information standards-COBie	BS 1192-4	Collaborative information production Part 4: Meeting employer information exchange requirements with COBie - Code of practice
Standards related to library object	BS 8541	Objects for AEC.
Standards related to data exchange	BS ISO 16739	IFC for sharing data in the construction and facility management industries
Standards related to asset management	BS ISO 55000	Management of the asset – Outline, principles and definition of terms
Design management standards	BS 7000-4	Design management strategy- provides guidance to design management in projects.
Briefing related standards for facility management	BS 8536-1	Design and construction briefing – Part 1: Code of practice for facilities management (infrastructure)
Design and construction standards	BS 8536-2:2016	Design and construction for Linear and geographical infrastructure asset management code of practice
Information organisation about construction standards-concept and principles	BS EN ISO 19650-1	Construction information organisation - Information management using building information modelling Part 1: Fundamental ideas and principles
Construction standards information organisation-delivery phase of assets	BS EN ISO 19650-2	Construction information organisation - Information management using building information modelling Part 2: Asset delivery phase
Information standards organisation and digitisation-asset operational phase	BS EN ISO 19650-3	Building and civil engineering information organisation and digitisation, including BIM for information management. Part 3: The Assets' Operational Phase
Information standards organisation and digitization (security minded approach to IM)	BS EN ISO 19650-5	Building and civil engineering information organisation and digitization, including BIM for information management. An approach to information management that is concerned with security
Information classification standard	ISO 12006-2	Information classification in construction
Publicly Available Specification (PAS)		
Specified information standards for the delivery phase	PAS 1192-2	Information specification and managing information using BIM for the delivery phase of construction projects.
Specified information standards for the operational phase	PAS 1192-3	Information specification and managing information for the operational phase of construction projects
Specification for security information standards	PAS 1192-5	Information specification for security-minded using BIM, digital built environments and intelligent asset management
Specification for collaborative sharing related standards (H&S)	PAS 1192-6	Information specification for sharing and using Health and Safety information as well as structured hazard and risk.

3.4.3 Interoperability and data exchange standards

There exists an urgent demand to standardise the exchange of graphical and non-graphical information among various players in the project life cycle to support BIM deployment and information management procedures. This demand has resulted in the OpenBIM concept. According to Jiang *et al.* 2019; Theiben *et al.*, 2020, OpenBIM is a collection of open-source data standards for information exchange between BIM authoring tools or validation software (Jiang *et al.*, 2019; Theiben *et al.*, 2020). Most especially, buildingSmart contributed to the development of the IFC (open-source data format), which is widely used by software developers and facilitates distribution of BIM-related data. A notable essential feature of IFC is its interoperability, which enable the use of BIM models to be exchanged across different enterprise software suppliers. For instance, instead of using incompatible native formats, an engineer can employ the IFC model with a quantity surveyor (QS) to discuss costing related information or estimation difficulties. As such, IFC's overall purpose is to support information sharing in an open-format standard throughout a project's lifecycle, making it a standard versatile data model (Shalabi & Turkan, 2016).

Furthermore, COBie is the UK government's most preferred information-sharing protocol for BIM-related information, in addition to the BIM model and PDF documentation (Schwabe *et al*., 2018). This is to offer a well-structured method for exchanging information all through a project's entire life cycle. COBie represented a structured spreadsheet that is filled out by various stakeholders in the project especially the supplier and facility manager which is later shared with the project owner at a specified point in the asset life cycle. The operation and management information recorded by COBie is a Model View Definition (MVD), a subsection of the IFC data model. Compared to a centrally controlled database or platform, a simple and user-friendly approach via COBie spreadsheets is provided detailing the exchange information among the various stakeholders throughout a project's life cycle. However, it is limited as a central verification process, and there is a risk that information may be lost across various spreadsheets (Hamledari *et al.*, 2018; Motamedi *et al.*, 2014). Further explanation on COBie is provided in subsequent sections.

3.4.4 Quality checks and verifications of information in the BIM model

Another aspect of BIM information management that should be addressed is the quality of the information exchanged. If information is suitable for its "intended uses in planning, decision making, and operations," it is considered good quality (Redman, 2004). The accessibility to high-quality structured information in the terms of construction products is essential for the AEC sector's information requirements. The quality of data communicated in BIM projects is essential for determining whether it meets the information criteria defined by the responsible lead appointed party, whether the quality of information is appropriate, and whether the information communicates the requested and needed for other project teams. According to Pishdad-Bozorgi *et al.* (2018), information quality and verification checks need to be done as often as possible most especially when transferring information throughout key milestones and when the project is nearing completion. At the start of the project, quality should be defined, as well as outlining how the model and quality of the information will be organised and handled. The information about the quality of project is specified in the BEP, and response from the teams is expected to be supplied at each check and verification stage before proceeding to the next stage. According to the Rail Baltica (RB) BIM manual (2019), quality control and verification checks measures for BIM Information models would be carried out through the design, coordination, checking, review, and audit processes. These processes assess how well BIM objects fulfil their objectives and adhere to the processes outlined to attain those objectives. RB BIM manual (2019) categorised the verification checks to be carried out throughout the lifecycle of a project into six (6) groups, as represented below in *Table 3.9*.

Table 3. 9: *Summary of quality control and verification checks (Adapted from Rail Baltica, 2019)*

Quality control check in BIM projects		
Checks	Explanation	Responsible party
Self-check	It is a thorough analysis performed solely by the modeller. Overall strategic direction: the design concept, visual presentation, and data are all consistent, complete, and coherent.	BIM model modeller/BIM specialist [supplier/service provider]
Visual check	Visual checks ensure that each component of the BIM model is reviewed. Ascertain that there are no unexpected model components and that the design intent has strictly been followed.	Discipline design leader/ BIM coordinator
Clash check ***Self-clash check:*** *clash between element contained in the same model* **Interdisciplinary clash *check*:** *clash between building components contained in different model of each discipline* **Progressive clashes check**: *clash between elements through the different progressive or temporal stages.*	Clash checks is done to discover areas where element in the different trades clashed. Identify areas of interference between components/elements in the model.	Supplier/service information manager
Model data check	Client data check of data entered into the software while creating the BIM models. Check that there are no undefined, poorly defined, or duplicated components in the project data.	BIM discipline/package coordinator
BIM standard check/BIM standard verification	Ascertain that models and drawings are created in accordance with BIM modelling requirements and guidelines.	BIM information management team or employer if the verification team is deployed by employer
Technical standard check	A technical checking should be carried out by evaluating the design to the technical design guidelines for each discipline.	Lead designers or supplier/services provider

Checking the model components in a BIM authoring tool like Revit is one method of validating data in a BIM model. Manual validation on the other is inefficient, time-consuming, and susceptible to omission. Therefore, the owner/employer may engage personnel with experience or knowledge of BIM modelling to carry out the work efficiently. Software solutions (Pishdad-Bozorgi *et al.*, 2018) such as "*plannerly* "may assist with the verification checks. A user can use such software to define BIM-based requirements for handover, data quality and analysis imported from a BIM model.

3.5 Collaborative Practices

The process of jointly developing and maintaining digital information on a built asset is referred to by the broad term "BIM." The UK government has required fully collaborative 3D BIM (with all project and asset information, paperwork, and digitised data) as the bare minimum for Level 2 BIM on publicly procured projects since 2016.

Establishing a regulated 3D environment with data that is organised into distinct discipline models is required for this level 2. The creation of these many models involve input from all project stakeholders or participants including the clients, designers (architects, civil/structural engineers, building services engineers), contractors/ subcontractors, suppliers/material vendors, and other consultants. A federated model that is collaboratively built combines numerous models to create a single, thorough structural model within the CDE. Constructing the Team, published in The Latham Report in 1994, examined the perceived challenges confronting the construction industry, describing it as "inefficient," "adversarial," "disparate," and "unable to deliver for its clients," and recommended increased collaboration and team coordination. This report's message was reiterated in the Egan Report; Rethinking Construction, 1998; the Government Construction Strategy, 2011; and the Farmer Review, 2016 (Winfield, 2020).

Construction projects often necessitate the collaboration of various professionals, many of whom have never worked together before, making collaborative techniques more important. Liu *et al.* (2017) and Schapke *et al.* (2018), attested to collaborative working of the construction project teams stating that they would unquestionably need the collaboration and integration of a huge amount of complicated data, techniques, and procedures. It could be disastrous if transparent and effective construction cooperation procedures are not developed. Early supply chain interaction and the incorporation of subcontractors, suppliers/vendors, and designers has become increasingly important as construction projects have evolved from ordinary employer-consultant-contractor interactions to a more integrated constructions with complicated finance activities. Even if specific technical details are left to be worked out later in the construction process, it is vital to describe the collaborative practices' principles as early as possible in the project. The client should decide to take a collaborative approach from the beginning (perhaps with the help and support of independent professional consultant or external client advisers) so that the requirement will follow appropriate procedures and be incorporated into the appointment documents. The collaborative practice is most often a factor in the procurement route, contract type, and tender documents development (Davies *et al*., 2015; Ibrahim & Belayutham, 2019). During consultant start-up meetings for the teams and specialist contractors, and pre-contract meetings, the application of collaborative practices needs to be thoroughly explored.

Furthermore, the early involvement of contractors or suppliers and appointing a construction manager (or appointing the design and build contractor early in the project) can lead to improved construction integration and operations (Arayici *et al.*, 2018; Blay *et al.*, 2019). It makes collaboration easier if consultants agree to use compatible technologies and adhere to the agreed-upon document and drawing standards throughout the project cycle. Computer-Aided Design (CAD), Building Information Modelling (BIM), Common Document Management Systems, Common e-document management system (in-house or externally hosted, i.e., project extranet), and CDE are examples of collaborative platforms. Furthermore, an accurate method to software versions and procedures, drawing standards, and formats of the file is vital for project information management to avoid duplication of work and errors (Alreshidi *et al.,* 2017; Lee & Borrmann, 2020). They also help facilitate collaborative practices. Some examples are listed below.

i. Common data environment (CDE)
ii. Interoperability
iii. Industry foundation classes (IFC)
iv. Construction operations building information exchange (COBie)
v. Unified construction classification (Uniclass) 2015

3.5.1 Common data environment (CDE)

BIM, as a model-based method, has a variety of consequences for construction project information and data management. Information sharing across the design and implementation of BIM projects generates unique requests for management of information, as several types of participants' information is exchange at various levels of development according to their needs, repeatedly and back and forth (Lai *et al*., 2019; Matarneh *et al.,* 2019). Structuring procedures for managing, merging, distributing as well as preserving of digital information must be established and technically supported in the information process for a robust model-based project management (Lee & Borrmann, 2020; Lai *et al*., 2019; Wong *et al.,* 2018). It is commonly acknowledged that digital collaboration platforms are ideal for the execution of BIM projects and the related collaborative practices (Schapke *et al.,* 2018; Ibrahim & Belaytham, 2019). The British PAS 1192 standards provides a generic architecture for implementing a central collaborative platform established on what is known as a CDE. The CDE is shared digital environment with defined accessibility in the central regions for stakeholders in any project, unambiguous definitions of status, aa well as a detailed plan description for collaborative sharing and approval procedures (Preidel *et al.,* 2016, 2021; Esser *et al.,* 2021).

The CDE is described as a single source of actionable information for the entire team in a project for collecting, managing, documents dissemination, graphical and non-graphical data sharing (project information) whether in a BIM environment or a conventional data format (Preidel *et al.,* 2015, 2021; Esser *et al.,* 2021). The single source of information enables project stakeholders to collaborate to avoid duplication and mistakes in projects. The creator/originator of information within the CDE maintains information model ownership. Separate models generated by each project team members do not interact; the models have distinct authors and are separately kept (Valluru *et al*., 2020; Daniotti *et al.*, 2021). The incorporation of the originators' model into the federated model however does not have any liabilities effect. But, where there is a change of ownership as the development continues, for example, changing the designer's objects with the contractor/subcontractor's objects, complications may occur (Valluru *et al.*, 2020; Menzel, 2021; Valra *et al*., 2021).

In general, the client is permitted to utilise the data contained in the different models for the intention for which the model was created for or the particular level of detail it was intended (Valluru *et al.*, 2020; Daniotti *et al.*, 2022) and model created by project team members can used by other project team members. According to the Construction Industry Council Building Information Modelling (CIC BIM) protocol, the CDE must be established and managed by a client-designated information manager who acts as a technical gatekeeper, policing the CDE to ensure that the data is secure and it follows the agreed-upon processes. The information Manager are not a BIM coordinator as such they are not accountable for the project design, clash detection, or coordination of the model. The CDE may house or contain different information environments. For instance, the CDE could include a supply-side CDE for the project delivery team as well as an employer's information environment for document and data management system to receive, validate, and approve supplier project data (Preidel *et al*., 2015; 2021). The employer's information requirements (EIR) determine the responsible party for providing and managing the supply-side CDE. According to PAS 1192-2, which specifies information management for the capital project delivery phase of construction projects using BIM, a CDE may use a project web service, an extranet, a file-based repository system, or other suitable collaborative environments.

3.5.2 Interoperability

Interoperability is a popular topic in today's digitally powered world of construction projects, and considered to be an important roadblock to getting the most out of digital transformation in most industries including the construction industry (Shehzad *et al.*, 2021; De Gaetani *et al.*, 2020). It signifies software's capability to exchange or share and use information or data without altering its format. Information workflows and automation are facilitated by proper data exchange between different applications, reducing the need for manual data copying from one application to another (Sacks *et al.*, 2018). Providing information regarding interoperability in projects is crucial when several project participants and software are engaged to enable outputs from one party to be opened, checked, and utilised by the other parties involved in the project. The whole lifetime of the project requires the use of the project deliverables, and interoperability assures that the information may be used without having to re-enter it (Borrmann *et al.*, 2018).

The information model, i.e., the BIM models and the activities from clash detection, construction, and cost simulations, must be supported by interoperability. Open standardised formats are recommended to facilitate exchanges without relying on particular software vendors. The IFC is among the most well-known, open and popular standardised data exchange format structure for the construction environment. BuildingSMART originated and managed IFC, which enables information communication or data exchange between various software and vendor interchange/exchange points (buildingSMART International, 2020). IFC displayed data in different data formats such as XML, JSON, and STEP formats that are utilised in various contexts including databases, files, and web services (buildingSMART International, 2020).

3.5.3 Industry foundation classes (IFC)

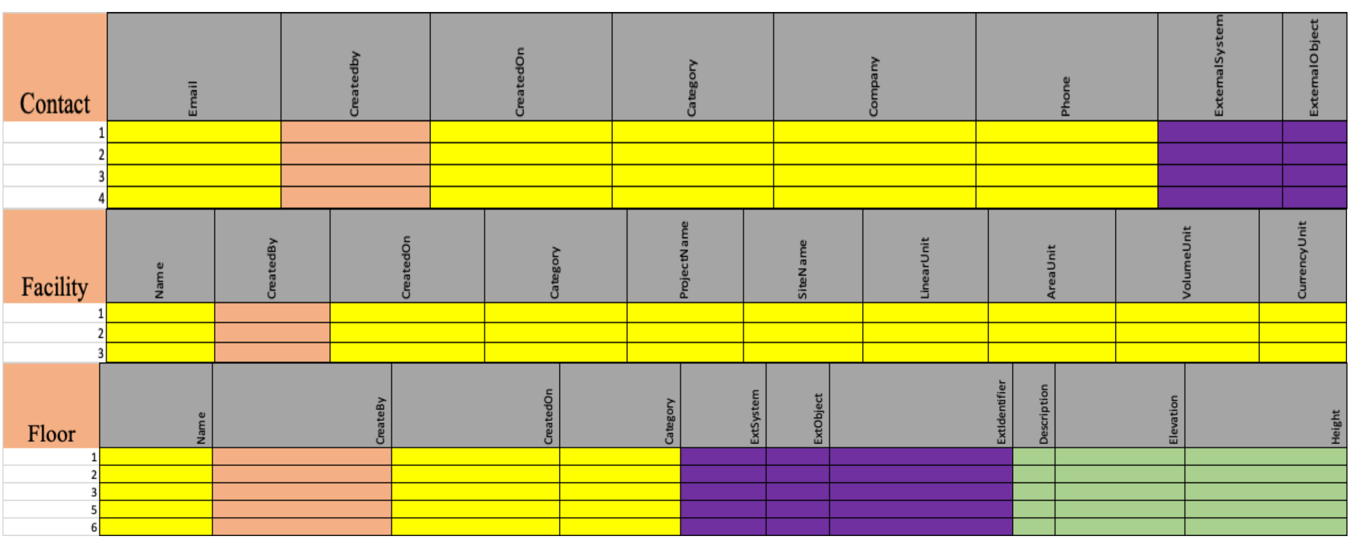
The IFC are standardised data format that allows for vendor-independent exchange of digital information construction models. As a result, it is a necessary foundation for Open BIM's establishment (Borrmann *et al.*, 2018). Since construction projects frequently bring together teams from several organisations, different hardware and software will inevitably be used. Therefore, a data exchange standard has been established to enhance collaboration amongst team members to create building information models while allowing them to continue to utilise tools that they have invested in and are acquainted with (Tang *et al*., 2020; Vieira *et al.,* 2020). The Industry Alliance for Interoperability, a consortium created by Autodesk, first developed IFC in 1994 (Laakso & Kiviniemi, 2012), changing its name to the International Alliance for Interoperability (IAI) in 1997 for the continuous progression of IFC as a non-proprietary data format, currently known as buildingSMART, a non-profit organisation (Laakso & Kiviniemi, 2012; Lee & Kim, 2011). The IFC is a neutral data format for describing, exchanging, aa well as sharing data. It is a BIM international standard that allows the sharing and exchanging of construction and facility management data between different software (Borrmann *et al.*, 2018; Ait-Lamallam *et al*., 2021).

3.5.4 Construction operations building information exchange (COBie)

COBie is a non-geometric international standard for information transfers in an open data format, which is essential for information exchange between earlier construction phases and the O&M phase. It is a standardised specification that grew out of the concept of Computer Aided Facility Management (CAFM) (Alnaggar & Pitt, 2018; Gnanarednam & Jayasena, 2013). COBie outlines the procedures and methods required for transferring data from earlier construction phases to the facilities O&M phases (East, 2013; Schwabe *et al.,* 2018). Up to this present time, the handover has consisted primarily of paper-based transfer and collecting Facility Management (FM)-relevant information. Collecting information in this manner has been time-consuming. As a result, COBie's collects and methodically store important information in a digital format as it emerges throughout the project. The COBie definition recommends open formats like eXtensible Markup Language (XML), spreadsheets, and the IFC

STEP format to achieve effective data exchange and ensure information consistency (Alnaggar & Pitt, 2018; Kumar & Teo, 2020, 2021). These formats are designed for data transfer between systems. For example, the submissions of BIM information for Level 2 are in the COBie format, often known as "data drops" *(Figure 3.2).* Data drops are essential at key points in the implementation of projects to ensure that information is effectively assessed and coordinated while the client is allowed to assess the information or data available to ensure its total compliance technically, to project brief, cost, or price (Schwabe *et al.*, 2018; Kuo *et al*., 2019). In general, data drops are synonymous with project stages, and the required information reveals the stage the project ought to have reached to attain its goals. The COBie can either include information from the client, contractors/subcontractors, suppliers, and even the consultants as the project continues (Chen *et al.*, 2018; Sadeghi *et al.*, 2019).

Conclusively, the provided information/data informs the efficient operation and management of the facility (Chen *et al*., 2018). COBie describes all the information an owner should expect for the project to be delivered at handover (Sadeghi *et al.*, 2019; Schwabe *et al.*, 2018). The purpose of COBie is to transfer the building data into a maintenance and facility system. Although COBie is delivered in XL and XML formats, the data is imported to other systems for use. The uncomplicated way to look at COBie is as a listing of all spaces and equipment within a facility and their associated properties. These properties include equipment type, location, room number, zone, system, manufacturer, installer (with contact details), repair, maintenance and replacement information. Instead of the operational and maintenance manuals and equipment specifications being delivered in plan format (traditional method), COBie provides all this information in digital form (Yi-Jao *et al.,* 2018; Chen *et al.,* 2020). A COBie sample spreadsheet is represented below in *Figure 3.1.*



Space	Name	CreatedBy	CreatedOn	Category	FloorName	Description
1						
2						
3						
4						

Figure 3. 1: *Blank example of COBie spreadsheet*

3.5.4.1 Data drop

Data is taken from the developing building information model and presented to the client at defined or specific milestones to make sure the projects are properly verified and organised as they develop. A 'data drop' or an 'information exchange outlet' describes the transmission of this data form the information model to the client at specified milestone. In general, the transmission corresponds to deliverables during the project phases, and the information required reflects the stage at which the project ought to have attained its goals or objectives (Kumar & Hayne, 2016). This could be likened to a stage report in the case of a traditional project approach. The Employer's Information Requirements (EIRs) defined data drop in BIM projects. The EIRs are applied in conjunction with the brief in projects. It defines the asset information of the built structure that the employer wants to acquire to make sure the design is well-developed according to the objectives of the project and to ensure that the completed product can be operated smoothly and effectively (PAS 1192-2:2013). The brief specifies the type of project that the employer desires to erect or build. Data drop would consist of the items shown in *Figure 3.2* below.

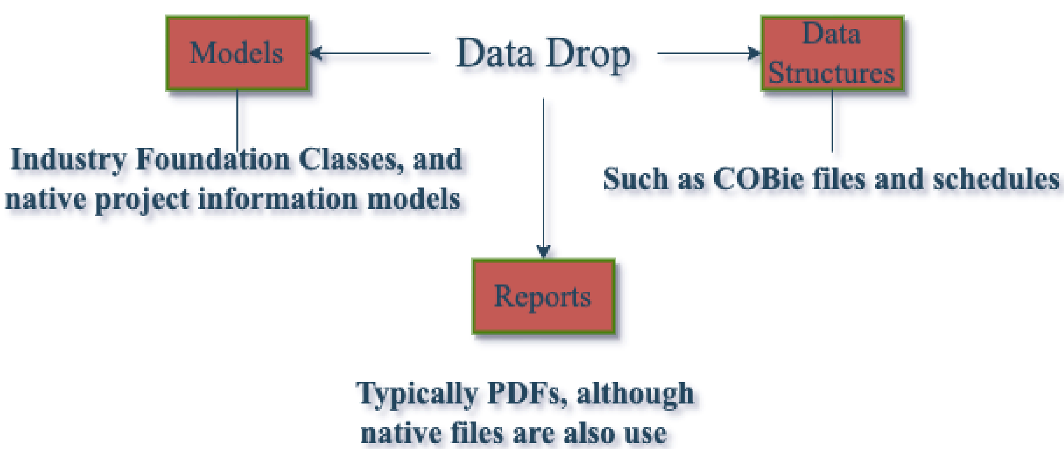


Figure 3. 2: *Data drops in BIM Projects*

3.5.5 Unified construction classification (Uniclass) 2015

Uniclass is a construction industry voluntary classification system for organising information at the design and construction stages (Danusevics *et al.*, 2022; Crawford & Stephen, 2015). Interoperability across different systems is made more accessible using a consistent Uniclass categorisation. The Construction Project Information Committee (CPIC) created Uniclass 2, the latest version, to replace the older version, which was believed to be primarily a paper-based system. Uniclass 2 is meant to develop a classification system for organising information that is clearly and openly available to all parties involved throughout the life cycle of the project and beyond. (CPIC, 2013; Partridge *et al.*, 2020). Uniclass 2 complies with ISO 12006-2, is BIM Level 2 compatible, and is supported by the BIM Toolkit. The BIM toolkit helps explain, manage, and verify responsibilities for the development and delivery of information at different stages of the project's lifecycle (Lu *et al.*, 2018). It ensures that information meets Level 2 BIM criteria and is suited for commercial and public-sector projects, such as buildings and infrastructure projects, such as rail and highways. Uniclass is now integral to BIM and the ISO19650 information management process.

3.5.5.1 Digital plan of work (DPoW)

The client creates the Digital Plan of Work (DPoW). The DPoW laid the framework for information validation at each stage of the asset lifecycle by identifying important strategic points for the client to define the maturity of building, infrastructure, or civil project information, including why it is needed, what it will be used for, and who will maintain it (BIM Task Group, 2013; Withanage & De Silva, 2018; Amin & Abanda, 2019; Benghi, 2019). The National Building Specification (NBS), funded by the UK government, created a free-to use online tool called the NBS BIM Toolkit for planning and managing information deliverables. Project teams utilise the BIM toolkit to assist them in creating a digital plan of work and to provide direction on the information required to align with particular project stages. In addition, other online tools, such as Excel, can be used to manage the DPoW. For example, a DPoW on an excel sheet is depicted below in *Figure 3.3.*

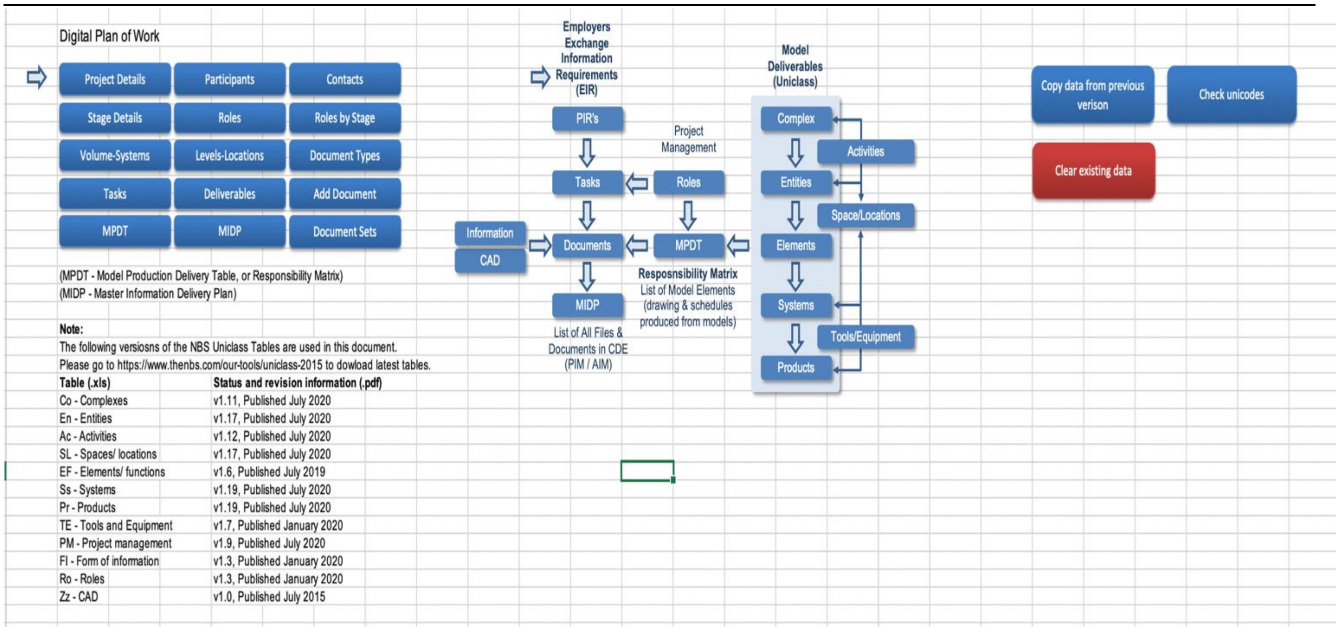


Figure 3. 3: *Sample of a Digital Plan of Work on an excel sheet*

3.6 BIM Information Management Requirements

Using digitally created building information models constantly for the project's lifecycle development, from early preliminary or conceptual design to detailed design through construction and long-term O&M is the idea behind BIM. These phases benefit from improved information flow between stakeholders with BIM, which also increases efficiency by reducing the time taken manually re-entre project data, a hallmark of conventional paper-based workflows (Eastman *et al*., 2008; Sampaio, 2015; Gao & Pishdad-Bozorgi, 2019). All through the life cycle of an asset, BIM is employed continuously to support the low-loss transfer of digital data or information (Eastman *et al.*, 2008). The information requirements, information delivery planning, and information delivery are all defined and differentiated by ISO 19650 (ISO 19650, 2018) and represented in the information models. These requirements would be discussed in subsequent sections.

The project client develops the information requirements and acts as an essential data source when making critical decisions. Therefore, information models must have structure and content that meet the requirements. In additional, information models may encompass a range of subjects at the project's life stages. For example, in any construction project, information models may include equipment schedules, technical schedules/specifications, 3D models as well as test certificates among others. The diagram below in *Figure 3.4* represent the relationships between required information in a model and resulting information models in a typical project life cycle. The horizontal division shows the various perspectives on the asset that significantly impact the requirements and information models that result from it.

3.6.1 Organisational information requirements (OIR)

OIR are a group of information or data that needs to be outlined by the client to realise and accomplish their organisational goals. OIR often focus on regulatory duties or policymaking process, strategic project or facility information management or portfolio planning as well as routine facility operations and administration (Heaton *et al.*, 2019; Cavka *et al.*, 2017; Ashworth *et al.*, 2016). As the asset management phase significantly affects the construction's life span and related costs, OIR, therefore significantly affects Asset Information Requirements (AIR) (Heaton *et al.*, 2019). Similarly, OIR must be taken into account while developing Project Information Models (PIM) because the information from PIM must be transferred to AIM (asset information model) (Jupp & Awad, 2017; Munir *et al.*, 2019) for the operation phase.

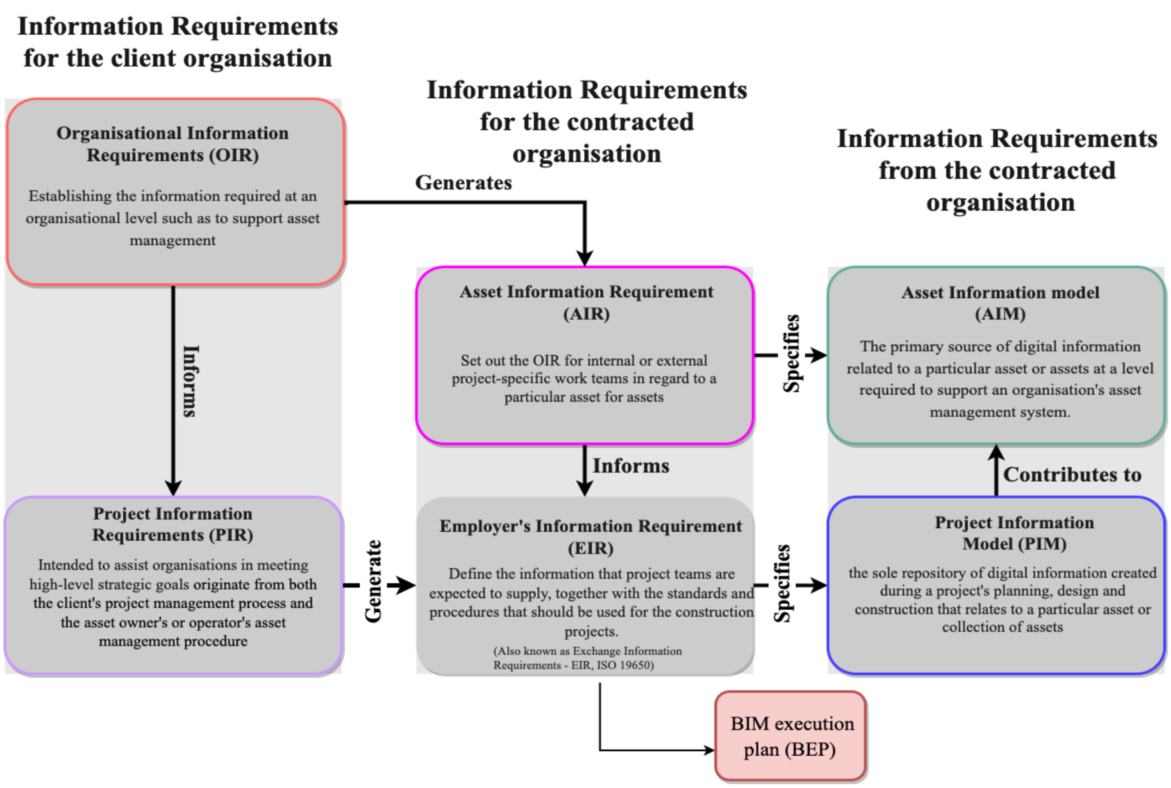


Figure 3. 4: *Order of BIM Information Requirements of the project life cycle (Adapted from ISO 19650-1, 2017)*

3.6.2 Project information requirements/model (PIR/PIM)

PIRs, or project information requirements, are intended to assist organisations in meeting high-level strategic goals. The owner's and operator's requirements for a particular facility are reflected in a PIR. They originate from the project management process defined by the client and the facility owner's management procedure. The PIM is a vital data source for the AIM and aids in project delivery. PIM is used for model-based tasks during the design and construction process of a project. The agreed-upon project BIM uses decides the PIM's content *(Table 2.1).* At the delivery phase of a project, the PIM is utilised for detecting clashes, estimating cost or scheduling. Geometric data, equipment location, and details of installed systems are found in a PIM and are all crucial for the AIM (PAS 1192-2, 2013; ISO 19650-1, 2017) development. In addition, PIMs are beneficial for cost verification purposes, as well as repair works and certification.

3.6.3 Asset information requirements/model (AIR/AIM)

AIR specifies the data needed for facility management and operations. For facility operations and maintenance purposes, the AIM is created following the contractual deliverables (the specification), which are detailed in the AIR. The information needed to contribute to the OIR is specified in Asset Information Requirements (AIR). With a focus on the interests of the asset owner, the AIM aids both ongoing facility management tasks and strategic project decision-making. AIM is used for model-based facility operations and maintenance. The facility and equipment information are included in the AIM, together with the geometric model in its as-built state. AIM may also contain graphical models, non-graphical data and operator certification (PAS 1192-2 2013). Content of the AIM frequently used includes equipment registrations, overall maintenance expenses, and dates. Furthermore, an existing AIM could serve as a PIM information source, for instance, by providing previous facility information as the main source for the project brief.

3.6.4 Exchange information requirements (EIR)

The required information for the design and construction phases are contained in PAS 1192, now known as exchange information requirements (EIR) but formerly known as the employer information requirements. The EIR specifies this required information, as it will be delivered and exchanged during the project's development. The EIR describes the contracting document (the BIM brief) for the consulting and contracting firms to deliver BIM for a particular project (Scheffer *et al.*, 2018). The EIR control the data and information provided by the appointed party all through the handover period, as stipulated by the appointing party. EIR may also incorporate AIR rules and regulations but primarily addresses the PIR. EIR accepted by an appointed party may be shared and delivered to sub-contractors because the nature of construction projects is determined by sub-contractor, covering the resulting supply chains (ISO 19650-1, 2017).

The BEP at the initial contract stage (pre-contract BEP) is directly responding to the EIR, according to PAS 1192-2:2013. Prospective suppliers produce the pre-contract BEP outlining the project proposed strategy, competence capability, capacity to satisfy EIR. The appointed supplier then produces a second BEP after the contract has been granted, attesting to the capabilities of the supply chain and develop a Master Information Delivery Plan (MIDP). The MIDP, based on many distinct Task Information Delivery Plans (TIDPs), outlines who is responsible for carrying out particular information tasks. The preliminary plan specifies the time the project information would be prepared, who will be responsible for the preparation, and what are the protocols and procedures to use. The EIR is an essential document that outlines the data that the employer needs at strategic points across the project life cycle. The EIR might be viewed as closely related to the project brief.

In order to improve the information quality, the reliability of the information requirements would be ensured by all the project participating teams at the different stages of the project, The information requirements in *Figure 3.5*, as explained in *Figure 3.4,* include the transfer of the information created at the different phases of a project's life cycle and the information documents of the project in those phases, including their definitions and functions, as represented in *Figure 3.6.*

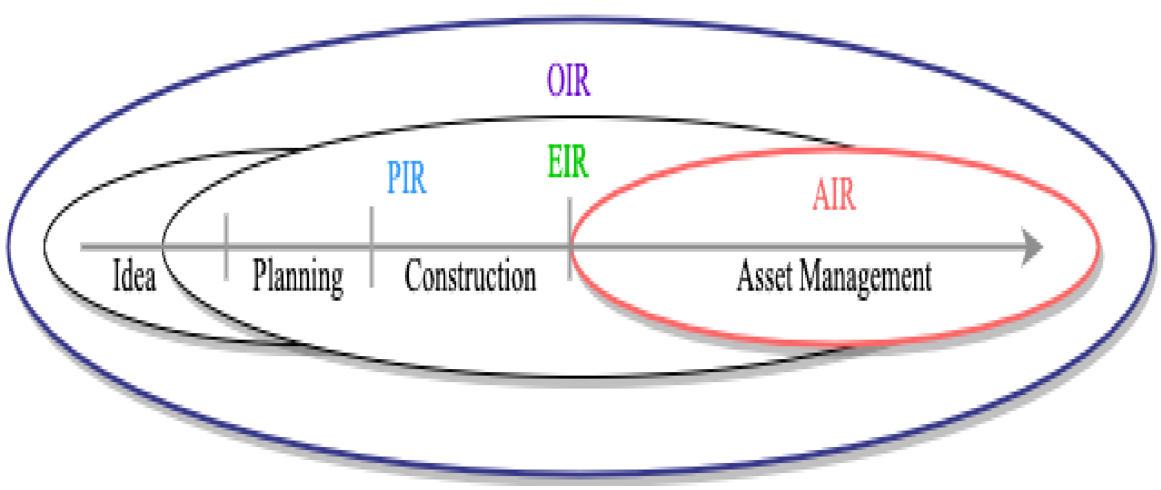


Figure 3. 5: *Information range across the asset life cycle (Adapted from Scheffer et al., 2018)*

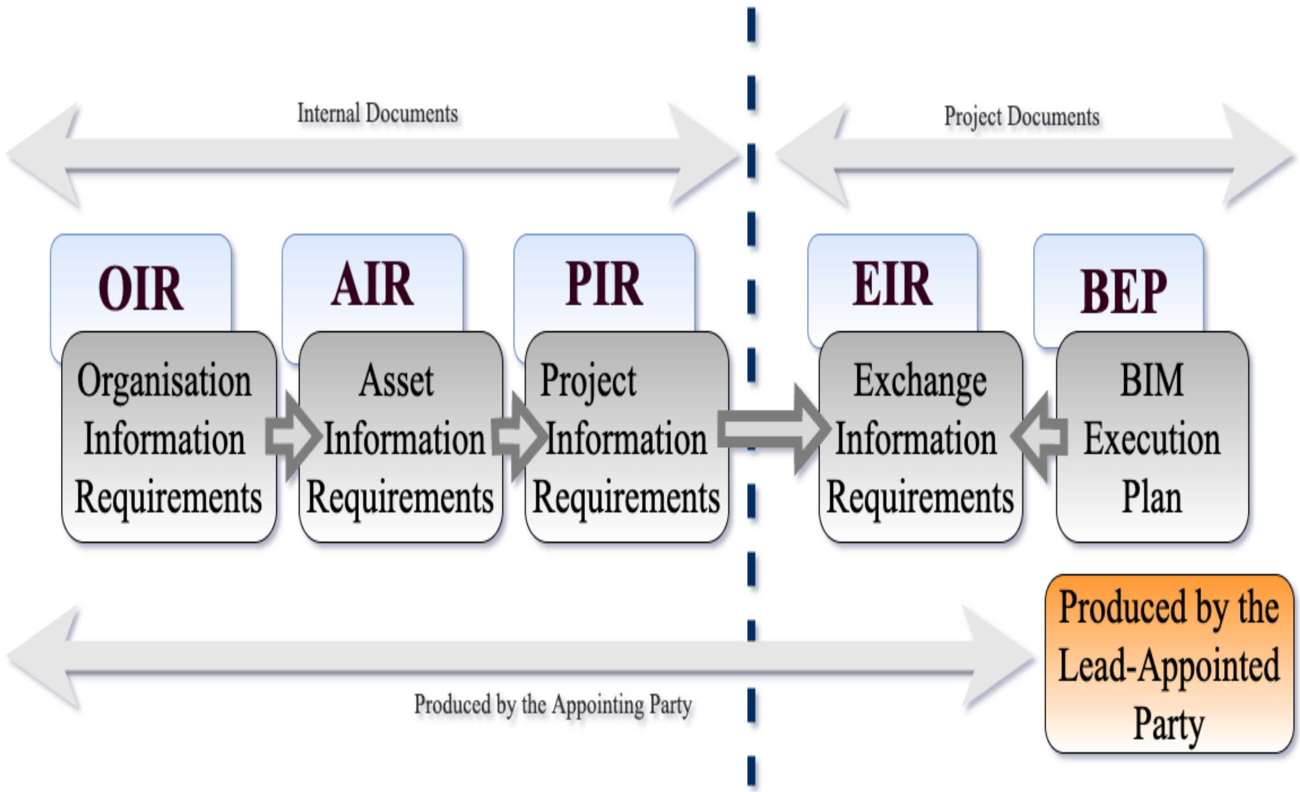


Figure 3. 6: *Project information documents*

3.6.5 BIM execution plan (BEP)

Project information management approach for the delivery team is set out in the BEP developed in accordance with the PIR. As a result, the BEP outlines steps for developing information models that are compatible with the client's EIR. In addition, each participating team submits a Project Information Plan (PIP) as part of the BEP, which is often based on the Construction Project Information Exchange (CPIx) procedure for accessing the supplier's information resources and technologies. The pre-contract BEP content is listed below, in addition to EIR other things requested in the EIR. These are contractual documents (the BIM brief), the required data/information by the appointed party all through the handover, the PIR and AIR regulations (PAS 1192-2, 2013).

i. The project implementation plan (PIP)
ii. Project collaboration and information modelling goals
iii. Important project milestones based on the project plan
iv. The deliverables for the PIM

Within the team, the BEP is continuously being improved and updated due to the dynamic nature of construction projects. Therefore, everything required in the EIR would be included in the BEP for the post award contract, in addition to those represented in *Table 3.10* below.

Table 3. 10: *The EIR as detailed in the post-contract BEP (Adapted from PAS 1192-2:2013)*

S/n	Management	Documentation and Planning process	Procedural method and standard	Technology solutions
1.	Management duties, roles, and authorities	Revision of the PIP confirms the supply chain's capacity.	The strategy of volume	Versions of the software
2.	Key milestones of the project in accordance with the project program	Agreeing to procedures for-information modelling and collaboration	PIM's orientation and origin (a point on the earth's surface using a known projection)	Formats for exchanging data
3.	Strategic information for the models developed in the project and deliverables (e.g., the Construction Industry Council (CIC) Schedule)	Responsibilities matrix as agreed by of the supply chain team	Naming nomenclature	Systems for managing construction processes and data
4.	Methodological survey may include using point clouds, 3D laser scanning or global navigation satellite systems (GNSS)	Task Information Delivery Plan (TIDP)	Layer naming nomenclature, where applicable	
5.	Use of existing legacy information	Master Information Delivery Plan (MIDP).	construction quality standards agreement for all parties	
6.	Information approval		Drawing sheet templates	
7.	The PIM authorisation procedure		Dimensions, abbreviations symbols and annotations	
8.			Characteristic/quality of data	

3.6.6 Task information delivery plan (TIDP)

The TIDP is a document used internally by the different development or participating parties (PAS 1192-2, 2013). Each individual team develops its TIDP to include significant milestones to specify who provides each supplier's data. In addition, a TIDP helps project managers keep track of the model preparation steps that must be taken for any work packages that are used (Di Giuda, 2019). Each TIDP's milestones must be linked to the designing and constructing processes for generating the MIDP. The team member in charge of each delivery is identified using the TIDP, or it might be stated that this responsibility has not yet been assigned (Scheffer *et al.*, 2018). The TIDPs outline the team members' respective duties for project document preparation.

3.6.7 Master information delivery plan (MIDP)

The MIDP includes a variety of information deliverables such as drawings or renderings, specifications, equipment schedules, models and room information sheets (Fontana, 2020). The MIDP is organised through strategic implementation and is developed in accordance with the team members' TIDPs (PAS 1192-2 2013).

3.6.8 Collaboration in information production

ISO 19650 defines the management of information processes that focus on exchange of information amid an AIM and a PIM at the beginning and completion of a project. Design, construction, and asset management are all covered by collaborative information generation or production based on regularly used supply chains. The client would be provided with the necessary information at each critical decision point, which is reviewed for consistency with the EIR. The complicated structure of teams and the numerous responsibilities are part of the supply chains that arise. Since information is maintained/stored and exchanged in various forms, a container-based collaboration system is employed in BIM projects. Written papers, schedules, and tables, as well as aggregates of information sources, make up a more generic information container than a 3D model file, such as folders or files. The CPIC provides recommendations for standard practices in the content, format, and planning of construction production information (CPI), which it describes as "information created by designers and provided to be built by a construction team" (CPIC, 2013).

3.7 Components of Information at the Project Delivery Phases

Digital technologies are becoming more widely employed by the construction industry for design, construction, and operation of buildings and infrastructure assets. However, compared to other industrial fields, the application of digital information continuously throughout the entire process chain lags significantly (Borrmann et al., 2018). As a result, essential information may be lost since it is mostly drawings presented on papers as tangible printed plots or in a restricted electronic format. As illustrated in *Figure 3.7*, these interruptions in the flow of information throughout the facility lifecycle exist across the entire design, construction, and operation processes. As shown below in *Figure 3.8,* PAS 1192-2 as a standard specifies the requirements for managing information throughout the project's delivery phases for project in the BIM process.

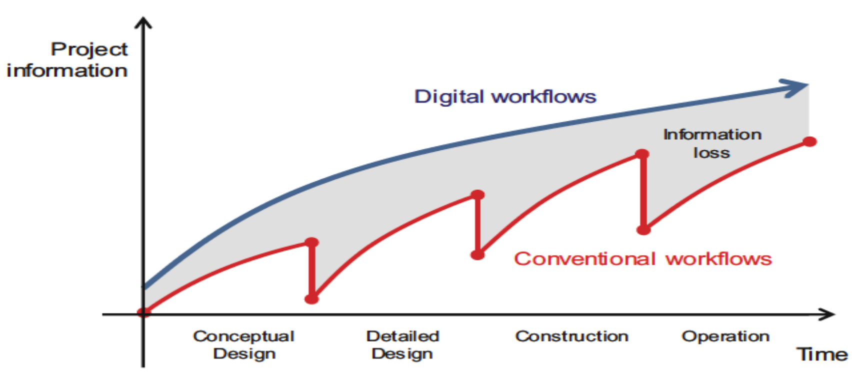


Figure 3. 7: *Interruptions in digital information workflow (Adapted from Eastman et al., 2008).*

Although not all project information will be developed, transferred as well as managed in BIM process, nonetheless, information management should be organised to support its effectiveness and correct transmission of the information. BS 1192:2007 provides the standards and procedures that must be followed in order to achieve these objectives *(Figure 3.8).* This PAS focuses solely on BIM-specific information flows. For exchanging information in a non-BIM project amid a main contractor, employer and supplier across the supply chain, the information needs to be managed using similar standards. Besides, all project information is exchanged using a single collaborative data environment, whether in BIM settings or traditional data formats, to avoid confusion. BIM creates information models and accompanying data all through the project life cycle of buildings, structural facilities, or other built assets.

In *Figure 3.8*, the area signified in grey represents the generic procedure of a typical project requirement (e.g., design representations, manufacturing/construction, or production), identifying and approving an agreement/contract, creating the production and information regarding the asset requirements and mobilising a supplier. This process is adopted for all phases of a project, including the development of information about design, as indicated below by purple showing the seven project stages. The region around the purple parts in the diagrams represent the CDE. The CIC scope of service stages is represented by the purple numbered ovals. The region inside the purple pictures represents the CDE responsible for collecting, managing, disseminating, exchanging, and retrieving information throughout project life cycle. The tiny purple circles indicate the exchange of information of all participating parties. To respond to the requests of the employer as specified in the EIR, information between the project team and the employer is shown by wine balloons.

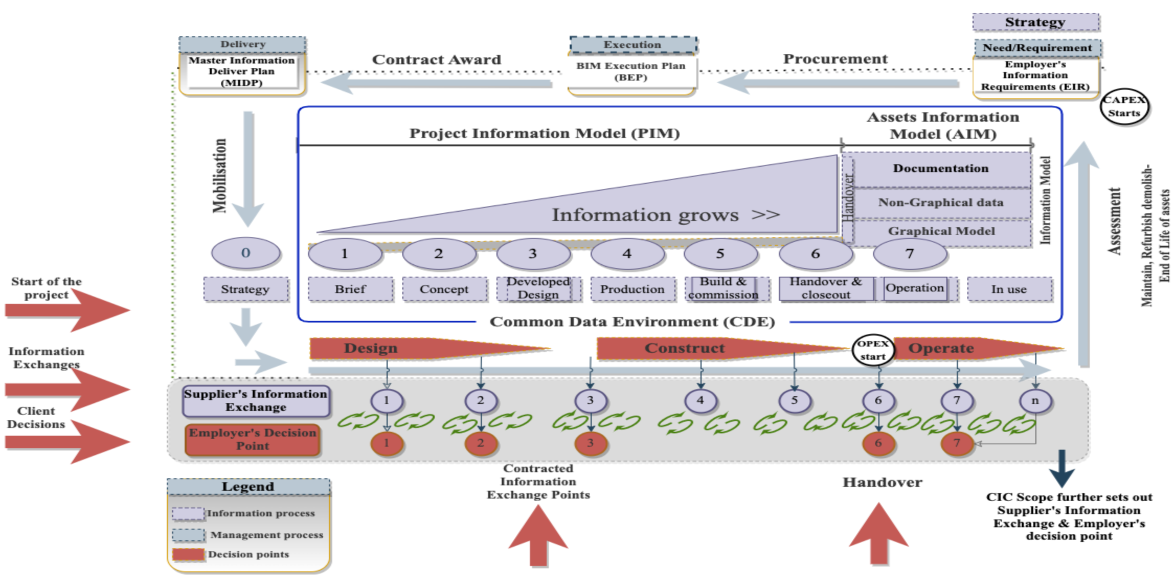


Figure 3. 8: *Information stages in the project delivery process (Adapted from ISO 19650-1: 2018)*

At the mobilisation stage, both the client and the project team need to make sure that everything is prepared to begin the project, such as setting up the CDE, documents, information management procedures and Technology Solutions. Following the decision to award the contract to a specific project team, the client and project team collaborate to produce the MIDP and the post-contract BEP, as shown in *Figure 3.8* above. During this phase, working in the CDE develops the PIM. The project team presents information at each data drop, which the client approves before proceeding to the next stage. The supplier will provide their BEP based on the EIR for the client to make a decision. The AIM phase develops all construction operation and maintenance information, including geometrical information, documentation, and alphanumerical information. This information provides direction on how to operate the assets from the time of handover until the asset's end of life.

3.7.1 BIM Information model at the design phase

Building information models may be referred to as PIM at the development of the design and construction stages (PAS 1192-2:2013). The original project information model created in the design phase by the designer is called the design intent model (DIM) (NBS, 2016), which demonstrates the architectural and engineering design aims. Early on in the design procedure, the design is represented by generic elements using 2D symbols, with some essential aspects being developed in greater detail. It demonstrates early coordination of several design elements and depends on the information needs of the employer, which include aesthetic purpose, architectural form, and spatial configurations. Other elements include general program details, preliminary construction and phasing sequencing studies, and a basic cost plan, in addition to outline specifications, high-level simulation findings (to determine whether the design would satisfy the requirements), outline site and landscape designs, and outline structural and services designs (Scheffer, Mattern, and König, 2018). As the design progresses and the level of detail develops, the model evolves. It first includes standard/generic representations, accompanied by detailed components with linked specifications and schematic statements, as well as space allocation information for access, O&M, assembly/installation, refurbishment/replacement, and other uses. Information model needed to fabricate, install, or assemble the model's objects is the virtual construction model (VCM), and is the outcome of the contractor and their supply chain taking-over model production from designers.

3.7.2 BIM Information model at the construction phase

According to PAS 1192-2:2013, PIM data, which is included in the BIM model in the design and construction phases consists of non-graphical data, supporting documents to form the federated model. The DIM (design information) and the VCM, are the first two stages of the PIM development which contains all the objects to be produced, installed, or built. The PIM is then developed in line with a MIDP and delivered to the employer through several data drops, which frequently include some deliverables. These deliverables include (i) a group of federated building information models made up of native and IFC files and incorporating non-graphical data and related documentation, (ii) COBie files, which are used in construction operations, and other structured data, such as schedules, and (iii) reports and other kinds of paperwork (Scheffer *et al*., 2018; PAS 1192-2:2013). Although these are read-only PDFs, native files are helpful because their content can be examined, copied, and altered more readily. These information exchanges occur throughout the key phases of implementation of projects that correspond decision-making procedures (gateways) of the employer as stated in the EIR.

The CDE handled the PIM within its collaborative environment. It is the single information source where information for the project may be gathered, managed, and shared by the entire project team (Hijazi *et al*., 2022). The four main areas of information in the CDE can all have different statuses or levels of information: progress of work, share (comprises reviewed, checked and approved information that has been shared with the involved teams), published (approved/signed-off information by the client or lead designer or their representatives) and archive (area to record progress milestones and change orders) (PAS 1192-2:2013). The information manager maintains or manages the CDE. An information manager as stated by the CIC BIM protocol is chosen by the employer and acts as the administrative gatekeeper for the federated model in the CDE. The work of the gatekeeper is to ensure that the project adheres to the established BIM process and the security of the data while also enabling the management of the federated model. Individual models do not interact, have distinct authors, and remain distinct, and the original initiator claims ownership of the information model in the CDE.

3.7.2.1 Gateways in BIM design and construction projects

The client must maintain control over the scope, the direction of development, and costs as the design and construction projects progress, from conception to completion and operation. Maintaining control of the scope is typically done by including crucial decision points, called "gateways," where the project owner assesses the development of the project and determines whether their strategic goals is met, is good value for money, is significant, or less risky (Shepherd, 2019). The decision to progress or not to the next phase will then be decided. If such a strategy is not implemented, projects tend to drift off course, with scope, budget, brief, and schedule deviating (Kumar and Raphael, 2021, Eynon, 2013). Gateways are introduced at various stages, dependent on the client's procedures, project’s nature, and the procurement method (Shepherd, 2019; Eynon, 2013).

3.7.3 BIM Information model at the operation phase

An AIM outlines the management of information for the operational phase of a built asset (PAS 1192-3:2013), which may comprise infrastructure or buildings, new or existing assets. Following the completion of construction, the PIM evolves into an AIM for usage in the operational phase (Scheffer *et al.*, 2018). An AIM model gathers data connected to or necessary for managing a built asset in the operational phase. AIMs convey documents, metadata, and graphical and non-graphical data (NBS, 2016; PAS 1192-2:2013). It is made up of a portfolio of assets or a single asset. AIMs can be created using data from PIMs created to construct new assets, fresh data, or current asset data. Original design intent information, 3D models, ownership, rights, constraints, surveys, completed work, operational performance information, condition information, and other information are included in AIM. For managing existing assets, some information contained in these assets are often incomplete. The AIM is managed within the CDE and an Information Management Process (IMP) ensures the AIM's integrity. A data manager/data administrator/data technician is in charge of the AIM and published information is received and authorised in the CDE's shared area.

Modifications in the status of parties in charge of managing the built asset, ownership, risk assessments, performance reviews, decommissioning, maintenance, changes in standards, and other processes may result in AIM modifications (Munir, Kiviniemi and Jones, 2019). As such, AIM takes care of necessary information for managing the asset and the advantages of BIM technology are increased when a digital construction model such as AIM model is used throughout the operational stage of a developed facility (Borrmann *et al.*, 2018). The effective transfer of BIM information model from the designers to the client/owner, as well as all information relevant from the construction to the operational phase, is a vital requirement at this phase. Instead of "dead/lifeless" drawings, the owner would receive high-value digital information model, which can then be integrated into his facility/asset management systems. Such information as details of room sizes, Heating, Ventilation and Air Conditioning (HVAC), energy use, and telecommunication in the context of buildings is thus instantly accessible and does not require manual entry.

Other details/information about installed devices, such as maintenance schedules and warranty terms, is required for a facility's smooth operation. The digital twin at this stage would reflect any physical facility modifications and would always reflect the most recent information. If significant adjustments or improvements are later required, the construction model is a reference point for the required design work. In addition, the digital twin gives complete information on the materials used in the construction of a physical asset when it reaches its end of life, allowing for environmentally acceptable recycling or disposal (Borrmann *et al.*, 2018). BIM uses including its description all through the project life stages i.e., design, construction, operation and maintenance is represented in *Table 3.11* for description of the information required for the operational phase.

Table 3. 11: *Common BIM use cases across project life phases (Messner et al., 2019)*

S/n	BIM Use Case	Case Description
1	Technical Sketch drawing/visualisation	Creation a 3D model for project starting points during project meetings, information gathering, and public relations.
2	Project specialists' coordination	At regular intervals, models created by the various discipline are combined into a single federated model, collisions are detected, and systematic resolution for conflict is performed.
3	Technical drawing	Derivation of the design and construction documents and drawings are done
4	BIM simulation and analyses	The BIM model is used as an input for different analysis and simulation technologies such as analysis of the structures, energy performance, daylighting analysis, and computational fluid dynamics, among others.
5	Cost estimation	Utilising BIM as a source for estimating the project cost i.e., in quantity take-off
6	Tendering	Utilising BIM to create the Bill of Quantities necessary for tendering in construction projects
7	4D modelling (construction sequencing)	Each component in the BIM model are connected/linked to the construction schedule's related processes.
8	5D modelling (progressive cost simulation)	The cost of creating and/or purchasing the relevant building components is linked to the 4D model.
9	Monitoring of project progress	Creating and maintaining the 4D model for commenting on and tracking the progress of the construction process.
10	Controlling and billing	Estimating, cost control and billing in accordance with information in the BIM model for monitoring the project's progress.
11	Management of issues and defects	The BIM model is being used to document building faults and track their elimination.
12	Operation and Maintenance of building	Transfer of BIM data to the client, followed by the integration of the operation and maintenance information into the facilities management systems

3.7.4 Level of development (LOD)

The design and construction operations are an ever-evolving, elaborating, and refining process. The scale of drawings is a well-defined technique for the required geometric description of a specific stage of designing in the project, thoroughly specifying the level of maturity, process explanation as well as the supplied design information. As no scale exists in digital models, an equivalence for geometric resolution and degree of detail are developed. The phrase "Level of Detail" was initially employed incorrectly because it placed a lot of emphasis on the appearance of the shape. The phrase "Level of Development" (LOD) was now coined and is currently in use. According to PAS 1192-2, a LOD specifies the necessary alphanumeric information and the geometric detail known as Level of Information (LOI) and Level of Geometry (LOG). A LOD specifies not only the scope of the information provided but also its level of maturity as well as trustworthiness (PAS 1192-2:2013).

In general, a LOD could be linked to a particular design phase. The US-American BIMForum defined six standardised LODs (100 - 500) and released a catalogue displaying the geometric aspect of the LODs for standard architectural components (BIMForum, 2017, 2013; AIA, 2013; BIMForum, 2013). The alphanumeric information required depends considerably on the individual BIM use cases and the type of construction project. LOD requirements are usually included in the EIR that the employer defines at the project's inception. The LOD or

Level of Model Definition (LOM) concept as shown *Figure 3.9* is an alternative approach to design and planning requirements and specifications using Model View Definitions (MVD) to determine what kind of information is to be delivered, by whom and at what stage (Beetz *et al.*, 2018).

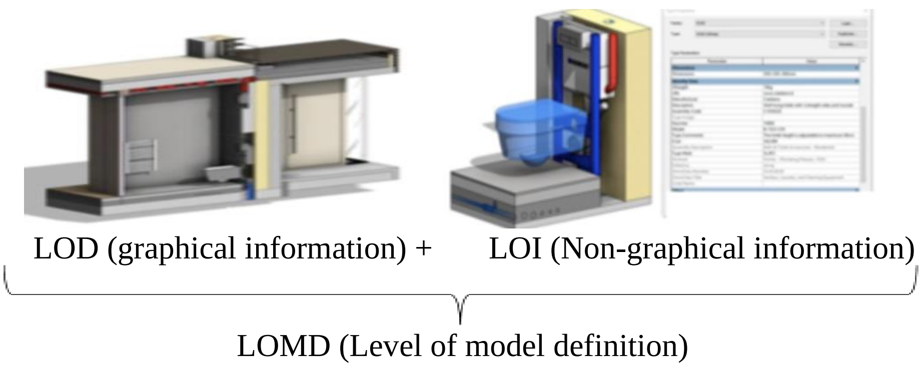
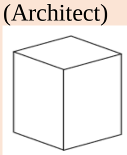
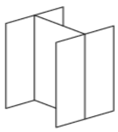
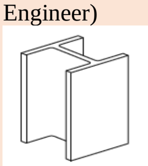
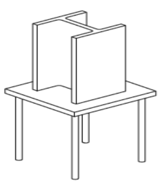
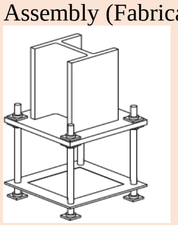
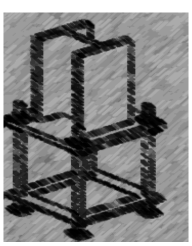


Figure 3. 9: *Definition of Information level of maturity and scope (Beetz et al., 2018)*

A MVD is a technological method of validating instance models for a certain information exchange situation. MVD is a similar concept to scale drawings: for example, a scale of 1:200 outlines approximate information, which is inherently uncertain; a scale of 1:10, on the other hand, includes information sufficient for the manufacturing of construction components of greater degree of accuracy and precision. As shown below in *Table 3.12*, associating a LOD to construction components or model allow the recipient of the information to judge its trustworthiness.

Table 3. 12: *Level of development (LOD) in design of steel column and its interconnection to the lower building elements as outlined by American Institute of Architects (AIA), (adapted from Beetz et al., 2019)*

S/n	LOD Definition	Description
1	**LOD 100**-Concept Design (Architect) 	The model element is graphically represented by a symbol or a standard representation. The 3D model of the project is created to interpret the information on a basic level. Other element of the model, like costs per square metre, can be used to obtain relevant information. Area, height, volume, location, and orientation are all defined parameters.

2	**LOD 200**-Schematic Design (Architect) 	The model element is represented graphically in the model by a standard element with approximate orientation, size, dimensions, location and shape. At LOD 200, non-graphical elements can be combined with model elements.
3	**LOD 300**-Detailed Design (Structural Engineer) 	Comprehensive modelling, plans and specifications with orientation of components, location, precise quantity, shape, size, and specific assemblies.
4	**LOD 350**-Construction Documentation (Structural Engineer) 	A specific object graphically represents the model element, specifying its orientation, position, form, dimension, size as well as its interactions with other building systems. It includes additional components and details that represent the interfaces of construction elements with various systems, as well as other elements with written definitions and geometry.
5	**LOD 400**-Fabrication & Assembly (Fabricator) 	A specific item graphically represents the model element, defining its orientation, position, form, size, dimension as well as production, assembly, and installation information.
6	**LOD 500**-As Built Model (Facility Operator) 	The size, dimension, form, position, orientation, and related attributes of the model element have all been verified on the construction site at this level. For operations and maintenance, elements are modelled equally as constructed assemblies.

3.7.5 Management of information at the delivery phase of a project

A strategy for defining the collaborative environment for information management systems used by the project's designated parties during the delivery phase of a project is specified in Part 2 of ISO 19650 (ISO 19650-2, 2017 & 2018), is described and shown in *Table 3.7* of this study. The table gave a description of the project information management structure during the delivery phase.

Before establishing the project information requirements (PIR), the appointing party examines the project-specific evaluation and requirements (as shown at P1 below), which are heavily impacted by OIR obtained from the strategic level as depicted below in *Figure 3.10.*

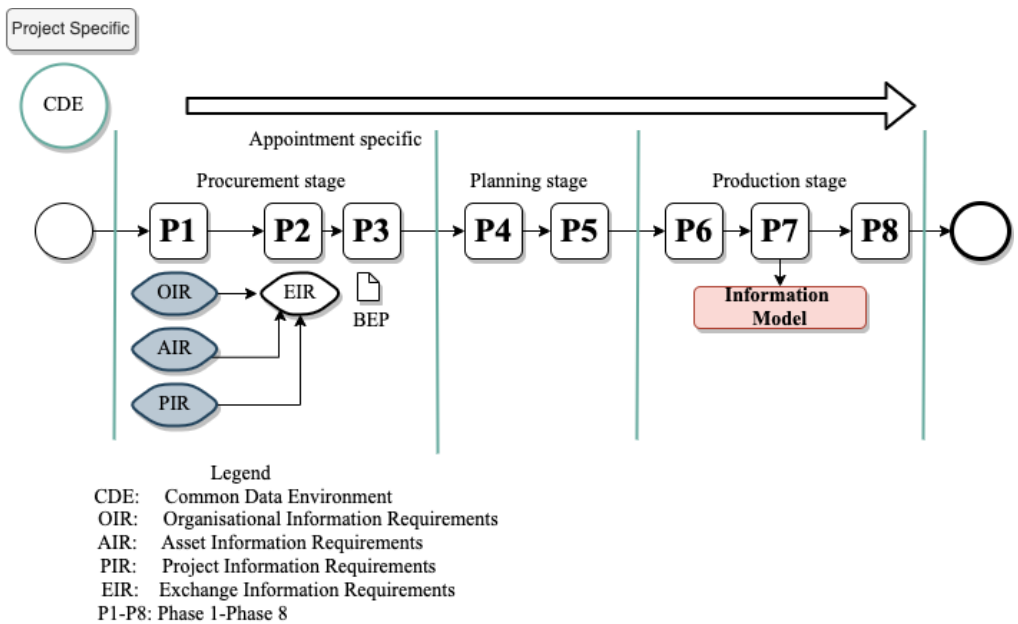


Figure 3. 10: *Information delivery process (Adapted from ISO 19650-2, 2017)*

PIRs according to ISO 19650-1 are defined by the project's scope, the purpose for using the information, and the number of critical decision points present during the delivery stage. The first phase entails the creation of project milestones, reference data, an information standard, an information protocol as well as shared resources. Based on the above, the appointing party establishes the CDE to meet the requirements of the whole project. Container-based information management is maintained in this phase. Prior to the establishment of the CDE, issuing and tender invitation, and exchange of information take place with the tendering organisations in a secured and well-established manner.

The second phase (P2) is the point for tender invitation. The appointing party specifies the EIR that the appointed party must meet during the appointment in accordance with the established PIR. When defining acceptable EIRs *(Figure 3.10),* OIRs, AIRs, and PIRs are taken into consideration. Additionally, the level of definition, which includes the level of detail and the level of information is established. The EIR's standards cover agreement criteria for the requirement of the information, dates of information delivery, and documents for supporting and evaluating the particular requirement and associated criteria. Also, each delivery team creates a pre-appointment

BEP and submits it together with the tender response (P3), as shown in *Figure 3.10* above. At P4, during the appointment (P4), the delivery team's BEP is established and agreed upon with each individual sub-appointed party. The BEP can still be altered at this stage. Simultaneously, the appointed party prepares an EIR for each individual sub-assigned party. The developed documents are kept up-to-date.

Mobilisation (P5) is primarily concerned with resource mobilisation, which includes the adoption of information technology and the CDE among other things. PIM at P6 defines the collaborative development of knowledge that is maintained in the project. Within this context, production/construction entails confirming the accessibility of shared resources and reference data, producing data, conducting quality assurance checks, and ultimately evaluating and approving data for delivery. Since numerous teams are involved, information is generated simultaneously. The chosen CDE facilitates the exchange and modification processes of the information. In P7, the resulting data is delivered. The information model is submitted to the specified party for approval, including reviewing and authorising tasks. If the submitted PIM corresponds to the required EIR, the appointing party accepts the model. If not, the appointed party will make the necessary changes. Phases 6 and 7 are concerned with information generation, which is typically divided into different delivery teams. Tasks are assigned to sub-appointed parties by an appointed leading team. The establishment of project and information management tasks enables effective exchange of data/information along the ensuing supply chain and during production. P8 is the project's last phase. In addition to archiving the published in the CDE, PIM data is also filtered and sent to the asset model i.e., AIM.

3.7.6 Participant roles in management of information at the delivery phase of a project

Figure 3.11 depicts the tasks and duties of the appointing party during the generation of collaborative information The CDE facilitated the production of information for the appointed parties. *Figure 3.12* equally illustrates the assigned parties' role structure. Information authors (BIM authors) are in charge of developing the constituent pieces of the information model concerning a particular task. As a result, information authors are speciality experts who technically create thorough deliverables. On the other hand, the Task Information Manager's (TIM) the major duty is to direct the developed information throughout the supply chain to the appropriate party. In this case, basic project standards, techniques, as well as processes are used.

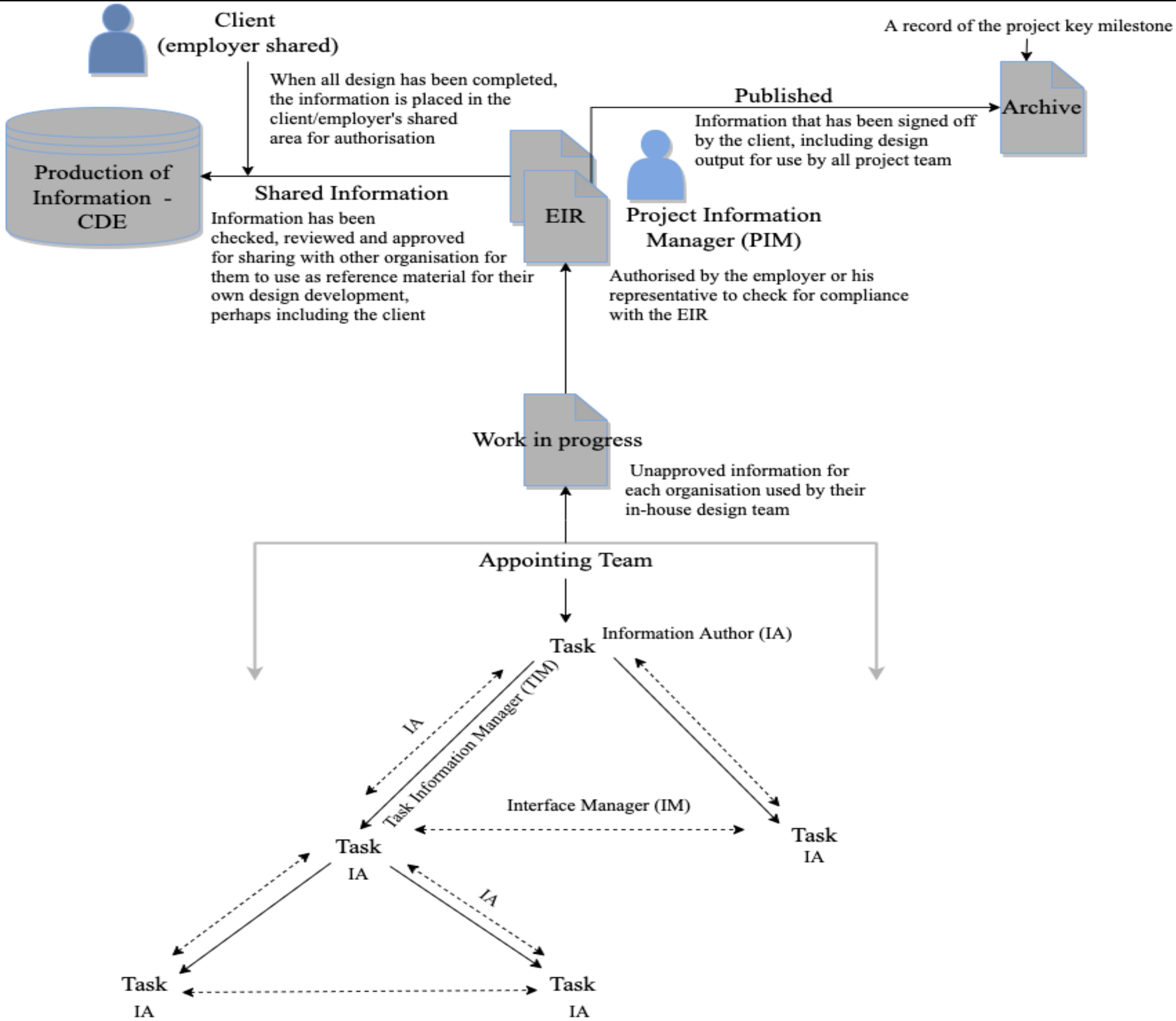


Figure 3. 11: *Participant roles in managing information of projects at the delivery phase as defined by ISO 19650-2:2018*

The Interface Manager facilitates information exchange between individual parties and among team members (Scheffer, Mattern, and König, 2018) The job of Interface Manager requires controlling spatial coordination and resolving coordination conflicts. The configuration, exchange and coordination of information in numerous formats/forms are critical aspects of the interface manager role. After the information authors have completed their deliverables, the TIM verifies the eligibility of the information still in the "work in progress" stage to be issued inside the CDE. The PIM assists the client while the appointed parties perform the functions mentioned above and determines the PIR. Accepting information into the information model, maintaining and supporting a dependable information exchange are additional tasks of the PIM. The PIM is in charge of receiving or refusing information exchanges in the CDE and incorporating and managing data in the model.

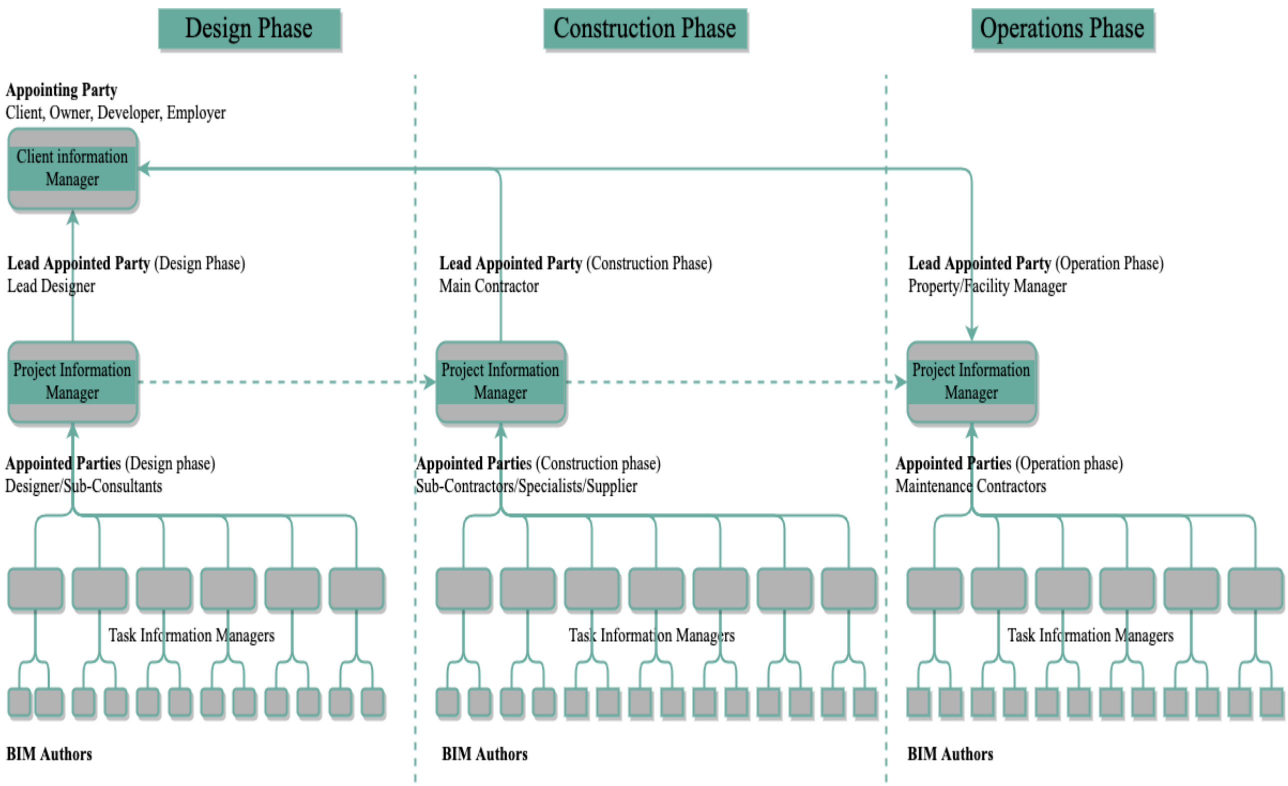


Figure 3. 12: *Roles Structure of the different stakeholders in information management process as defined by ISO 19650-2*

3.7.7 Terms related to stakeholders within BIM information management systems

This section discusses the terminology used by stakeholders to characterise the structure of the responsibilities in BIM information management as illustrated in the above diagram *(Figure 3.12)* and outlined by ISO 19650. These terms appear throughout the research. They are the Appointing Party (AP), the Lead Appointing Party (LAP), the Appointed Parties (APs), the Task Information Manager (TIM), and the BIM Authors.

3.7.7.1 Appointing party (AP)

The AP is in charge of managing all information as well as tasks assigned by the other project stakeholders. The client, owner, developer, or employer is the appointing party. They create the Project Information Requirements

(PIR) and project standards, establish the CDE, collaborate with the Lead Appointed Party to record project-related lessons learned, and hand over existing data to the Delivery Team to complete the project (Das, Tao and Cheng, 2021; Sanhudo *et al.*, 2020).

3.7.7.2 Lead appointed party (LAP)

The delivery strategy of the project fundamentally specifies how the Lead Appointed Party will proceed. The general contractor oversees all planning and responsibilities in a DB project. Even though under DBB (the convectional procurement strategy), there may be more than one LAP in a project. For instance, LAP for design activities (such as an architect's office) and a different LAP for construction (general contractor). A LAP is allocated directly by the client and serves as an intermediary servicing the delivery team and the AP (Scheffer *et al.*, 2018). In the design phase, the LAP is the lead designer; in the construction phase, it is the main contractor; and during the operations phase, it is the property or facility manager (Daniotti *et al.*, 2020).

3.7.7.3 Appointed parties (APs)

The designer or sub-consultants, subcontractors or specialists or suppliers, maintenance contractor or suppliers are the Appointed Parties (APs). All parties involved in creating and disseminating information adhere to the conditions of their contract (appointment) with the Lead Appointed Party. The APs work together with the lead appointed party to develop the BEP, reach a consensus on the information that each appointed party should produce, create TIDP for information delivery, jointly produce information that satisfies the task's requirements, and take part in the information model review (Daniotti *et al.*, 2020*;* Scheffer *et al.*, 2018*)*. The AP (client/owner or his representative), the LAP (the delivery team), and APs (the task team) make up the project team, as shown in *Figure 3.13.*

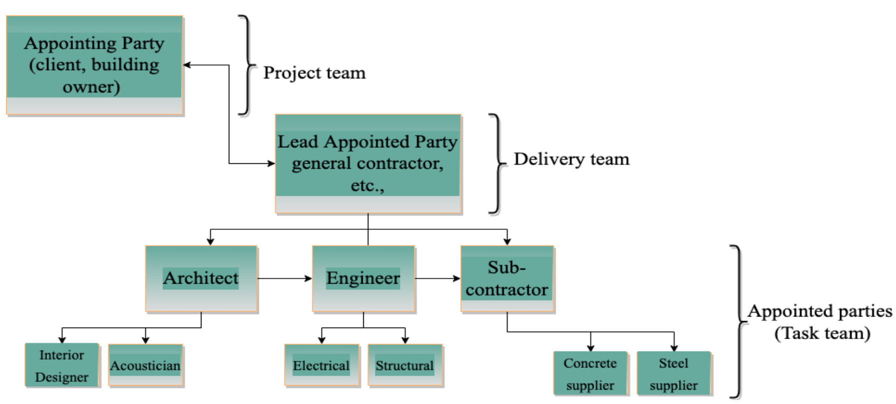


Figure 3. 13: *Stakeholders within the project team as defined by ISO 19650-2:2018*

3.7.7.4 Task information manager (TIM)

An information manager is a representative of an organisation chosen by the client or the employer for a particular task/project. (Bilge & Yaman, 2021). His responsibility is to establish, govern and ensure the flow of information to and from the CDE in the design, construction, O&M of a built asset and its disposal or decommissioning (Scheffer *et al.*, 2018; Bilge & Yaman, 2021). In addition, he manages the CDE, which involves confirming and ensuring that information is suitable for issues within the CDE, managing information production according to established standards, and evaluating information deliverables. Additionally, he oversees the project team and information exchange and ensures communication and cooperation in the CDE.

3.7.7.5 BIM authors

In conjunction with a particular assignment, the BIM author develops components that make up the information model (PAS 1192-2:2013). In addition, he is responsible for creating project deliverables or outputs and maintaining ownership of model information. *Figure 3.14* below illustrates the relationship between the task team manager, task information manager, and the BIM author, while *Figure 3.15* depicts the information flow between stakeholders and the BIM author.

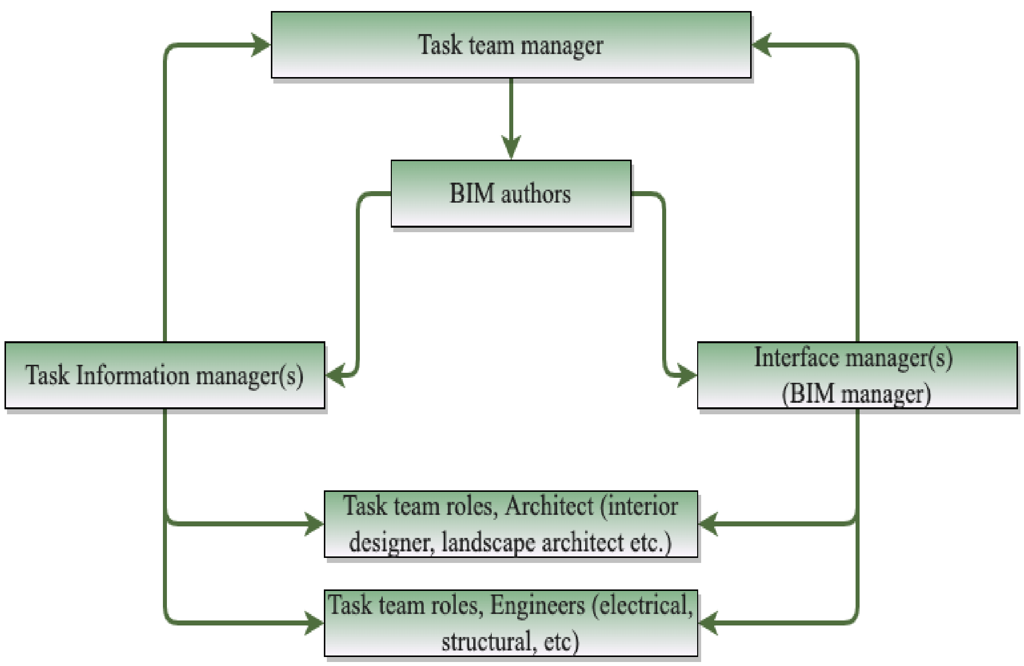


Figure 3. 14: *Relationship between the task team manager, task information manager and the BIM author as defined by ISO 19650-2*

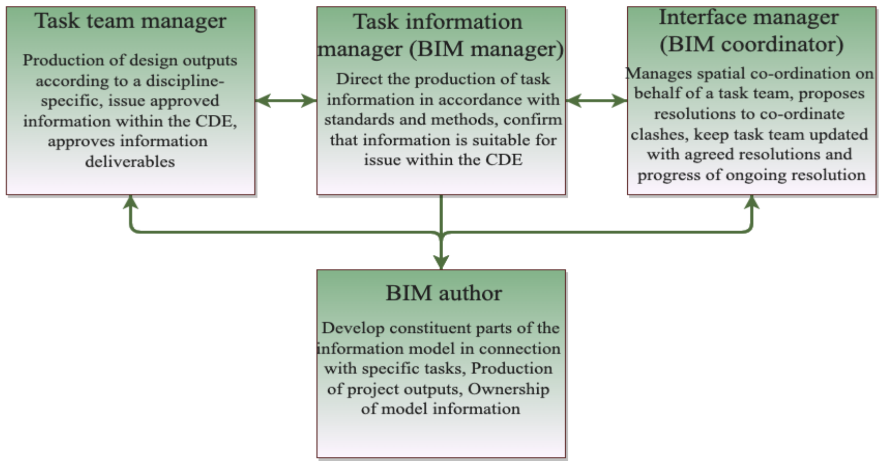


Figure 3. 15: *Relationship between the information stakeholders and the BIM author as defined by ISO 19650-2*

3.7.8 Container-based collaborative working strategy

As a result of the high level of human interaction in managing asset information activities, a collaborative information container approach is presented in BIM projects (ISO 19650-1, 2017). Written documents, schedules, spreadsheets, and three-dimensional model files are all examples of "information containers" (Scheffer *et al.*, 2018; Hoeber & Alsem, 2016). In more complex cases, containers (files/documents and folders, or their sections such as sections of designs or chapters of document) can be nested. This form of collaboration contains schematic information management that are specific to a particular project or entails such processes as definition of information content, version control agreement mechanisms, as well as the use of information and access to its management (Scheffer *et al.*, 2018). A CDE assists in checking the applied information requirements, paying particular attention to the delivery phase with its numerous crucial points of decision-taking/making and accompanying data drops. ISO 19650 standards defined and described the form and purpose of a container-based information environment.

3.8 Chapter Summary

The overview of information management for BIM construction operations and process are the key themes of this chapter. Information waste occurs throughout construction due to a lack of an improper information management strategy for handling information of projects. BIM, which has transformed the process of managing information among project participating parties, is one of the most recently used among construction practitioners. BIM is promoted as a valuable tool for digitising and preserving project information, which can subsequently be extracted, interacted with as well as shared across project parties to improve operations of the construction business and for effective decisions-making. The chapter discussed earlier studies on information management that focused on the many aspects of managing information in the BIM process. The BIM concept of information management systems, incorporating established BIM standards, collaborative practices, BIM project information requirements, and participant responsibilities at various project development phases, was also outlined in the chapter.

Chapter 4

4 Theoretical Framework Underpinning the Study

4.1 Chapter Overview

The role of theories in research is to aid in the understanding and explanation of observed behaviour, as well as to serve as a useful tool for determining the possible research direction. An overview of fundamental theories that serve as a foundation for developing research arguments is known as a theoretical framework (Iyamu & Roode, 2010). The theory that supports a research study emphasises its significance while enhancing its value. Researchers construct theories to describe a research topic, establish connections, and draw conclusions. The current theories that support the research are discussed in a theoretical framework to demonstrate that the work will be the anchor of established ideas. In other words, the theoretical framework justifies and contextualises the research (Seymour *et al.*, 1997). Although there may already be a variety of theories about the research, the theoretical framework would evaluate, compare, and choose the ones that are most relevant to the study. A study's theory highlights the research's significance and enhances its relevance. Furthermore, the theoretical framework offers a chance to explain what has been learned in similar situations, as Love (2002) emphasises that while constructing a theoretical framework, theories can be assessed critically from various angles. However, acceptable theories are frequently lacking in a given discipline, but theories from other areas of discipline could be effectively applied to understand a particular study. On this premise, this chapter intends to review existing theories relevant to this study.

4.2 Review of Existing Information Management Theories

Selecting a theory underlying information management study is challenging, primarily because of human interactions with the digital aspect of processing information. Human beings are unpredictable and, as such impacted and influenced how information systems develop, implemented, used, reused, and stored (Tatnall, 2005; Alexander & Silvis, 2014). As a result, theories in the sociology profession have been used by many scholars to support a wide range of studies in information management. Based on the above statement, sociological theories have made practical and theoretical contributions to information management for decades. The Information Management Framework, Information Processing Theory, Action Theory, Actor-Network Theory, Structuration Theory, Contingency Theory, Diffusion of Innovation Theory, Activity Theory, Grounded Theory, are some examples of theories in information management studies. For many years, using these information management theories in research has continued to evolve because some theories are unable to completely explain the need and purpose for which they are employed (Iyamu, 2013). While these concepts manage to contribute to information management practices in general, those that are particularly relevant to this study are examined in this section. They include information management framework, information processing theory, actor-network theory and structuration theory as shown in *Figure 4.1* below. However, each of these theories present different perspective on information management.

4.2.1 Information management framework (IMF)

Information management frameworks provide high-quality information to assist in better decision-making and action by individuals. It essentially examines who is developing, using, maintaining, and using constructed assets and the services they offer to users. For example, the Centre for Digital Built Britain (CDBB) stated in a report made public on May 29, 2021, that all information produced must be of sufficient quality to be helpful for the intended use. The quality considers appropriateness, completeness, accuracy, and the sources from which the data was generated.

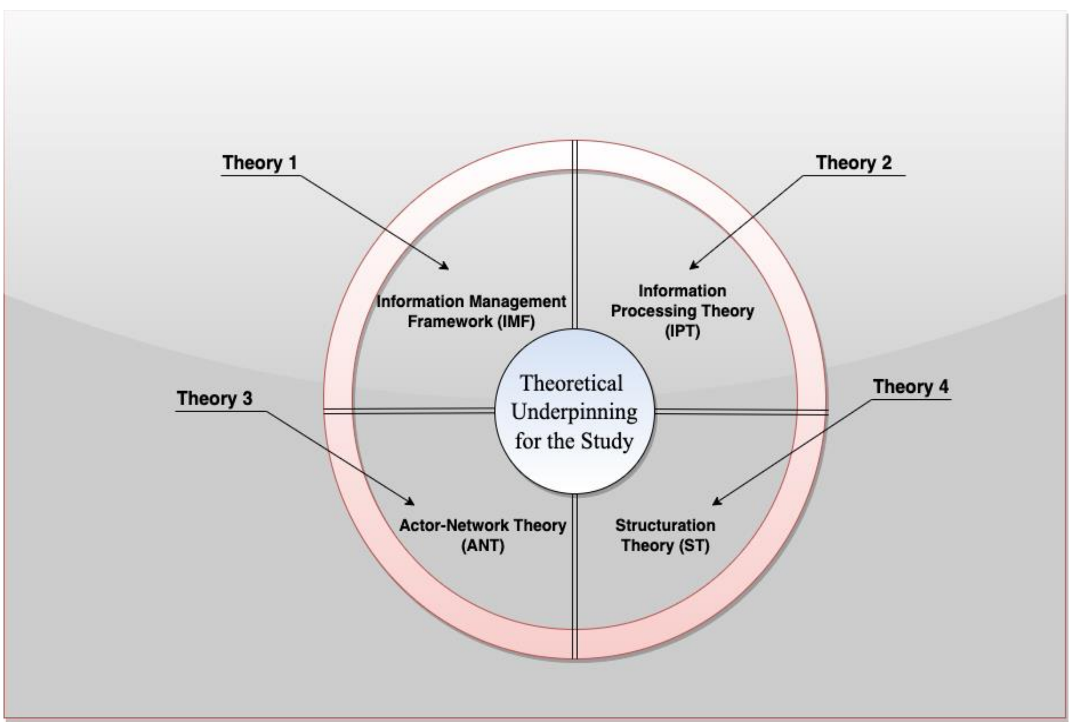


Figure 4. 1: *Theories underpinning the study*

It continued by stating that before any information is produced, its availability, clarity, and consistency in terms of its sources must be determined. The information must be streamlined and free of ambiguity for the information and its meaning to be easily understood. Consistency means that the terminology and concepts used in the data or information are consistent throughout all systems and cooperating teams and have a standard way of describing the same thing. Accessibility demonstrates that the ability to transfer data from its point of origin to its point of need is established to protect it and ensure that sensitive data is only available to authorised individuals.

4.2.2 Information processing theory (IPT)

The core principle of information processing is cognitive psychology. It treats each individual as a processor of information, much like a computer does when it receives input and executes a program to produce output. The theory uses the comparison that the mind functions like a computer because it assumes that rather than simply reacting to inputs, human beings process the received information to meet their requirements. In this situation, the mind acts as a living computer that analyses data gathered from the environment. The standard information-processing framework for the development of the subconscious mind states that the mind includes attention mechanisms for attempting to bring in information, working memory (WM) or short-term memory (STM) for actively using information, and long-term memory (LTM) for passively storing information for future use.

The above idea explains how information develops and eventually matures, enhancing the information's quality and how people react to it. It is considered to be particularly connected to the information processing theories developed by Atkinson and Shiffrin (1968) and Alan Baddeley and Graham Hitch (1974). In 1968, Atkinson and Shiffrin proposed a framework to demonstration how human memory works (Atkinson & Shiffrin, 1968). Memory is divided into three sub-sections: sensory memory (SM), short-term memory (STM), and long-term memory (LTM), from when information is received until it goes around the various stages for use, manage and store. The SM stores information the mind receives via the senses, such as auditory and visual information, and interprets it or reveals what kind of information it is. STM preserves the information it receives for a short period before using it for its purpose. Finally, the LTM functions when it is necessary to recall a specific instance from a person's past experiences to re-apply those experiences.

However, Alan Baddeley & Graham Hitch (1974) contributed to the information processing theory that helped human being understands how the mind might develop the information they receive. Four elements was added to explain the thinking, learning, and understanding process of information. The four elements include the central executive (CE), phonological loop (PL), visuospatial scratchpad, (VS) and episodic buffer (EB). This theory splits the working memory into multiple components rather than a single entity. The central executive works as a supervisory system responsible for controlling and regulating the thinking, learning, and understanding of information to ensure that the temporary store is operational and to take action if something goes wrong. It updates and codes the incoming information while replacing the old information from different sources in a more readable and understandable format. The CE has the VS for visual information and the PL for verbal information as its two principal components (Endel, 2001). The theory emphasises a consistent pattern of improvement in the memory capacity to actively hold in the memory a small amount of information in an easily accessible state for some time until it is put to use.

4.2.3 Actor-network theory (ANT) and structuration theory (ST)

Atkinson and Brooks (2003), states that ANT and ST are complementary theories that serve as the theoretical framework for research on information management systems. The two theories provide an ontological and epistemological background for an investigation into information management. Both offer insight into the core ideas being explored in the research and instructions on how to learn more about the phenomenon being studied. The two theories, ANT and ST, are sometimes combined to inform the study's data gathering, data processing, and result interpretation. Hence, their combination in this Study.

ANT sees the significance of interactions between human and nonhuman actors from a distinctive angle. Actors work to create, maintain, and improve organisational networks with shared interests by developing, negotiating, sustaining, and altering them (Tatnall & Gilding, 1999). On the other hand, structuration is a sort of ongoing structural modification that involves the system's reproduction and creation. Giddens (1984) indicated that the theories' structure comprises resources and guidelines for analysing information. Understanding how factors like organisational rules and regulations, and resources are influenced and driven by innovation is among the most crucial components of the information era. Innovative techniques can transform social and organisational systems, but these theories' structure also impacts them in relation to their design, execution, and operations (Harrison *et al.,* 2007). The presence of the components in one or more physical forms does not inevitably direct or control individuals or groups. Conversely, people and groups understand the elements that support and restrict their behaviour. They do this by putting the rules and regulations into practice when allocating resources and carrying out operations and activities. Combining ANT and ST theories yields new insights, which makes the theories applicable to information systems.

Some studies employed ST first, followed by ANT, and vice versa. The examination of network alliances, the various interests of actors, and their interactions in the information technology environment are all topics of interest to the ANT. Several people who are linked by a mutual interest is known as an "actor network." The emphasis of ANT is on the varied character of actor-networks, which are linked together and comprising of technical and non-technical components (Callon, 1991). ST is beneficial for recognising and examining the opposing sides of the organisational structures, the technology structures and environment, and behavioural patterns. Both theories are used as supporting platforms for building and understanding the interactions that take place throughout deployment/technology use. This covers the who, what, when, why, where, and how of developing, deploying, and using technology in IM.

Structuration theory, according to Orlikowski & Robey (1991), explains how IT and organizations interact. On the other hand, ANT is applied to a variety of information management studies and has a great deal of promise for advancing the knowledge of socio-technical systems (Walsham, 1997). Instead of focusing on how larger social institutions influence socio-material activity, ANT focuses on how things are done. It includes insightful information on regional events as well as the preparation of materials for those events (Latour, 1991). Instead of approaching explanation and clarification from the standpoint of spectators, the ANT and ST theories primarily focus on the actions and experiences of participants. The concepts allow the researcher to communicate with subjects, changing how both sides view the studied event. These theories allow for social interaction to contextualise and interpret events. However, the two theories have each been utilised separately in IM investigations. Additionally, only a few studies have jointly used the two theories in various ways across several IM investigations.

Iyamu & Roode (2010) claim in their study that there are no contravening opinions about using ANT and ST in the same study. They continued by saying that ANT and ST may be combined without ever being compared. In order to appreciate studies on ANT and ST, Johnston (2001) seek to comprehend how the theories situated action to provide an integrated perspective in IM studies. Atkinson & Brooks (2003a) combined ANT and ST to create the "new" theory known as the StructurANTion theory in IMS. Information processes and activities in health research were analysed using the StructurANTion. Iyamu & Roode (2010) utilised both theories independently and in conjunction to comprehend and examine how the technology approach was established and developed in IM systems in two different organisations making them more suitable to information management theories. Regarding events in organisational social construction, structuration and ANT theories are compatible.

4.3 The theories' Implication for the Study

As a result of critical analysis and research of various theories, various theoretical and methodological challenges have evolved. The opinions in IMF showed various details that influenced the research's assumptions. The information management schema considers the supply of quality information to enable improved decision-making in creating, operating, maintaining, and using built assets and the services they provide to users. The theory also emphasised information quality, which considers correctness, appropriateness, completeness, and the sources of information from creation to usage across the asset life cycle. In addition, it highlights the implications of evaluating information sources, availability, clarity, and consistency before developing the knowledge base. Finally, the theory gives a structure for explaining the process of information management throughout the asset lifecycle.

In contrast, information processing theory (IPT) investigates how information grows and matures throughout the project’s lifecycle, improving the quality of the information and how project teams respond to it at different stages of the development procedure. It proceeds to describe how the brain receives and clarifies messages for thinking, learning, and comprehending the information process at different levels of development. Information processing theory focuses on how knowledge evolves and matures throughout the project’s lifecycle resulting in an improvement in information quality and how project teams respond to it at each stage of development.

Both ANT and ST are commonly combined, and they attempt to describe how technology impacts the structure, design, implementation, and usage of information. It explains how people and groups understand the data about the elements that support and restrict their behaviour. These happen as they put the laws and regulations into practice while allocating resources, carrying out operations, and undertaking other tasks relating to the technological environment.

4.4 Chapter Summary

Through socio-technical theories, this chapter framed the study of information management systems. It examined the theories that provided various perspectives and theoretical understanding for the investigation. Furthermore, actor-network and structuration theories, for instance, provided various perspectives for understanding information systems, in contrast, the information management framework and information processing theory provided a variety of perspectives on the topic under study.

Chapter 5

5 Research Methodology

5.1 Chapter Overview

In most cases, research begins with the researcher being interested in solving a specific problem and familiarising themself with the relevant data. Research, according to Zikmund (1994), literally means to "search again," which implies that part of the process entails reviewing issues from many researchers' differing points of view (Zikmund, 1994). Every researcher's journey begins with understanding the research paradigm. Researchers frequently struggle to choose the best methodology for the research they are trying to conduct. As a result, when doing research, questions that are fundamental research components or paradigms are generated, which guide the selection of the research's methodological approach and its justification (Crotty, 1998). Thus, the methodology and epistemology presumptions of the study, including the research strategies and research philosophy, are covered in this chapter.

The advantages and disadvantages of each philosophical school of thought concerning the study's emphasis were evaluated to conceptualise the study within the proper worldview and epistemological perspectives. The chapter further undertakes a critical analysis of research methodologies or strategies to establish which were appropriate for the study's objectives before choosing and describing the most practical methodological viewpoint. The appropriateness of the various research methodologies for this study was then assessed. The chapter further examined the research philosophy to create a suitable design for the study. Various research design approaches for the study such as quantitative, qualitative and mixed-method designs were discussed. Following a thorough assessment, it was concluded that a qualitative data collection and analysis approach was appropriate for the study. As such, the study discussed induction as the research approach, multiple case study as the research strategy, and a qualitative methodological approach, including the review of relevant literature, semi-structured interview and document analysis as the research choice. A quick summary of these methods concludes the chapter, which focuses on embracing and justifying the necessity of the qualitative research design adopted for the study.

5.2 Research Philosophy

Theoretical perspectives, usually referred to as research paradigms, considerably impact how research will be generated and carried out (Mackenzie & Knipe, 2006). Kuhn (1970) describes *paradigms* as the presuppositions and conceptual frameworks that support research development in a field of inquiry. Similar to how architectural characteristics determine the integrity of buildings, paradigms govern scientific research (Fellows & Liu, 2021). While scholars have distinguished between research methodologies and paradigms, the research paradigms continue to impact, among other things, the methods of collecting and analysing data and the interactions between the researchers and those being studied in the research (Crotty, 1998; Creswell & Creswell, 2017).

Therefore, it is crucial to address paradigm issues at the earliest of a scientific study or research project. In addition to establishing the researchers' intended interaction with the participants, this would also establish a suitable method for gathering, collecting, and analysing data. The research paradigm of a project combines the ontological, epistemological, and methodological perspectives (Guba, 1990). The following sections assess some familiar research paradigms so that the study can be seen through the appropriate frames or lenses. The themes covered are ontology, epistemology, research philosophy, and logical reasoning. Ontology and epistemologies vary depending on the paradigm. Also, constructivism, positivism, and post-positivism (post-positivist) research paradigms were discussed, among others. This is further represented in *Table 5.1* below. The table summarises the epistemological and methodological approaches for the research, as well as the choices of the methods and the justifications for making those choices.

Table 5. 1: *Summary of the epistemological and methodological approach for the study*

Research philosophy A research philosophy is a set of beliefs about the nature of the reality under investigation (Bryman, 2012). It is the fundamental definition of all research.		**Choices made and their justifications for making them in the study**
Objectivism	Objectivism is an epistemological viewpoint which holds that things exist independently as meaningful entities with truth and meaning residing in them as objects (Crotty (1998).	**Interpretivism** The adoption of this paradigm helps the researcher to study and understand human behaviour and interpret the realities subjective to every human being under study. Also, to acknowledge that reality is the result of human intellectual ability to engage with real-world experiences.
Constructivism	Constructivism is the opposite of objectivism. It is a viewpoint that holds that social phenomena are created by social actors (Ã-stlund *et al.*, 2011).	
Positivism	Positivism generates testable hypotheses and gives an explanation that is measured against existing knowledge (Newman, 1998).	
Realism	Realism is related to positivism in its method and principle that the researcher and reality are independent of each other, and thus the generation of biased results is avoided (Saunders *et al.*, 2007).	
Critical realism	Critical realism explains the principles researchers can apply to develop theoretical explanations for phenomena (Bhaskar (1998).	
Interpretivism	Researchers in this approach examine the meanings individuals ascribe to other people and their own actions, establishing that change and cultural existence could be comprehended by examining what people think about, their beliefs, and the explanations and significance they give to those beliefs (Saunders *et al.*, 2007).	
Pragmatism	Pragmatism enables a researcher to examine a topic from either the researcher's perspective or on its influence on social actors and use these perspectives to develop a practical approach to research (Saunders *et al.*, 2007).	
Research approaches Deductive and inductive are the most common approaches in research.		
Deductive	The hypothesis is based on an existing theory and then the researcher develops the research strategy to test it (Silverman, 2013).	**Inductive** Inductive make an inference based on observation to arrive at a suitable conclusion on a particular observed situation. Hence, its adoption for this study.
Inductive	The approach is distinguished by a shift from the specific to the general (Bryman & Bell, 2011). The observations serve as the researcher's starting point, and patterns in the data are then examined and analysed (Beiske, 2007).	
Research strategies This defines the way the researcher wants to do the research		
Experiment	It is a research strategy that compares the results of an experiment to the results obtained in the research. Data generated by experimental strategies are statistically analysed.	**Case study strategy** The study employs a case study for its comprehensive exploration of cases in their real-life context. In addition, it enables the researcher to obtain a
Survey	A deductive approach is associated with the survey strategy. It provides the researcher with a highly-cost effective method of gathering huge amounts of data to explain the occurrences in a given research topic (Sapsford, 2017).	
Case study	Case study strategy entails conducting in-depth research on two or more cases in a real-life setting (Yin, 2009**)**	

Action research	This strategy addresses issues/problems in order to develop and execute solutions. The Action Research process progresses from an objective identification of the issue to its analysis and then generates a list of possible actions to proffer solutions to the problem (Somekh, 2006).	detailed result of the object or subject of study for analysis. **Phenomenology** For this study, phenomenology provides an opportunity to understand existing approaches and principles of information management and general knowledge of managing information in a BIM process. It also helps to uncover what a particular experience means to a group of people and how they have experienced it.
Grounded theory	To construct theory, inductive methods are used to predict and explain behaviour in grounded theory. This strategy begins with collecting data from observations, generating patterns/predictions and theory from the collected data, and finally, testing the result (Strauss & Corbin, 1998). (Strauss & Corbin, 1998).	
Ethnography	The researcher becomes a part of the studied situation in ethnography.	
Phenomenology	Phenomenological research investigates lived experiences in order to gain a better understanding of how people interpret such experiences. Specifically, it investigates the participants' lived experiences.	
Archival research	Archival research focuses on collecting existing materials/data sets/archival documents (Flick, 2011).	
Research choices The research style that is used for collecting and analysing data is referred to as a choice. As long as a research choice can be justified in the research, one or more of these options may be used to collect /design data.		
Mono methods	In mono method research, either quantitative or qualitative data is used instead of both.	**Multi-methods** A multi method was chosen over the other research choices for this study as it adopted more than one qualitative method. The qualitative study provides a predictive element, offers specific insight development, creates subjective information points, uses fluid operational structure and uses individuals and their experience as workable data to benefit from the diversity that the individual experience provides.
Mixed methods	In a mixed method, researchers employ both quantitative and qualitative research methods in the collection and analysis of data (Halcomb *et al*., 2009; Bergman, 2008).	
Multi-methods	In the multi method approach, each part of the research is investigated using either quantitative or qualitative methodologies (Feilzer, 2010). The methodology may employ two or more quantitative, qualitative, or both methodologies. The study employs multi-method research because it employs more than one qualitative method.	
Research time horizon This is the required time to complete the research work. Two types of time horizons were specified within research work (Saunders *et al*. 2007 & Bryman, 2012).		
Cross-sectional	In a cross-sectional time horizon, the period to carry out the research is already set, and the data is collected at this specific set point during the research period (Flick, 2011).	**Cross-sectional** The data for the study was collected over the duration provided for the study.
Longitudinal	Data are collected repeatedly over a long period of time in a longitudinal time horizon. It is typically used when a crucial aspect of the research changes during the research or a specific factor for the research being investigated changes over the research period (Goddard & Melville, 2004).	
Data collection methods This is the procedures used in collecting data. It contributes significantly to the study's overall reliability and validity (Saunders *et al*., 2007). It is dependent on the methodological approach used (Bryman, 2012).		
Observation	Researchers in observational data collection systematically observe the behaviour of a particular thing explicitly used for the research and record the result in a natural setting.	**Documentation/Archival Reviews**

Interview	An intensive individual discussion with several participants to obtain their views or their perspectives on a specific idea, programme, process/ procedure or situation.	Documentation was adopted in the study to gain insight into the existing approaches of the study by consulting records, journal portions, and documents that serve as sources of information about the study
Questionnaire	A method of data collection that consists of a set of questions designed to obtain information from multiple participants or a larger population.	**Semi-structured Interview**
Documents/Archival reviews	This strategy collects data from existing material data sets from reports, meeting minutes, diaries or company resources relevant to the particular research and then documents the information for use in the study (Flick, 2011).	The interview is adopted in this study (semi-structured interviews) as it explores research subjects' or participants' opinions, behaviour, experiences about the phenomenon under study
Data Analysis Data analysis involve the process of reducing data to a storyline and evaluating it to derive insight or draw conclusion. Data analysis process assists in breaking down a large chunk of data into smaller understandable pieces.		
Discourse analysis	Discourse analysis involves interpreting or drawing meaning from words used in a body of data. It investigates the functions of words or language and how meaning is constructed, and that people understand the world from a subjective point of view.	
Content analysis	The content analysis identifies word clusters, themes, or concepts within the content of the gathered data or in a given set of qualitative data. (i.e., textual data)	**Thematic analysis**
Thematic analysis	The thematic analysis defines a systematic way of analysing as well as processing qualitative information using "coding" (Braun & Clarke, 2006).	The study adopted thematic analysis as it provides a flexible way of data analysis and brings out emerging themes from qualitative data. It also enables using the gathered data to gain knowledge and insight from a particular study. **Discourse analysis**
		Discourse analysis was adopted as it studies how the powerful use of language was used to increase individual experience for coding the words used in the body of data.

5.2.1 Ontology

The word ontology, which means "study of being," is a Greek term "ontos," which means "being," and "logos," which means "study." Any research begins with its ontology and then moves on to its epistemology, methodology, and methods. The investigation of "claims and assumptions concerning the nature of social reality, assertions concerning its existence, however it appears, which units comprise it, and how the units relate with one another" is known as ontology (Blaikie & Priest, 2019, p. 59). According to Ponterotto (2013) and Guba & Lincoln (1994), the form and nature of reality and being are central to ontological assumptions, as well as what is known about that reality. Someone studying ontology investigates what it means to declare that something exists. It is a field of study of being that reveals a person’s interpretation of what constitutes reality and is fundamentally concerned with whether a thing is regarded as relative or real. There are two essential types of ontology: realism and relativism.

According to Creswell (2007), social reality is created/constructed by the interrelationship between language and several characteristics of an independent world, and the actual individual worlds are evidence of multiple realities (Creswell, 2007). Relativist ontology underlies the interpretive paradigm. In the meantime, various approaches have been used to investigate information management in construction. However, using these approaches has achieved fewer results in having an efficient management of information system for projects. This merely means that to achieve a comprehensive information management strategy, a comprehensive understanding of the methodologies and procedures is required to implement a robust management system. From an ontological standpoint, it makes sense to view reality in multiple ways, with the potential for experiencing the ideal method differently.

5.2.1.1 Realism

Realist researchers hold that social phenomena and realities exist separately from social actors. According to Bryman (2021), realism and positivism share the idea that social and natural sciences ought to use the same techniques for collection and analysis of data. It maintains that everything science teaches us concerning the world around us is true and that research subjects like ethics and cultures exist independently of realist researchers' understanding of them. Consequently, they can be methodically examined, much like natural phenomena (Gray, 2021). Empirical realism, also known as naive realism, holds that the world is comprehensible and has an objective reality. Therefore, it holds that reality can be comprehended using appropriate methods (Bryman, 2021).

On the other hand, critical realism holds that certain sensitive data can accurately describe reality externally while others (such as illusions) cannot. According to Lincoln, Lynham, & Guba (2011), critical realism holds that "actual reality is imperfect and based on probabilities."

5.2.1.2 Relativism

Relativists assert that there is no prior reality other than the one created and maintained by social actors (Blumer, 1986). Realism and relativism are incompatible with one another ontologically. According to Scotland (2012), reality is subjective and varies from individual to individual; hence, there exist as many realities as there are individuals. Crotty (1998) asserts that because different people inhabit diverse worlds, they employ different techniques to learn about knowledge and comprehend various realities. From the perspective of moral philosophy, Relativism is a type of philosophy that employs situation-based evaluations instead of absolute principles. Therefore, ethical behaviour in one situation might be unethical in another (Zikmund *et al.*, 2013).

5.2.2 Ontological assumptions of the study

A relativist ontological perspective is adopted based on this study, which aims to provide a solution to what is perceived to be an improved method of information management in construction projects within a BIM environment. This is premised on the presumption that no absolute validity exists (Blumer, 1986). This ontological viewpoint holds that the research's purpose is to uncover reality, which, in this study's context is a better method to investigate the management of information for construction projects. Therefore, a value-laden ontology is required in place of value-free assumptions, which would otherwise be founded on factual data rather than hypotheses to establish an evidence-based approach. In contrast, the realist ontological perspective, which presupposes a single and independent reality outside the mind (Guba & Lincoln, 2005), is not considered appropriate for this study and, therefore, not adopted.

5.2.3 Epistemology

If ontologists investigate what it means if researchers say that things exist, then epistemologists examine what researchers mean if they get the knowledge to understand something. The Greek words epistēmē, which means "knowledge," and logos, which means "reason," are the origin of the term epistemology, according to several literary sources. As a result, the field is referred to as the theory of knowledge in line with Crotty's definition (Crotty, 1998, p.3). It is a significant area of philosophy that addresses issues like how people know what they know, do humans acquire knowledge, or do they require first-hand experience to understand it? What kind of connection does the researcher have with the subjects of their research? The creation, acquisition, and transmission of knowledge are topics covered by epistemological assumptions (Scotland, 2012). It is in charge of gaining in-depth knowledge and is concerned with creating new models or theories of knowledge (Grix, 2002). There are two significant ways of knowing when analysing, anticipating, explaining, or managing a phenomenon: subjective and objective approaches (Dancy, Sosa & Steup 2010*;* 2009).

5.2.3.1 Objectivism

According to Guba & Lincoln (2005), in the objective approach, the researcher is self-sufficient and capable of studying the unit of study and not influence it or be influenced by it. As a result, objective researchers collect data using pre-determined research instruments like surveys and interviews. Thus, only studies strictly following scientific laws are considered reliable sources of knowledge about reality (Burns, 2000). Furthermore, the epistemological approach of the objectivist contends that if a true "reality" exists, the knower and the known relationships should reflect value freedom (Guba & Lincoln, 1994). Therefore, a value-free strategy independent of the researcher's bias would be necessary to collect data in a manner that reflect credibility (Burns, 2000).

5.2.3.2 Subjectivism

In contrast, subjectivism involves the researcher and the subjects of study interacting to understand and construct meaning (Collis & Hussey, 2009) because meaning and reality are assumed to be produced inter-subjectively. Hence, meaning is compelled/imposed on reality through the subjective experience of the individual (Burns, 2000). Blaikie (2019) argues that subjectivist epistemology is idiographic and emphasises personal interpretation of meaning over the establishment of general principles. Subjective research lacks pre-defined study instruments (Burrell & Morgan, 2017).

5.2.4 Epistemological stance of the study

Stemming from a relativist ontological perspective, this study naturally adopts a subjectivist epistemology as it has enormous potential to enhance the findings. Throughout the study, a subjectivist approach is helpful in gaining a comprehensive understanding of different information management approaches through inter-subjective contact with industry practitioners. The subjective approach's overarching goal is to ensure that the final result is as thorough as feasible and emanates from the collective experiences of construction practitioners who used BIM on projects. Since the strategy is thought to be more appropriate in situations when a phenomenon has not been sufficiently explored, it would therefore be helpful for the study, especially when there is a need to learn more about the topic under inquiry (Van Manen, 1990; Jasper, 1994) to reach an improved conclusion. As a result, a subjectivist epistemology is required for the study to arrive at an extensive information management schema for construction projects.

5.3 Research Paradigm

In any research, the ontological and epistemological perspectives serve as a pointer towards the research's philosophical perspective or paradigm, also known as worldview (Creswell, 2014), theoretical perspective (Crotty, 1998), research methodology (Neuman, 2009), and in the social sciences. Paradigms are a way we perceive, understand, and interpret the world. Paradigms is therefore seen as a logically organised series of propositions, assumptions, and concepts that shape the thinking of individuals (Bogdan & Biklen, 1998). Hence, paradigms are considered foundational beliefs that guide researchers' frames of reference in choosing the ontology and epistemology perspectives and the methodology (Guba & Lincoln, 1994). Thus, the study demands the adoption of a paradigm to be well-grounded in practice.

Research paradigms provide the framework within which research is carried out and describe the sequence of assumptions and beliefs governing research investigation within a discipline (Weaver & Olson, 2006). It holds the guiding concepts and vocabulary for research methodologies and lenses for perceiving and interpreting phenomena. According to Hinshaw (1996), paradigms are created by scholarly communities with similar patterns and modes of knowledge formation and common views and assumptions about what constitutes reality. Adhering to a paradigm implies that the paradigm serves as a boundary for knowledge acquisition, theory building, and the applicability of research methodology. Therefore, all worldview specifies in what way information is gained, gathered or managed, and established within its tenets or beliefs.

Existing social and natural research paradigms have been categorised using various models or frameworks. Some of the frameworks proposed that aid in understanding the research paradigms is also considered in this research. These frameworks include those by Burrell and Morgan (2017); Guba and Lincoln (1994) Guba and Lincoln (1998); Alvesson and Wilmott (2012) and Krauss (2005) among others. For example, according to Burrell and Morgan's approach, research is divided into four different paradigms: "radical humanism," "radical structuralism," "interpretivism," and "functionalism". Constructivism, positivism, post-positivism and critical theory, were the categories of paradigm used by Guba and Lincoln (1994). *Table 5.2* depicts a representation of Guba and Lincoln (1994) paradigms' basic beliefs as it closely related to those discussed in the study.

Table 5. 2: *Foundational paradigmatic analysis in research (Adapted from Guba & Lincoln, 1994)*

Item	Positivism	Post-positivism	Critical Theory	Constructivism
Ontology	There is reality or truth (more realist)	Critical realism entails a "real" reality that is imperfectly based on comprehensible probabilities.	Historic realism/critical realism-historical reality constructed over time by sociocultural, political, historical, economic, ethnic, and gender values	Local and specific constructed realities/relativism
Epistemology	Since reality can sometimes be measured, the emphasis is on reliable and valid tools for obtaining results.	Dualist/objectivist, critical tradition: most likely true findings	Subjectivist/ transactional and value-mediated findings	Subjectivist/transactional generated findings
Methodology	Experimental/manipulative research; verification of hypotheses; mainly quantitative methods	Methodology is modified experimental/manipulative; critical multiplism; falsification of hypotheses; that might involve qualitative methods	Dialectical	Dialectical

In a similar framework to Guba and Lincoln, Crotty (1998) classified what was referred to as theoretical perspectives or viewpoints by referring to "constructivism" as "interpretivism," “post-modernism" as "feminism." Critical theory is also a well-known philosophical method of inquiry (Alvesson & Willmott, 2012), to which various scholars have given several names. For instance, critical theory was termed post-positivism by Guba & Lincoln (1994) and Krauss (2005), "Neo-positivism" by Manicas & Secord (1982), realism by Healy & Perry (2000) and critical realism by Hunt (1994). These categories of paradigms, i.e., positivism, post-positivism, critical theory, constructivism, and interpretivism, are discussed briefly in subsequent in sections in this study.

5.3.1 Positivism

Positivism is a principal paradigm in the social sciences method of inquiry, where it is described as a "scientific method/scientific research.” (Gray, 2009; Shah & Al-Bargi, 2013). As such, positivist researchers apply scientific methods in the social sciences to study phenomena considering them subject to scientific explanations and value-free. This ontological stance of this paradigm is naïve realism (realism), assuming the existence of reality (Guba & Lincoln, 1994) as well as pursue the social world objectively (Mertens, 2005) (i.e., objective epistemology) by adopting all methodologies that harmonise scientific techniques within the social world (Grix, 2018) to measure social entities without influencing them. The positivist distinguishes the researcher from the researched, whereby the researcher treats the social world as a natural one. The positivists believed in establishing laws or generalisations that apply to people (Punch, 2009) and forming facts as applicable (Scott & Usher, 2011). Correlational survey research designs, quantitative statistical analysis, and experiments are adopted by the positivists in their pursuit of patterns, causes, and effects in the social world, along with quantitative data collection and analysis methods such as tests and surveys (Mertens, 2010; Scott & Usher, 2011).

In the social sciences, this paradigm overlooks the significance of human actors' objectivity in research and in constructing reality (Cohen *et al.*, 2013). Also, critical theorists attack the positivists' claims of generalisation by ignoring the world's complexity (Blaikie, 2004; Cohen *et al.*, 2013). Positivists like Scott and Usher (2011) criticise this paradigm on the ground that it ignores the understanding of the world of individuals in terms of complexity and multiplicity in life. However, few information management studies are based on a scientific assumption where the research explains complex phenomena. As such, positivism has been less adopted as the methodological perspective in most information management studies for decades. As such, this study will not require the explanatory power of positivism.

5.3.2 Post-positivism

Criticism of positivism led to the emergence of post-positivism, which is developed as a result of the shortcomings of positivism (Richards, 2003). Critical realism (Guba, 1990) is a post-positivist ontology that believes realism exists outside of the individual's mind/consciousness but could be uncovered in a particular sphere of possibility (Mertens, 2010). The post-positivist adheres to an objective epistemology (Guba, 1990), which maintains a strict separation between the researcher and the research subject. The post-positivist methodology is modified and experimental (Guba, 1990), where it can be done in a natural setting following the use of qualitative methods with an ethical obligation to conduct good research (Mertens, 2010). As such, the research paradigm permits the use of qualitative and quantitative research methods including the adoption of a mixture of qualitative and quantitative methods of data collection and analysis such as interviews, questionnaire surveys, case studies and statistical analysis techniques. According to Denzin (1970), the technique is called triangulation which provides the required interaction and terrain required to incorporate the combination of qualitative and quantitative approaches. The main aim of triangulation is to increase the reliability, validity and dependability in research outcomes.

Within contemporary literature, post-positivism is sometimes referred to as realism or critical realism or neo-positivism. Researchers in information management often combine methodologies in carrying out research, which is becoming popular as it gives researchers the freedom to choose several methodological approaches. For example, qualitative and qualitative or qualitative and quantitative methods. However, this method does not fall under the purview of this investigation because it rejects interaction between the researcher and the research subject.

5.3.3 Critical theory

The positivist and post-positivist paradigms are challenged by the critical theorist (Scott & Usher, 2011) with a completely different perspective. *Critical theory* is a philosophy that holds beliefs and challenges dominant social constructs (Gray, 2009) by proposing changes in societal and educational structures with the intention of making them more practical (Alwan, 2007; Crotty, 2003; Pring, 2000). Besides, it seeks collective liberty and structural transformation (Cohen *et al.*, 2007). According to Crotty (2003), critical theory sees the researcher as a social transformation intellect who frees people from their mental, historical, social, and emotional circumstances. Historical realism is the ontology of critical theory (Guba & Lincoln, 1994), which holds that reality is historically constructed but exists outside of the individual mind (Lather, 2006). Critical theory queries all sociocultural ideas/meanings and emphasises that ideas emerge in unique social contexts (Creswell, 2003).

Critical theorists use dialogical, dialectical, and transformational methods and techniques. According to Guba & Lincoln (1994) the inquiry's transactional nature engages the researchers and the researched in dialectical dialogues to transform misconceptions and misinterpretations. The methodology of critical theorists is not value-free, and they employ techniques that aim to institute dialogues with participants as bases of information (Pring, 2000). Ideology critique and action research are research approaches ascribed to critical theory paradigm (Cohen *et al.*, 2007). Ideology critique seeks to expose the corporate interests and unauthorised actions of those in authority, as well as to raise marginalised people's awareness of an unjust social structure. As a result, there exist a relationship between data, theory, research questions and analysis (Talmy, 2010). The action research on the other hand is concerned with giving researchers a "voice" (Cohen *et al.*, 2007). It is a strategic approach for changing the situation under investigation and raising the standard of practice in a variety of contexts (Morrison, 2005). The ethical feature in the research is crucial as it establishes trust and respect with the participants (Creswell, 2009). This approach is not adopted by this study as it is historically constructed, seeks social transformation and collective liberty (Cohen *et al.*, 2007).

5.3.4 Constructivism

As an underpinning philosophy, constructivism is the paradigm that effectively gathers data representing a person's constructed sense of reality (Denicolo *et al.*, 2016). Constructivism sees meaning as entities created by humans actively engaging with the phenomenon under investigation. Ontologically, realities are understood as a collection of logical constructions that are experientially and socially based (Guba & Lincoln (1994). The epistemology is subjective and transactional. The researcher and the research subject are believed to be linked interactively, so the findings emerge as the research progresses (Guba & Lincoln, 1994).

As such, constructivists see knowledge as created in the interaction between investigator and respondent, interpret data using convectional hermeneutical techniques and compare them through a dialectical interchange. Thus, constructivism's hermeneutic/dialectic methodology is aimed at reconstructing previously held constructions in the social world through these interactions. In the words of Guba & Lincoln (1994), change is made possible as reconstructions are formed and individuals are encouraged to act on them. More studies in information management now employ methodology such as a case study strategy in which concepts are established from the data while carrying out the study (Menn & Seliger, 2016). Another example in this category is field study and observation (Tomar & Bansal, 2019; Wu *et al.*, 2014). Quality criteria in constructivism are not well resolved, and further critique is needed (Guba & Lincoln, 1994). Although constructivism forges a connection between the researcher and the subject under inquiry, it will not play a role in this study as reality is created through an individual's socially constructed experience and not by an individual's social interactions with the phenomenon.

5.3.5 Interpretivism paradigm

Interpretivism emerged as an opposition to positivism and is frequently used in conjunction with concepts like "constructionism," "naturalism," "subjectivism," and "qualitative approach." The paradigm attempts to comprehend the phenomena under investigation from the perspective of those involved. It accepts double hermeneutics (textual criticism) and multiple interpretations. In contrast to positivism, this paradigm is inductive, emergent, and context-bound and does not seek generalisability. Additionally, interpretivism is value-laden and strives to understand ideologies (Scott & Usher, 2011; Creswell, 2012). Interpretivism is founded on a "relativist" and "anti-foundationalist" ontology (Guba, 1990; Grix, 2004). Unlike positivism, ontologically, interpretivism believes in socially constructed realities rather than one that exists independently (Cohen *et al.*, 2007). Epistemologically, interpretivism is "subjective" (Guba & Lincoln, 1982; Guba, 1990; Grix, 2004), where meaning is the outcome of the researcher's interaction with the subject.

The interpretive paradigm seeks to better comprehend these realities from the participants' perspective. Generalisation is not sought in interpretivism and cannot be accomplished because the entire paradigm is built on respect for individuals. The interpretive methodology incorporates dialectic and hermeneutic techniques as ontology and epistemology impact methodology. Individual constructs are hermeneutically refined and elicited, then dialectically contrasted and compared to yield a few constructions upon which there is strong consensus (Guba, 1990, p. 27). Phenomenology is another philosophical movement that has a significant impact on interpretivism. "Phenomenology examines humans' perception of the world and subjective interpretations (i.e., investigate the lived experience of the individual) to understand the phenomenon" (Ernest, 1994, p. 25).

Ontologically, the interpretivism assumption holds that social reality is experienced by multiple people with different perspectives, resulting in a different interpretation of the same incident. Other techniques used by the interpretive approach include case studies and grounded theory (Dornyei, 2007; Cohen *et al.,* 2007). Although they have differing objectives, all interpretive techniques involve observing, describing, or reporting a phenomenon in its natural environment.

The importance of the researcher's position is highlighted in interpretive research, and interactions between the researcher and those being studied are acceptable as long as they are acknowledged and recognised. The interpretive approach primarily employs qualitative tools, such as interviews, documents, field notes, diaries, and observation. Owen (2008) states that interpretivism's ethical considerations are "vast and require ongoing negotiation throughout the study process." He continues by saying that because interpretive research is emergent, the researcher would obtain the participant's consent at every stage of the investigation. Additionally, the interpretative paradigm's commitment to respecting the rights of individuals encourages researchers to protect respondents' confidentiality and anonymity during the research and while the findings are disseminated (Cohen *et al.,* 2007; Fikfak *et al.,* 2004). In qualitative research, trustworthiness depends entirely on how subjectivity is managed (Holliday, 2010). Guba and Lincoln (1982) identified four concepts—transferability, credibility, dependability/consistency, as well as confirmability—that can be used to assess the quality of interpretive research. These requirements assure the initiator of the research that all necessary steps have been taken to ensure that data from contexts and human sources has meaning, can be tracked, is verifiable, and is well-grounded in the original real-life settings (Creswell & Miller, 2000; Shenton, 2004; Perry, 2011).

Researchers' primary goals in the interpretive paradigm are to gain a deep understanding and detailed knowledge. As such, the quantitative method—which explains the world in numbers and measurements rather than texts—is inappropriate for this study. In contrast, the qualitative method is fully detailed and textually rich, and researchers frequently employ "rapid attention and intuitive knowledge" (Punch, 2009) in collecting data. This study is rooted in the opinions, understandings, and experiences of stakeholders in the construction industry regarding information management systems in their respective projects. Therefore, the study aims to understand the participants' world of experience (Cohen & Manion, 1994) to develop an improved information management schema. As Creswell (2009, p. 4) asserts, "qualitative research is a method for investigating and comprehending the significance of what individuals or groups attribute to human problems." In addition, Hussain *et al*. (2013) argue that interpretive researchers cannot distance themselves from the observed object, the subject matter, and the study methods. As in the case of this study, the participants' view, i.e., the construction stakeholder's perception of information management problems in the construction industry, is explored in the study to gain insight into the human problems of managing information about projects. As such, the research participants' interaction with the observed subject enables the researchers to unravel these problems and make a proposition based on the results from the adopted qualitative methods to achieve the aim of the study. Based on the above arguments, an interpretive paradigm is adopted for this study.

5.3.5.1 Research paradigm selected for the study

The studies seek to comprehend respondents' perspectives on BIM information management systems. As such, the study adopts the interpretivism research paradigm. According to Kivunju & Kuyini (2017), interpretivism is also known as the constructivism paradigm, considering that reality is socially constructed (Kivunja & Kuyini, 2017). The interpretivism paradigm position includes relativist ontology, subjectivist epistemology, a naturalist approach, and an equal research attribute (Kivunja & Kuyini, 2017). From the above assertion, relativism is the ontological stand of interpretivism, i.e., subjective reality (Scotland, 2012), to equally understand the subjective world of human experience (Kivunja & Kuyini, 2017). This subjectivity, therefore, supports the approach essential for this study to comprehend the contextual meaning that the subjects are creating while the researcher interacts with the subjects under study.

The study tries to comprehend personal experiences with information management in BIM projects to improve the systems for construction operations, just as interpretative research seeks to comprehend the phenomenon from an individual viewpoint. As a result, through a series of interviews and observations, this phenomenon is investigated in light of the perceptions and experiences of various parties in the construction industry. Other considerations for the adoption of the interpretive philosophical paradigm and qualitative research for this study, as opined by Kivunja and Kuyini (2017), include the existence of an emic relationship between the subjects and the researcher, that is it involved the analysis of phenomena from the perception of one who participates in the studied; the significance of knowledge gathering (i.e., the use of case study strategy, semi-structured interviews, among others) approach plays a critical role. Thus, the philosophy of the interpretive research paradigm serves as the foundation for this study.

5.4 Research Approach and Logical Reasoning for the Study

The method of employing existing understanding to conclude, make predictions, or develop explanations in research is termed logical reasoning (Draine, 2001). The four research reasoning techniques are deductive, inductive, abductive, and retroductive.

5.4.1 Deductive approach

This type of reasoning begins with the assumption of a general rule and progresses toward a specific conclusion (Chetty, 2016). Deductive reasoning applies general rules to specific applications and holds that the conclusion must be equally valid if the original assertions about investigations are factual. Although deductive inference is frequently applied to the analysis of qualitative theory-driven research, researchers claim that using deductive inference in qualitative data analysis is limited to academics engaged in theory development (Meyer & Lunnay, 2013). As this study is not into theory development or testing a theory, deductive inference does not apply to this study.

5.4.2 Inductive approach

The inductive approach starts with precise observations of the phenomena and progresses to a general conclusion that is likely but not certain in light of the combined data (Chetty, 2016). However, inductive reasoning is reasonable and rational. The evidence appears complete, relevant, and generally compelling, and the conclusion is thus most likely correct. Inductive reasoning differs from deductive reasoning in that it cannot provide a particular conclusion; it can expand human understanding. Furthermore, it can create projections regarding future events or previously undiscovered phenomena (Kennedy & Thornberg, 2018). The study aims to develop a BIM-based schema that would be useful in improving information management processes for the construction industry. As such, an inductive reasoning technique is adopted for the study, as it concludes with the general decision of providing an improved understanding of managing information practices to the construction stakeholders.

5.4.3 Abductive approach

Abductive reasoning generally starts with an incomplete series of observations and then proceeds to the most likely possible explanation for the set (Walton, 2014). Abductive reasoning produces daily decision-making that does the best it can with frequently incomplete knowledge. While inductive reasoning presupposes that the evidence that could explain the issue be somewhat full, whether positive or negative, abductive reasoning is distinguished by a lack of completeness, either in the evidence, the explanation, or both (Kennedy & Thornberg, 2018). Thus, it is not appropriate for this study

5.4.4 Retroductive approach

Retroductive inference is an innovative analytical approach that allows scholars to update and redevelop social theory (Meyer & Lunnay, 2013). According to Danermark *et al*. (1997), retroduction inference develops a new conceptual framework or theory. They concluded that critical realism employs abduction and retroduction approaches.

5.4.4.1 Selected research approach and logical reasoning for the study

Inductive research is the approach used in this study, as it is associated with interpretivism. Bryman & Bell (2011) described inductive reasoning as being characterised by a shift from the particular to the general. That is, the researcher engages in the study of a particular phenomenon and reach a conclusion about it. The study begins with the observations and then searches for patterns in the data (Beiske, 2007). The induction procedure helps to unravel the issues with BIM's information management of construction activities and come up with solutions for the system's improvement. As a result, the study would not only identify issues with the existing BIM information management method but also suggest an improved information management system. The inductive technique in this study entails gaining holistic insight (Charmaz, 2014; Gale *et al*., 2013) from the BIM IM system data in the construction industry and ensuring that all the significant parts of the data were captured. By adopting the inductive method, themes are extracted from the raw data without the possibility of a researcher employing a predetermined/prearranged conclusion (Bradley *et al*., 2007; Braun & Clarke, 2006; Glaser, 1992).

5.5 Research Strategy

Research strategy also referred to as research methodology, describes the way the researcher intends to carry out the research (Saunders *et al*., 2007). The research strategy is influenced by the research questions, the level of information in the field of the research, the researcher's philosophical assumptions, and the amount of time available for the study. Experimental research, grounded theory, action research, ethnography, phenomenology, survey research, narrative inquiry, and case studies are popular research strategies (Saunders *et al*., 2009; Collis & Hussey, 2009). However, to select the ideal method for the inquiry, a researcher must evaluate the study's issue (Walliman & Baiche, 2005), as there exist different interrelationships between the research methodologies (Yin, 2003).

5.5.1 Experimental research

Experimental research is one of the most rigorous strategies in research and is frequently referred to as the "gold standard" in research designs (Bhattacherjee, 2012). This design involves the researcher manipulating one or more independent variables (as treatments), randomly assigning individuals to various treatment levels (random assignment), and observing the effects of the treatments on outcomes (dependent variables). Experimental research has a distinct advantage in that it may link cause and effect through treatment manipulation while controlling the inaccurate effect of unrelated variables, known as internal validity (causality). As such, it is best suited for explanatory research where the study aims to examine cause-effect correlations. This technique, however, is not appropriate for this study.

5.5.2 Action research

Action research is a methodology that actively engages the participants while simultaneously focusing on action and research (Coghlan & Brannick, 2010). The action researcher is a change agent committed to not only studying organisations, communities, and processes but also improving them to address real-world problems. The researcher participates in the practices or collaborates with practitioners who are actively involved in them. As a result, action research brings about a change in the studied phenomenon. Although this methodology works well as a change-driven strategy, the study's goal is not to make any changes; instead, it proposes processes that could improve the BIM information management system.

5.5.3 Ethnography

Ethnography has its roots in socio-cultural and anthropology background. As a research strategy, ethnography entails the researcher becoming involved in his surroundings (Cleland, 2017). In-depth exploration or continuous contact with the culture under study, along with strong observational abilities on the researcher's part (Glesne, 2016), are essential components of ethnography. Because of the direct contact of the researcher with the target cultural being, it may be possible to require information that is otherwise difficult to obtain and record. As the goal of this research is to acquire an emic view of the concept of the particular study and explore the shared lived experience of a group, ethnography is slightly applicable to this study.

5.5.4 Grounded theory

Establishing a theoretical model from the knowledge acquired through studying the sampled population and subsequent evaluation of their behaviours/actions and words is termed “grounded theory” (Huston & Rowan, 1998). Grounded theory research is inductive compared to other research methods, like quantitative research, which tests/confirms an existing theory and is deductive. Grounded theory is thus suitable for research examining social interactions or experiences (Cleland, 2017; Foley & Timonen, 2015). Fundamentally, grounded theory aims to describe/explain occurrences, for instance, in what way will an event occurs and the reason for the occurrence, or how individuals may behave in a given manner and the reason for that behaviour. A Grounded theory researcher may employ the methodology to create a hypothesis to describe the desired phenomenon by monitoring the population. Although grounded theory entails examining social interactions or experiences, the reason for the occurrence of an event, and the reason people behave in a particular way, this study is neither generating a theoretical model nor a theory from the experience of the observed population. Hence, grounded theory research is outside the scope of this study.

5.5.5 Phenomenological research strategy

Fundamentally, phenomenology delves into experiences from the individual's point of view (Cleland, 2017). Phenomenology examines the "lived experiences" of the participants and seeks to determine, from their point of view, how and why things were done in a particular manner. The main goal of phenomenology is to accurately represent how those who experience a phenomenon live their lives (Creswell & Poth, 2018; Giorgi & Giorgi, 2003). This research strategy study describes the experiences of the participants and the way they lived the experience (Moustakas, 1994). Converse (2012) stated that in phenomenological studies, there are at least two main kinds of foci. The first explains the phenomenon and aims at developing descriptive categories of the observed real-world according to the narrations of the participants. The second kind focuses on giving an explanation to what occurred in the phenomenon and in what way people's significance processes were affected by their options (phenomenologically writing and reflecting on comprehending the event's value) (Converse, 2012). The use of phenomenology in this research allows the researcher to comprehend the current information management systems from the participants' perspective.

5.5.6 Narrative research

One of the benefits of qualitative study is its capacity to tell stories, frequently from the viewpoint of those actively engaged in them. When writing about qualitative research, it is essential to specify the context and participant quotes. According to Cleland (2017), A "thick" or "rich" description is a strength of qualitative research (Cleland, 2017). As this strategy pulls together a series of narrations of events, typically from one, two, or more participants, with the hopes of establishing an organised storyline, or narration, it is loaded with the potential for a "thick" or "rich" description. Understanding information from one or more people about the occurrence of an event helps researchers understand more about the factors that contributed to those narratives. This strategy is applicable in the study because it aims to elicit lived experience from the participant.

5.5.7 Survey research

Survey research employs standardised questionnaires or interviews for gathering information about people and their preferences, ideas, and actions in a methodical way. The research strategy effectively reaches a large population by circulating the same questionnaire to establish a more comprehensive view of the people. For quantitative social science research, this approach is prevalent. Descriptive, exploratory, or explanatory research can all be done using the survey approach. The ideal applications for this approach are studies where individual people are the unit of analysis, which is part of the case in this study.

5.5.8 Case study strategy

An analysis of a complex and particular case while learning about its activities and unique circumstances is known as a case study (Stake, 1995). Yin (2017) highlights the essential components of case studies. (i) case studies "in-depth analysis of a current phenomenon within its real-life environment, particularly as distinctions between the occurrence and setting are invisible"; (ii) case studies incorporate multiple sources and types of information to fully address the complexity of a phenomenon under investigation (Yin, 2017, p. 18). The case study approach provides a comprehensive explanation of all the interrelated components. Case studies are frequently used interchangeably with qualitative research, partly because they enable the generation of multiple perspectives using multiple data-gathering procedures or the establishment of multiple stories using a single technique. (Lewis, 2013). A deep and thorough understanding of a context can be developed by integrating and contrasting multiple points of view. A case is challenging to describe because practically anything might be a case (Punch, 2013), from an individual to a role, occupation, or even a country.

Case studies' investigations typically adopt various forms, such as explanatory, exploratory, or descriptive approaches, subject to the area or type of research (Yin, 2014). Both multiple-case and single-case designs are acceptable and appropriate for research (Yin, 2017; Merriam & Tisdell 2015; Stake, 1995;). Additionally, a case study can be positivism, interpretivism, or criticism. The natural science model of research criteria—controlled observations, controlled deductions, replicability, and generalisability—are used to plan and assess case study research in the positivist tradition (Lee, 1989). Although case study research does not allow for the experimental manipulation of variables, theoretical constructs can be developed, empirically evaluated, and measured, and naturally existing controls can be found (Lee, 1989; Cavaye, 1996). In multiple case studies, the research's literal and theoretical replication enables the generalisability of its findings from case study research (Lee, 1989; Yin, 1994, pp. 46-51).

5.5.8.1 Single-case positivist

Single-case positivist studies have been contrasted with experiments. The argument's premise is that a single experiment's results cannot be extrapolated to include other sets of empirical circumstances (Lee, 1989). The theory's generalisation is strengthened and broadened by more trials under various empirical situations that support it. No single case study would be sufficient to generalise a theory; generalisability is increased when the theory is evaluated under different empirical conditions (Lee, 1989). This argument disregards the possibility of meticulously planned studies with controls and participant assignment to various treatment groups at random. These experimental setups and statistical analysis methods aim to increase the generalisability of experimental results. Each person in an experiment receives treatment and is measured independently. A single case study is quite different. Participants are individually questioned to gather data, but their answers are combined at the "unit of analysis" level.

5.5.8.2 Interpretive case studies

Typically, interpretive case studies aim to describe phenomena by the meanings that individuals give them. Quality is determined by the story's plausibility and overall argument in interpretive case studies (not validity and reliability). Interpretive case studies concentrate on how and why people perceive the world in the ways they do or how reality is socially constructed (Myers, 1997). The knowledge base for information systems includes a significant and expanding portion of interpretive case study research (Walsham, 2006). Interaction between researchers and respondents is emphasised in interpretive case studies during the process, observing each example as actual respondents in the description (Dubé & Paré, 2003; Kvale, 2002). Thus, distinguishing them from positivist case study research. This study would benefit more from interpretive case studies because they closely focus on the interaction between the researcher and the participants, are anchored by the interpretive philosophy, and see the case member in the study as essential respondents in developing the case narrative.

5.5.8.3 Critical case study

Critical case study research critically explores contemporary practices, challenges assumptions taken for granted and criticises the status quo in light of one or more critical theorists (Easton, 2010). In interpretive or critical case studies, words like validity and reliability, which suggest an objective reality independent from social reality, are not typically employed. However, researchers have not widely accepted the case study approach as trustworthy, impartial, or legitimate, as Yin (2009) evidenced. One issue is that establishing generalisations from a particular case is frequently challenging—and even harmful. Though Yin justifies case studies by pointing out that several examples of the experiment must verify most scientific investigations, the same is true of case studies, which can also be established based on multiple examples or instances of the same subject or phenomenon. Gummesson (2000) argues in favour of this point of view and claims that, even in medicine, a doctor's expertise is frequently acquired through experience with multiple specific cases. As the study requires information from practitioners in the construction industry regarding information management in their BIM projects, the case study research is applicable in this study to generate and explore the different views of experts on these projects. Based on the above arguments, this study adopts multiple case studies.

5.5.9 Selected research strategy and justification for the study

Following an evaluation of various research strategies, phenomenology and case study research strategy was chosen for this study. Different data gathering and analytical processes are employed for the research strategies. First, phenomenological research strategy was undertaken in this study, and then case study research to analyse the particular case while learning about its activities and unique circumstances within information management processes. For this study, phenomenology provides the opportunity to understand existing approaches and principles of information management and general knowledge of managing information in a BIM process. It also helps to uncover what a particular experience means to a group of people and how they have experienced it. Case study on the other hand, was employed for its comprehensive exploration of issues in their natural/real-life context (Yin, 2009). In addition, it enables the researcher to obtain a detailed result of the object or subject of study for analysis.

5.5.9.1 Selecting the case

The first requirement for a case study researcher is to select cases because doing so also establishes an agenda for studying those cases. When work is focused on one or a few instances of a more significant phenomenon, the processes of selecting cases and studying those cases can hardly be separated. A case is a common item or unit whose particular characteristics and situation need to be thoroughly examined within a restricted system (Blaikie, 2000). A unit (case) like this could be an individual, a thing, a group, a series of connections or a process (Blaikie, 2000; Stake, 2013). On the number of cases to select and use, Eisenhardt (2008) claims that although there is no established number of cases to use, in most situations four (4) to ten (10) cases usually work well. Thus, four case studies were selected for this study. They comprise construction companies in the UK with proficiency in the application of BIM for their projects.

5.5.9.2 Single case or multiple-case design

Usually, multiple case studies are employed to replicate an intervention and illustrate multiple contexts. A commonality across the instances in a multiple case study allows researchers to assess and identify distinct differences that can be replicated or transferred to situations with similar features (Yin, 2012). Based on Yin's assertion, a multiple case study design was chosen for this study. Therefore, four case studies of UK construction firms that are proficient in using BIM for construction project delivery were selected for this study. The researcher would be able to investigate various viewpoints on BIM projects in these industries by using four cases of construction firms in the UK to capture construction practitioners' subjective and experiential opinions.

5.6 Research Choice

Research choice refers to the research style for collecting and analysing data. As long as the research choices can be justified, more than one of these choices can be selected to design, collect and analyse data (Saunders *et al*., 2007). For example, the research choice could be single (mono), mixed, or multi-method.

5.6.1 Mono-method research

As the name of the approach suggests, the mono-method entails adopting just one research approach for the study. Although the study adopted only one type of research method i.e., qualitative but, more than one qualitative research methods throughout the study. As such, the study is not mono-method research.

5.6.2 Mixed-method research

A mixed method describes research that uses two or more methods or typically combining qualitative and quantitative research methods for collecting and analysing data (Halcome *et al*., 2009; Bergman, 2008). According to Morse (2016), “mixed method research” is designed for use with one (or more) research methods in only one study when one (or more) method is not complete if adopted alone (Morse, 2016). This means the incorporation of one or more methodological approaches to access a segment of a subject that cannot be accessed using a single approach. Mixed methods involve using two or more qualitative and two or more quantitative methods or quantitative and qualitative methods. A wider variety of research methods are used in the multi-method approach (Bryman, 2012) as discussed below. The mixed-method entails the use of multiple methodologies to generate a single dataset, which distinguishes it from multi-method research (Flick, 2011).

5.6.3 Multi-method research

A multi-method approach analyses the research in clearly defined sections, each of which produces a distinct result. Each section is then individually investigated using methods from either qualitative or quantitative method (Feilzer, 2010). Multiple methods, also known as multi-method design, use two or more research studies, each complete in its own right, to address research questions or hypotheses, a topic, or a programme (Morse, 2003; Martha, Sousa & Mendes, 2007). The studies adopting multi-methods like mixed methods, may use a combination of two or more quantitative, two or more qualitative, or both methodologies. Multi-method research is employed for this study, as it adopts more than one qualitative method where each of the methods is complete in itself.

5.7 Research Choice for the Study

Accordingly, the study adopted multi-method research, as evidenced above. Walterbusch, Martens, & Teuteberg, (2013) have used this approach in information management studies.

5.7.1 Quantitative research design

In the natural sciences, quantitative research is more prevalent and typically develops from a positivist theoretical perspective and deals with investigating, observing and measuring (Antwi & Hamza, 2015). The research method implements a deductive approach to hypothesis testing and investigating connections between variables. This approach supports the use of a positivist philosophical standpoint (Creswell & Clerk, 2007). Quantitative research design is informed by objectivist epistemology established on the presumption that a socially constructed reality exists to be observed (critical realism). The researcher will clearly define the terms used (so that what is meant is known) based on observable facts. Quantitative researchers try to investigate the occurrences that took their interest. As such, the project seeks to study or observe society or human problems through a well-established strategy to develop an explanatory and established process which does not apply to this study.

Experimental designs and survey research are the most commonly used quantitative research strategies. Random assignment experiments are frequently used by researchers to divide participants into different groups (Cohen *et al.,* 2013) which eliminates the chances of human bias while establishing the comparison groups. Survey research is an effective method for investigating a phenomenon by using a sample to represent the overall population. It allows for the numerical explanation of opinions as well as trends (Creswell, 2014), which aids in generalising or establishing results from the sampled population.

As argued by Galiers (1992), surveys aid in the identification of additional variables/factors in experimental research. Standardised surveys questionnaires together with other quantitative measuring/assessing tools are used to carefully measure the observed results.

Four criteria are highlighted by Guba & Lincoln (1994) for quality assessment of quantitative research. They are internal validity, external validity, reliability, and objectivity.

- ***Internal validity*** is the research instrument's consistency to ensure the research's soundness. It is obtained through the manipulation of variables to arrive at the result.
- ***External validity*** ensures how the results of a research especially an experiment can be estimated to suit the different subjects/settings of the research and perhaps the experiment. Sampling methods sometimes alter the strength (Bracht & Glass, 1968) of the result. It deals more with replication or representativeness of what has been done in research.
- ***Reliability*** ensures internal dependability and replicability in research over time, across instruments, and across groups of respondents (Cohen *et al.*, 2013).
- ***Objectivity*** eliminates bias to achieve effectiveness between researchers and the research.

5.7.2 Mixed-method research design

In a mixed method design, the study is more comprehensive or complete than in a single method. According to researchers, understanding the subjective (individual), inter-subjective (language-based), and objective (causal and material) aspect of research is essential. The benefit of a mixed method design is that it can show high-quality and complex inferences while also corroborating errors in other methods (Ivankova & Plano Clark, 2018). A researcher must consider four fundamental challenges when planning a mixed-method study. They are (i) the data collection implementation sequence, (ii) the priority of the method when collecting and analysing the data, (iii) the integration of the results/findings, and (iv) the theoretical perspective to be used during the design process (Creswell, 2003). The data collection implementation sequence relates to which method comes first in the order of the procedure or whether they will occur simultaneously. Priority corresponds to or refers to the significance given to the methods, i.e., which method receives the most attention. Integration refers to the point at which the methods are brought together into a single system that will work as one and the viewpoints of the methods (Ivankova *et al.,* 2006; Creswell, 2003). Creswell (2003) identified six mixed-methods research designs. They are sequential explanatory, sequential exploratory, sequential transformative, convergent parallel/concurrent triangulation, concurrent nested, and concurrent transformative (Creswell, 2003). However, three of these methods would be discussed in this study. They are convergent parallel/concurrent triangulation, sequential explanatory and sequential exploratory mixed-method research design.

5.7.2.1 Convergent parallel/Concurrent triangulation mixed-method research

In a convergent parallel mixed-method design, a researcher gathers quantitative and qualitative data, interprets and analyses them separately, and then compares the findings for triangulation (Õzer, 2021; Creswell, 2003).

5.7.2.2 Sequential explanatory mixed-method research

A sequential explanatory mixed-methods design incorporates a two-phase procedure in which a quantitative research design for collecting and analysing data is adopted along with a qualitative investigation (Ivankova *et al.,* 2014). This method is more pleasing to quantitative researchers interested in a mixed-method research design (Liem, 2018) than a single-method approach.

5.7.2.3 Sequential exploratory mixed-method design

In a sequential exploratory mixed-methods design, a researcher first conducts a preliminary investigation of a research phenomenon using the qualitative method of data collection and analysis, followed by quantitative research in the study's second phase, which includes the quantitative method of data collection and analysis (Antony, Sony & McDermott, 2021).

5.7.3 Qualitative research design

Qualitative research analyses provide a more in-depth understanding of issues that exist in the real world (Korstjens & Moser, 2018). Participants' experiences, viewpoints, and actions are gathered in qualitative research. Instead of addressing how many or how much, it addresses how's and why's, whose responses are not easily quantified. It might be set up as an independent study that uses qualitative data, or a component of mixed-methods research that uses both quantitative as well as qualitative method (Tenny *et al.,* 2017). The adoption of a qualitative method enables individuals to describe why, how or what they were feeling, envisioning, and undergoing at a particular time and during a necessary experience (Tenny *et al.,* 2017). It is targeted at investigating and analysing specific phenomena by creating a comprehensive picture of the meaning that research subjects attribute to human or social problems (Creswell, 2003). The method primarily depends on textual and visual data obtained in real-life settings where the individuals are confronted with the issues under investigation

(Creswell, 2014). Also, some form of unique phenomenological perspective is reflected in qualitative research (Newman & Benz, 1998).

Data collection in a qualitative method can include observations, audio/video graphic data, interviews, among other types of documents based on participants' interpretations that are captured, organised, and reviewed (Kilani & Kobziev, 2016). This can then be analysed using various analysis methods, including thematic, content, and discourse analysis (Graue, 2015). In addition, interviews in qualitative research may be *unstructured or structured*, including *close* or *open-ended* questions on the subject. Open ended where the individual conducting the interview can adjust to the respondents' answers or *close ended* featuring dichotomous (yes/no) or multiple questions. Regardless of these methods, the analytical process often entails familiarising oneself with the collected data/texts, data coding, looking for themes, identifying themes, and analysing themes (Alhojailan, 2012; Braun & Clarke, 2006) to develop a thorough understanding of the phenomenon.

The management of subjectivity in the research design is entirely responsible for the trustworthiness of qualitative research (Anney, 2014). As shown in *Table 5.3* below, four concepts (Korstjens & Moser, 2018; Devers, 1999; Guba & Lincoln, 1982) may be used to compare the authenticity/quality of qualitative research to quantitative labels. These criteria ensure that the recipient receives meaningful research appropriate for the situation and that data from human sources and contexts is impactful, actionable, reliable, and firmly rooted in the natural/real-life settings from which it has been generated (Shenton, 2004; Perry, 2011).

Four concepts (Korstjens & Moser, 2018; Devers, 1999; Guba & Lincoln, 1982) can be used to judge the quality of qualitative research against quantitative labels, as shown in *Table 5.3* below. These criteria assure the recipient of quality research with all appropriateness and ensure that data from human sources and contexts is meaningful, trackable, verifiable, and grounded in the real-life situations from which it was derived (Shenton, 2004; Perry, 2011).

Table 5. 3: *Reliability/trustworthiness concept in qualitative and quantitative methods (Korstjens & Moser, 2018)*

S/n	Qualitative research	Quantitative research
1.	Credibility	Internal validity
2.	Transferability	External validity
3.	Dependability	Reliability
4.	Confirmability	Objectivity

In qualitative research, the reliability/trustworthiness of the work can be increased by ensuring that these four concepts are met and correctly thought out to prevent problems from arising in the study. *Triangulation and evaluation* are examples of indicators that can be used to assess the credibility of qualitative research. "Rich" and "thick" narration for *transferability*, while an "audit trail" could ensure *dependability* and *confirmability*.

5.8 Qualitative Research as the Adopted Approach for the Study

The study adopts interpretivism approach as represented below in *Figure 5.1.* The approach is characterised by a qualitative research design that provides *a*ctive human engagement in the phenomenon under studied. Recognising the subjectivity of human interaction/experience is the central theme, which holds that qualitative study is characterised by subjective inquiry that sees knowledge as created in interaction among investigator and respondents, value-bound or value-laden, where realities are multiple, socially constructed and holistic. As a result, for the researcher to comprehend the current BIM information management systems and become part of the research process, the researcher must establish meaning through social interaction to understand the world of information management in BIM. In this study, the participants' opinions were greatly valued for creating an improved system.

When a qualitative researcher enters the field, he observes or studies the world around him, conducts an interview, voice-records it, and then analyses it using qualitative data analysis techniques. Thus, this study adopted a multiple case study strategy, and conducting semi-structured interviews with construction practitioners in the four adopted case studies and then the analysis of documents relevant to the study from the industries. The interviews were voice-recorded, transcribed, and the interview responses were coded for thematic analysis. The interview questions were open-ended.

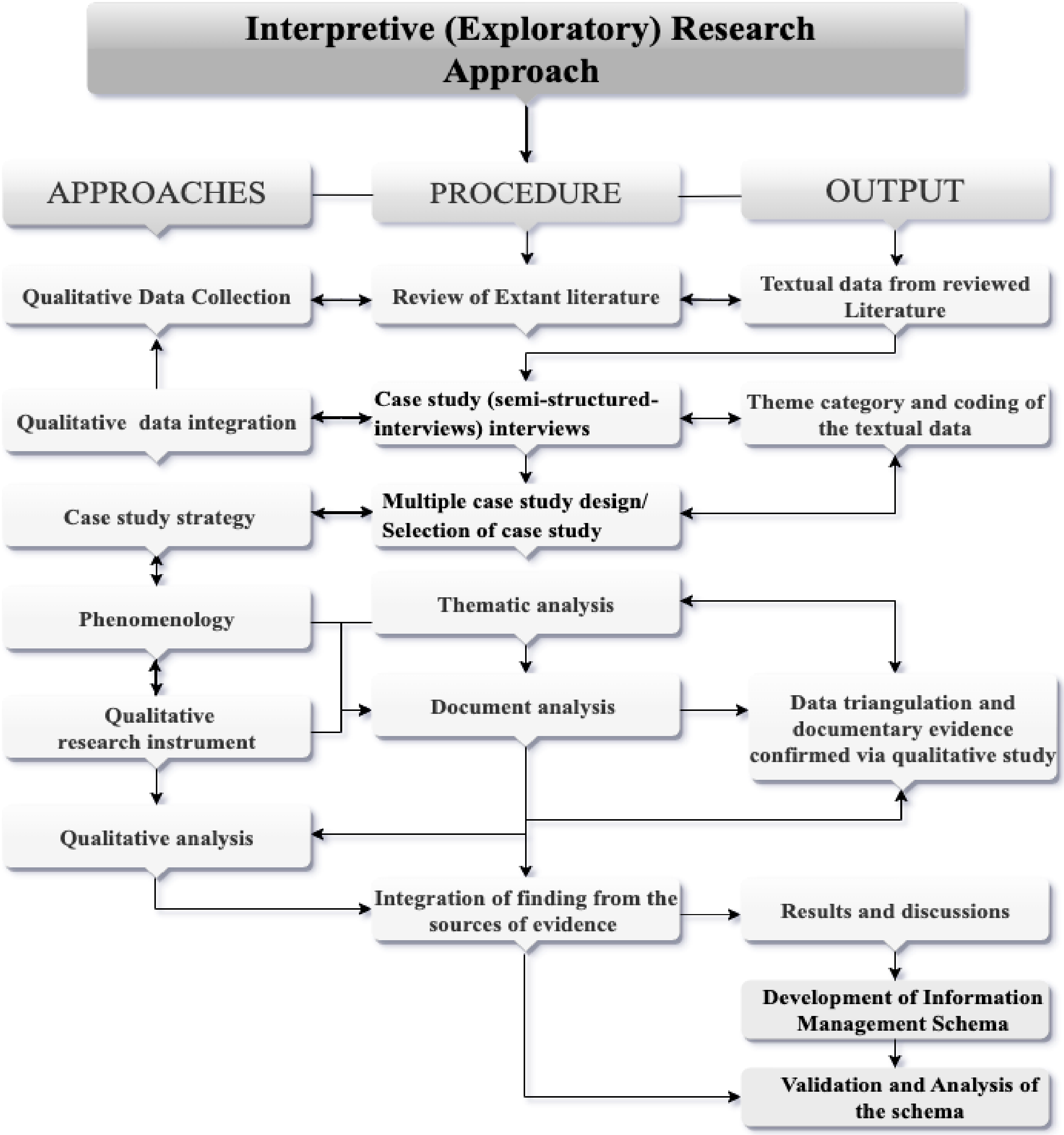


***Figure 5. 1**: Illustrations of the interpretive approach adopted for the study*

5.9 The Researcher's role

The researcher took on a subjective role throughout the research. The researcher plays a lively and crucial role in ensuring and maintaining the rigour and integrity of the various aspects of the study. In addition, the researcher interacted with the research participants to explore unique ideas within the study. The following heading describes the researcher's role in this study:

i) Integrity of the research

The research integrity equals the integrity of the researcher. In all research, researchers make errors and face different challenges in conducting the research, which undermines the studies' validity, reliability, and utility. As such, the researcher relies on competence, honesty, and transparency. Credibility, dependability, and transferability rest on the person and performance of the researcher. The researcher employed various methods of collecting data in the study, including interviews and surveying an appropriate representative sample of the participants, who were the study's target audience. The researchers provided a series of documented procedures outlining the selection of participants and the collection of data for the study. A thorough engagement with the participants, with detailed explanations of the situation and statements from them to make inferences about the facts, was also achieved in the study. To guarantee dependability, credibility, and transferability, the study used "audit trail," "thick," and "rich" descriptions (Huston & Rowan, 1998) of the setting and quotes from the participants. These criteria guarantee the recipient of high-quality research with all appropriateness and ensure that information from human sources and settings is relevant, traceable, verifiable, and trustworthy to ensure the integrity of the research.

ii) Monitoring and minimising bias

Bias is less of a problem in quantitative studies than in qualitative studies, especially when conversing with participants. The researcher's ideas about the study, the researcher's knowledge of the study, topics from the literature review, hope for the study, and human distractibility create bias in research. As such, "confirmation bias" (McSweeney, 2021) in every aspect of the research, including during interactions with participants and data, is common. The researcher controls the intrusion of bias by being conscious of her previous knowledge about the study and her attitude throughout the interaction with the participant. The interactions were accomplished by being mindful of her thoughts about prior knowledge rather than being receptive to the participants' information. As a result, the researcher ensures to maintain her moderator role properly without meddling with the participant's ideas or comments.

iii) Displaying method competence

Like every other research methodology, the qualitative approach necessitates the appropriate use of specialised knowledge. For instance, the researcher displays appropriate competencies when writing and analysing the project's data. Competencies were achieved in this study by 1) providing information about the subject without prejudicing potential participants; (2) correctly conducting interviews in accordance with the design to avoid any ambiguity; (3) choosing appropriate participants, journal portions, artefacts, and images; (4) proper handling of data; and (5) accurately presenting the research findings.

5.10 Chapter Summary

The various research principles, such as paradigms, research methods, and strategies, were reviewed in this chapter for their relevance and how they have assisted in applying the most appropriate method of inquiry in the study. The use of the interpretive approach as a philosophical viewpoint has been justified in the study based on critically examining the studied concepts. Based on this, the research design most suitable for achieving the study's objectives is the qualitative or exploratory research design approach. Furthermore, the phenomenological approach, combined with an evaluation of the existing literature, provides an option for obtaining rich data from the participants for the study. Finally, a case study research strategy proved to be most appropriate technique for further exploring the study. All these were justified in this chapter.

Chapter 6

6 Research Sample and Sampling Techniques

6.1 Chapter Overview

This chapter explains the study's sampling procedure and justification, including information on the sampled population, sampling techniques, data collection methods, the data analysis process, and issues relating to validity and ethical considerations.

6.2 Sample in Research

A collection of cases is referred to as a "sample," while a population represents an enormous collection of cases. A sample accurately represents a broader population (Bryman, 2012). Selecting a sample is the primary purpose of sampling techniques in research. Effective sample selection is essential, as inappropriate practices can negatively impact a study's findings. The features of a sample in qualitative research are often smaller than in quantitative, and most of the time, two or more methods are used to ensure credibility in research. However, in quantitative research, the research's finding’s reliability can be determined using the selection process and sample size.

6.2.1 Sampling criteria

Qualitative research participants are regarded as individuals capable of reflecting on and communicating their practices, principles, points of view, and contributing their ideas to the research (Lopez & Whitehead, 2013). As far as the participants are concerned, different qualitative or quantitative techniques have different sampling objectives. Therefore, the selection of the participants is made in accordance with the sample criteria, which describes the characteristics of the sample population and establishes their suitability for the research established on previously selected exclusion and inclusion criteria (Lopez & Whitehead, 2013).

6.2.1.1 Exclusion and inclusion criteria

Exclusion criteria are features that render a participant unfit to participate in a study. For example, cognitive impairment or the participant's second language in the study's primary language, which does not apply to this study. *The inclusion criteria,* on the other hand are a person, population, or research element's specific features that must be possessed to be eligible to take part in the study. In addition, the methodology of the specific research, such as qualitative or quantitative, automatically determines the inclusion criteria (Lopez & Whitehead, 2013). For instance, this study's participants were chosen for their understanding of the phenomenon being studied. As a result, when choosing the participants for this study, the participants must have previously been associated with the specific events, actions, or phenomena, or the participants were already in the observable vicinity of the study.

6.2.2 Sample size

The sample size is represented by the number of participants drawn from the entire population to take part in the study (Matuszak & Matuszak, 2011). In quantitative research, sample size significantly impacts how reliable a study's findings are. Results from samples significantly less than 30 tend to be off-centre by the individual respondents. In these situations, the greater the sample size, the more credible the result. On the other hand, the sample size is much smaller in qualitative research and is not a significant indicator of the research's validity (Flick, 2011), since the purpose is to examine a few cases to identify the spread of variety and not its largeness or quantity. The data determines the sample size in these circumstances at a particular stage during data collection or the data saturation stage. A data saturation stage is reached when new information is negligible or no longer obtained (Ranjit, 2012).

In qualitative research, there are no basic guidelines for determining sample size (Dell, Holleran & Ramakrishnan, 2002). As a result, no specific techniques for defining whether the size of a sample is either small or far too big for a particular study (Lopez & Whitehead, 2013; Whitehead & Whitehead, 2016). In essence, the "richness" of the data obtained matters a lot more than the overall participants' number (Tuckett, 2004). Notwithstanding, the researcher must still know the sample size that would fulfill the goal, the circumstance, and the value of the data to gather (Patton, 2002) for the study. Typically, a range between 8 and 20 participants is recommended in several studies (Hennink & Kaiser, 2021; Sim *et al.,* 2018; Guest, Namey & McKenna, 2017; Guetterman, 2015). Although, this number can fluctuate greatly within the above range. However, some qualitative researchers recommend a particular sample size for some qualitative design.

In contrast to Malterud, Siersma, & Guassora (2016), who offers a sample size of around seven participants for a phenomenological investigation to 25–45 for ethnographic research, Creswell (2007), on the other hand, recommends 2-5 participants for a case study, 8-10 participants for a phenomenological study, and 16-20 participants for grounded theory research. The choice of a substantial number of individuals is rarely involved, and the choice of the number is frequently compared to the chosen method of analysis in the literature, especially for focus group interviews. Hence, rather than the entire number of study participants, the sample size ought to be the number of groups in the study (Carlsen & Glenton, 2011). Nonetheless, due to the abundance of potentially rich and detailed data, small samples are much easier to manage in a qualitative study.

6.2.3 Sampling techniques

Sampling techniques are ways or plans to select an acceptable sample size for the entire research project (Bryman, 2012). In research, a variety of sampling techniques can be used. Sampling techniques are either probability (convenience, purposive, snowball, or theoretical sampling) or non-probability (stratified, random, purposive systematic or cluster sampling). In qualitative research studies, non - probability sampling is often employed, which differs from probability sampling, commonly employed in quantitative research. Probability sampling involves recruiting people with qualities representative of a larger community. For example, researchers adopt non-probability sampling in qualitative research when the whole population is unknown or unavailable or when the researchers want to focus on a particular issue (Whitehead & Whitehead, 2016) as in the case of this study. However, some of these sampling techniques can be used for both qualitative and quantitative methods. Thus, the following sections will discuss some of the sampling techniques mentioned above.

A *stratified sample* is used to make sure that the population representatives in the sample accurately reflect the essential features of the larger population, such as ensuring that the sample accurately represents the demographic characteristics of age and gender (Newman, 1998). A *random sample* comprises individuals drawn randomly from a larger group. However, the random nature of sample selection can lead to random distribution, which can result in severe skewing (Neuman, 2003). It is easier to gather respondents for a convenience sample because it is obtained from an existing framework, like an educational institution. *Purposeful sampling* is a selection established to provide the most informative data according to the researcher's justification of the research objective or purpose (Emmel, 2013; Suri, 2011). *Purposive* is a type of non-probability sampling that involves the researcher deciding which individuals should be included in the sample according to a variety of criteria, such as expert understanding of the study issue or willingness and capability to be involved in the study (Rai & Thapa, 2015). The selection of participants by referrals from other participants for possible participation is termed "*snowball sampling*" or "*chain referral*" (Sharma, 2017).

Criteria sampling (sample selection according to pre-identified factors) and extreme case sampling (targeted sample selection of rare cases) are not commonly used. Other non-commonly used sampling techniques include theoretical sampling (primarily used in grounded theory) and typical case sampling technique (sample selection according to regular/average participants) (Whitehead & Whitehead, 2016; Moser & Korstjens, 2018).

6.2.4 Quantitative sampling techniques

The sampling techniques greatly influence the research question and the final outcomes of the whole study. In quantitative study, the size of a given sample is a significant consideration based on the study type and project requirements (Neuman, 2003; Doherty, 1994). Large sample sizes are designed to develop policies, examine associations or correlations, or establish effect assessments because a larger size is believed to ensure that people from a varied backgrounds are well-represented in the study. Hence, the lower the sampling error, the greater the confidence level and generalisability of the results/findings (Cooper *et al*., 2006). Nonetheless, quantitative sampling is not the focus of this study. As such, this is not relevant to the study.

6.2.5 Qualitative sampling techniques

Qualitative sampling in research aims to get in-depth information about a situation, event, or episode or obtain information from a larger group's individual representatives (Lopez & Whitehead, 2013). It concerns the context and extent of knowledge of a social phenomenon (Blaikie, 2000). A purposive, snowball and purposeful sampling is the qualitative sampling techniques adopted for this academic research. Snowball sampling is also known as "chain referral" or "networking sampling" (Whitehead & Whitehead, 2016). Purposive (*maximum phenomena variation sampling (MPVS)*. Purposeful and snowball sampling techniques were adopted to recruit participants for the semi-structured interviews. A purposeful, judgemental, selective, or subjective sampling technique is a sample selected according to the population's features and the study's objective. It is believed to be the most informative of all qualitative sampling techniques (Tenny *et al.,* 2017). Stakeholders in the BIM-compliant projects in the UK construction firms were recruited to align with the characteristics and nature of the study. The participants' experiences as working staff in construction firms were shared in order to collect as much data about information management on BIM-based projects as possible for the development of the proposed schema to meet the overall aim of the study.

On the other hand, the snowball sampling technique is a selection established according to a referral from participants who know other participants who may want to take part in the study or have the experience the study requires. It helps recruit 'hidden populations' only known to potential participants. This characteristic also helps recruit more study participants (Whitehead & Whitehead, 2016). Purposive sampling is of two types; *Quota sampling (Qs) and maximum phenomena variation sampling (MPVS)* (Lopez & Whitehead, 2013*)*. For Qs, the researcher establishes the number of participants in addition to the qualities they possess to qualify to participate in the study, while *MPVS* takes into consideration the entire spectrum of the phenomena being researched or represented for selecting the participants (Lopez & Whitehead, 2013; Whitehead & Whitefield, 2016). In order to accurately portray the heterogeneity of a population, *MPVS* focuses on choosing population samples that are completely distinct from one another (Draucker *et al.*, 2007). Thus, this study adopted *MPVS* for selecting the four case studies. The sampling technique is also known as *Maximum Diversity Sampling (MD*S) (Suri, 2011). According to Neergaard *et al.* (2009) and several other pieces of literature, *MPVS* is a type of purposive sampling. The sample is used to represent the entire population in the study to obtain the most accurate representation of respondents possible (Lopez & Whitehead, 2013).

It is also beneficial to consider a small sample population in *MPVS* (Patton, 2005). As such, consideration was given to a small sample size in this study. Four BIM-compliant construction firms were selected for the case study strategy adopted for the study to represent the population of all BIM construction firms. The researcher also determines the case study's sample size, which is another characteristic of *MPVS*. The recruitment of participants with possible experience or experience linked to the research issue was made possible by the inclusion criteria such as years of experience and profession. Through this technique, several viewpoints were examined, enabling the identification of vital and varying characteristics of a phenomenon (Koerber & McMichael, 2008). Based on the above, purposeful sampling, snowball, and *MPVS* were selected to recruit participants for the interviews and case study. This sampling technique has been adopted in information management research by Paré (2004).

i) Semi-structured interviews participants selection

A purposeful and snowball sampling technique aligns with nearly all qualitative research designs and is appropriate for the qualitative research adopted in this study (Naderifar *et al.*, 2017; Merriam, 1998; Patton, 1990). They were adopted in this study to select the participants for the semi-structured interviews. The adoption of purposeful sampling in the study allowed the researcher to select information-rich participants to freely comprehend the phenomenon under study. In contrast, the adoption of snowball sampling increased the number of participants recruited through referrals from potential participants. According to Creswell (1998), this sampling technique is appropriate in a qualitative study because it ensures the findings' logical transfer to similar studies. Palinkas *et al.* (2015), Kalu (2019), Naderifar *et al.* (2017), and Shaheen & Pradhan (2019) have used this sample strategy in information management studies. Other sources that helped attract participants for the interview were a LinkedIn network of contacts, WhatsApp, and email contacts.

The stakeholders in the construction industry are the study's target demographic. Thirty-six (36) participants were involved in the interviews from the four case studies selected for the study. The interview selection criteria include the participants' years of experience, and the job description, which must fall within the profession of architecture, construction project managers/project managers, BIM managers, information managers, civil or structural engineers, supply chain/procurement managers, site managers/site investigators/site supervisors, facility managers, planners, builders and quantity surveyors. In addition, the individual had to have worked in a BIM-compliant construction industry for some years before being deemed a data-rich participant for the study, whether their employment was office-based or site-based.

ii) Case study selection

Four (4) UK BIM-compliant construction firms served as the study's case studies. The experiences of these firms' employees in BIM projects were sought to contribute to the research. The construction firms are labelled Company A, Company B, Company C, and Company D. The selection criteria were based on the company's BIM projects to investigate the information handling approaches for those projects. This is explained further in the next chapter.

6.3 Method of Data Collection

Sampling is inherently related to the data collection process. As a result, information is gathered directly from the defined and chosen sample population (Lopez & Whitehead, 2013; Whitehead & Whitehead, 2016). In contrast to the qualitative data collection method, everything about quantitative data is figures and numbers, i.e., data expressed in numerals. To contextualise the data collected through surveying the study sample, researchers frequently use quantitative data when they intend to quantify attributes, attitudes, behaviours, and other defined variables with a motive to either confirm or refute the hypothesis of a particular phenomenon (Williams, 2007). The two main types of quantitative data collection methods are discrete and continuous. Discreet collects data in numbers with finite numbers and constant values, while continuous data collection in research is limited to the study of the physical elements of measurement of the population, such as height, age, weight, or age. The most common quantitative data collection methods are surveys or questionnaires (web-based or email-based). Since this study is not focused on quantitative data gathering, subsequent discussion will be on qualitative data collection techniques appropriate for the study.

Collecting data from samples comes in two ways in qualitative data collection. They are direct and indirect methods of qualitative data collection. Direct is data collected through spoken, recorded or written texts as well as visual gestures or body movement, actions, and dialogues. According to Whitehead and Whitehead (2016), the interaction could be from person to person or from person to object. However, the basic idea is that anything that can be experienced as well as communicated is regarded as potential/real/actual data. This can include people's and groups' thoughts, feelings, experiences, meanings of those experiences, reactions, activities, encounters, language, and actions within their social and/or cultural context (Lopez & Whitehead, 2013 and Whitehead & Whitehead, 2016). Indirect data is first created by someone or something else, such as with written or visual accounts of events or with artistic representations of them (e.g., songs, paintings, books, or photographs) for use in the qualitative study (Lopez & Whitehead, 2013; Whitehead & Whitehead, 2016). Nonetheless, the most typical method of data collection for most qualitative study is direct data collection, which is adopted in this study.

6.4 Qualitative Data Collection Method

In exploratory qualitative study, interviews (in-depth) with individual participants could be used to gather data (Creswell, 2013). In this study, semi-structured interviews were adopted to collect textual data from experts in UK construction firms to develop and gain a thorough grasp of the participant's field experience (Hancock *et al*., 1998) in BIM information management. The participants were all selected from within the UK BIM construction industry, from small, medium to large firms with two (2) to above twenty-five (25) years of experience in the construction firms. A semi-structured interview was employed rather than focus group interviews to guarantee that individuals did not influence other participants during the interview process and allow for flexibility to inspire and trigger the participant to discuss their experience and adaptation freely (Van, 2014; Gagnon, 2011).

Meanwhile, to obtain the participants' permission to be interviewed, they were first contacted by phone, and when their permission was granted, they were invited to participate via email. The participant information sheet, which contained extensive information about the study, together with a UWE Policy Notice and a consent form was administered to the participants to obtain their willingness to participate. Informed written consent was obtained on a signed consent form. These forms informed participants about the study and assisted them in deciding whether to participate or not. Copies of the signed consent form were given to the participants to keep. Thirty-six (36) participants were interviewed, with each interview lasting between 50 and 65 minutes. Interviewing all the participants lasted for seven (7) months, depending on the participants' availability. The participants' recruitment was based on the sampling strategies discussed above. The interviews were voice-recorded and subsequently transcribed and coded for analysis. *Table 6.1* below represents a summary of the details of the interview participants. Semi-structured interviews proved to be an effective method of collecting open-ended data in qualitative study to deeply examine participants' opinions, ideas, and views concerning a specific topic (Khallio *et al.*, 2016).

Table 6. 1: *Summary of the details of the interview participants*

S/n	Experts/participant's role	Number of expert(s)	Years of experience
1.	Managers		
	Contract/Project/Construction/Facility Managers	6	4-15
	Site Supervisor/Site Managers	2	5-10
	BIM Managers/Practitioners/BIM Demo Consultants	8	4-10
	Information Managers	2	5-10
	Supply Chain/Procurement Managers	2	9-11
2.	Architects/Designer		
	Design Managers	2	5-8
	Architects	5	10-30
3.	Engineers		
	Design Engineers/Digital Engineers	3	2-6
	Site Engineers/Structural/civil Engineers	3	2-6
4.	Others		
	Quantity Surveyor	1	Over 2
	Planner/Builder	2	4-8
	Total	**36**	

The semi-structured interview was followed by the case study investigations, with practitioners handling the case study projects and documentation. Apart from the strategies mentioned in the previous sections to ensure creditability, reliability and greater accuracy, another strategy for achieving the study's credibility regarding the data collection method is triangulation, which was achieved in this study by using multiple data collection methods. *Table 6.2* below summarises the study's four case studies. The selected case studies will further be discussed below.

Table 6. 2: *Summary of the selected case studies*

Company A	
Project	Construction, consulting and digital partners in infrastructural projects.
Company's turnover	>£1,170 million
Employee	>3,300
Company B	
Project	Office and commercial, civil & infrastructure, student accommodation, fit-outs works, build-to-rent, sustainable specialist builds, leisure and retail schemes including fulfilling of turnkey project needs
Company's turnover	>£750 million plus
Employee	>400
Company C	
Project	Health care, infrastructure, and housing projects
Company's turnover	>£2,000million
Employee	>18,000

Company D	
Project	Construction, Infrastructure, Fit outs, refurbishment, housing and property services
Company's turnover	>£1 billion
Employee	>6500

6.4.1 Data triangulation

Due to the features that underlie qualitative research, its scientific rigour is frequently questioned. This is related to the reliability, validity, and generality standards utilised in its development. However, these arguments are based on quantitative presumptions that do not respond to the objectives of qualitative research, which tries to comprehend, evaluate, and describe a specific event rather than measure or quantify it (Ullrich *et al.*, 2012). Qualitative research does not rely on statistical methodologies to assure the reliability and validity of the data and results/findings. However, it is possible to utilise methodological techniques that provide transparency and adhere to the evidence throughout the preparation and execution of this research methodology, ensuring the refinement of the data presented and their credibility and dependability (Noble & Smith, 2015). One of these methods for enhancing qualitative research involving several viewpoints is triangulation. Using a multiple case study strategy in this study helped to accomplish triangulation. *Figure 6.1* depicts how triangulation was achieved in the study.

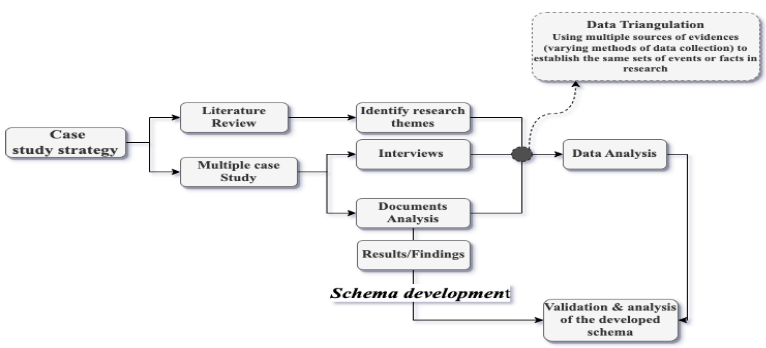


Figure 6. 1: *Triangulation in the study*

6.5 Data Analysis

Inductive analysis, as adopted in this study, was conducted in line with Thomas (2006) by carefully reading the data to ensure a holistic understanding and recording of what was discussed with the participants as well as to acquire a comprehensive grasp of what was stated (Charmaz, 2014; Gale *et al.*, 2013; Thomas, 2006). In the study, an inductive approach was used to (i) compress raw textual data into a precise, summarised form; (ii) develop apparent connections between the analysis or the study's subjectivity and the summary of the analysis of the study's data; and (iii) create a methodology for the underlying structure of experiences or workflows that are evident in the raw data. The general inductive approach offers a set of systematic methods for assessing qualitative data that can result in precise and valid results. Thorough reading and exploration to become familiar with the data were the first steps in conducting qualitative data analysis in the study. The recorded conversation was translated into written scripts and analysed to obtain the participants' views on the study. Major themes were identified after a thorough/systematic studying and reading, and transcripts' coding to allow significant emergence of themes. Using thematic analysis, sections of interview text were coded to establish relationships between themes and identify significant themes to participants. The thematic analysis offers a comprehensive, organised scheme/structure for coding data in a qualitative study and using the coding to find/locate patterns in the datasets that relate to the purpose of the study.

6.5.1 Coding scheme and grouping categorisation

As claimed by Braun and Clarke (2006), thematic analysis (TA) aids in identifying main themes and sub-themes to examine the structure and relationship among the themes' textual data in a qualitative study. TA is a qualitative method based on descriptive phenomenology. TA was carried out in this study using NVivo 1.6.2 software by employing a structured coding scheme for the classification of the various challenges within the concept of BIM information management. NVivo 1.6.2's navigation panel has been redesigned so that nodes are now represented by codes. Codes are labels generated by the software for data analysis. They are brief extracts or descriptions of specific parts of the collected data that are useful for organising the data but are not meaningful on their own. These codes produce themes that are more closely related to the research questions. The themes emerge as a result of categorising/classifying the codes. The following is the process of theme generation and development used in this study:

Entering data sources into NVivo: The data was transcribed in a word document and imported into NVivo software, as shown in *Figure 6.2* below. The transcript was then read line by line, and a theme was assigned by clicking on the code tab and creating new codes. This was done for the entire transcript, as shown in *Figure 6.3* below.

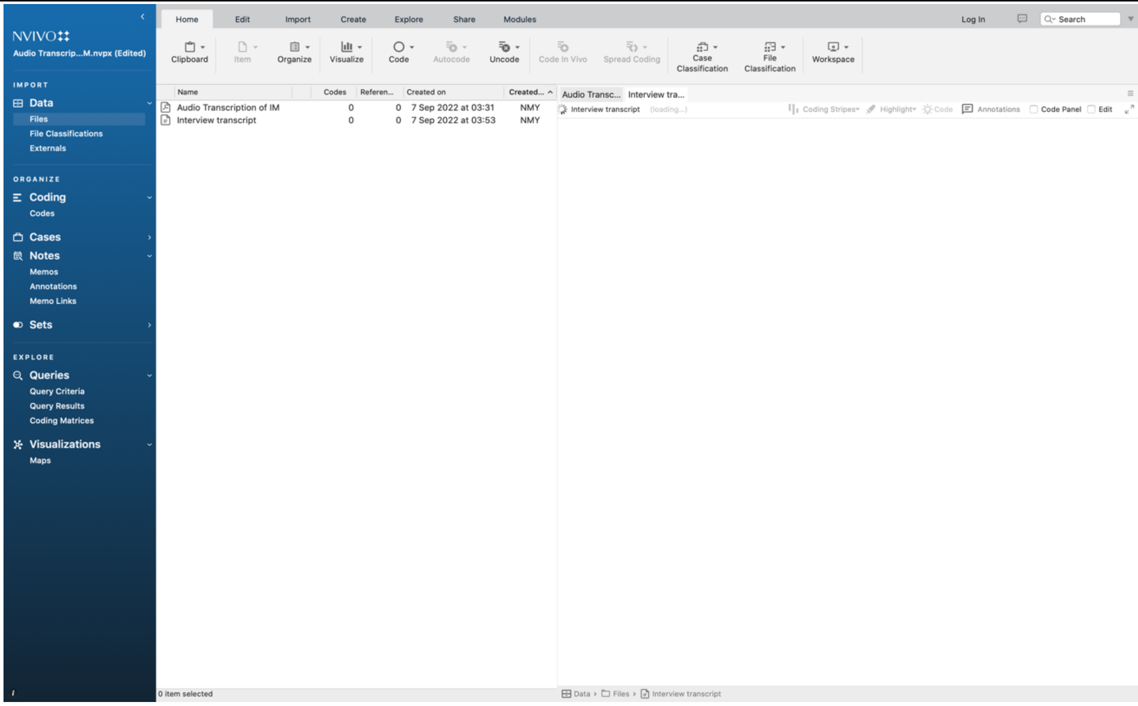


***Figure 6. 2**: Transcribed data imported to NVivo software*

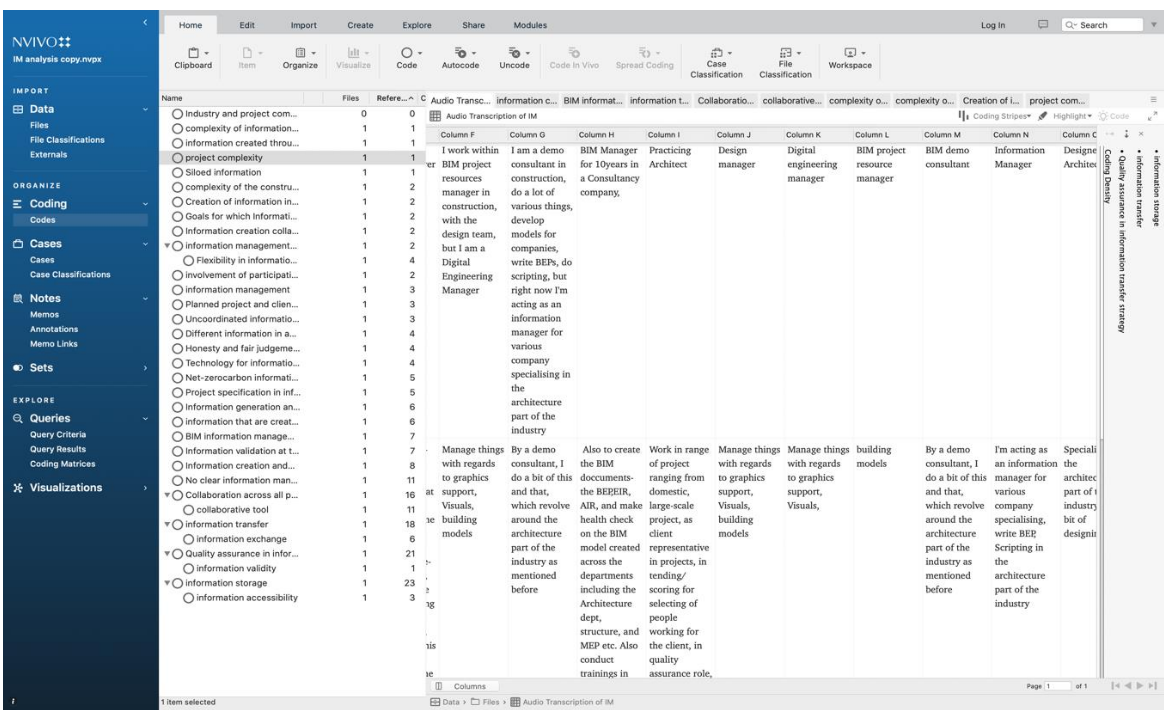


***Figure 6. 3**: The coded data*

Organising and coding the data: Following the coding of the entire transcript, the created codes were reviewed for any similarities or duplications and were either removed, combined, or deleted.

Analysing the data: The coded data was interpreted and critically analysed to ensure that the data was suitable enough to answer the research questions. As shown in *Figure 6.4*, a set of themes were generated that were supported by multiple quotations from the data to demonstrate the researcher's close contact with the data to interpret and understand the collected data.

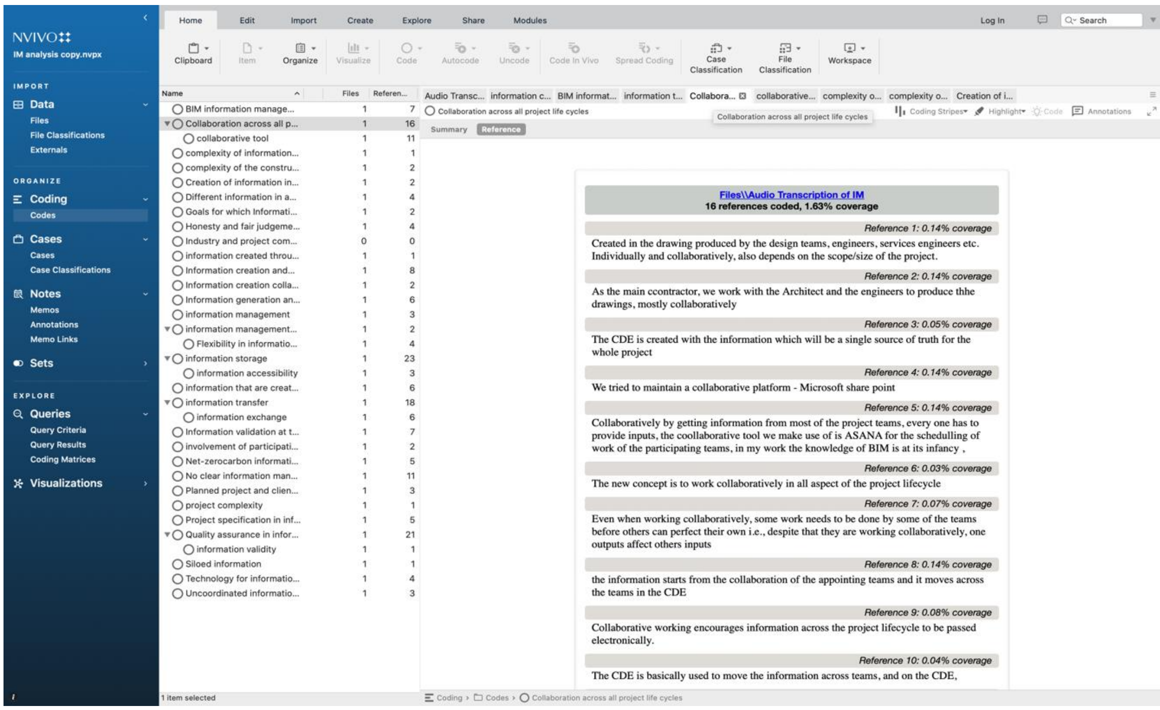


Figure 6. 4: *Generated set of themes supported by multiple quotations from the data*

Extracting responses from the data to include in the results section: The themes that provided answers to the research questions were extracted from the generated themes for discussion in the result sections.

Afterwards, the codes were organised into themes. The process of organising the codes into themes to include in the results sections was done manually on word document which was followed by theme categorisation/classification. Gu and London (2010), Silverman (2006), and Burnard *et al*. (2008) all advocate for using labelling to create a coding system and identify themes. In this study, the labels used are *interviewee* *tag/source*, *context*, *keywords,* and *theme categories.* The draft of the manual process of organising the codes into themes is represented below in *Figure 6.5.*

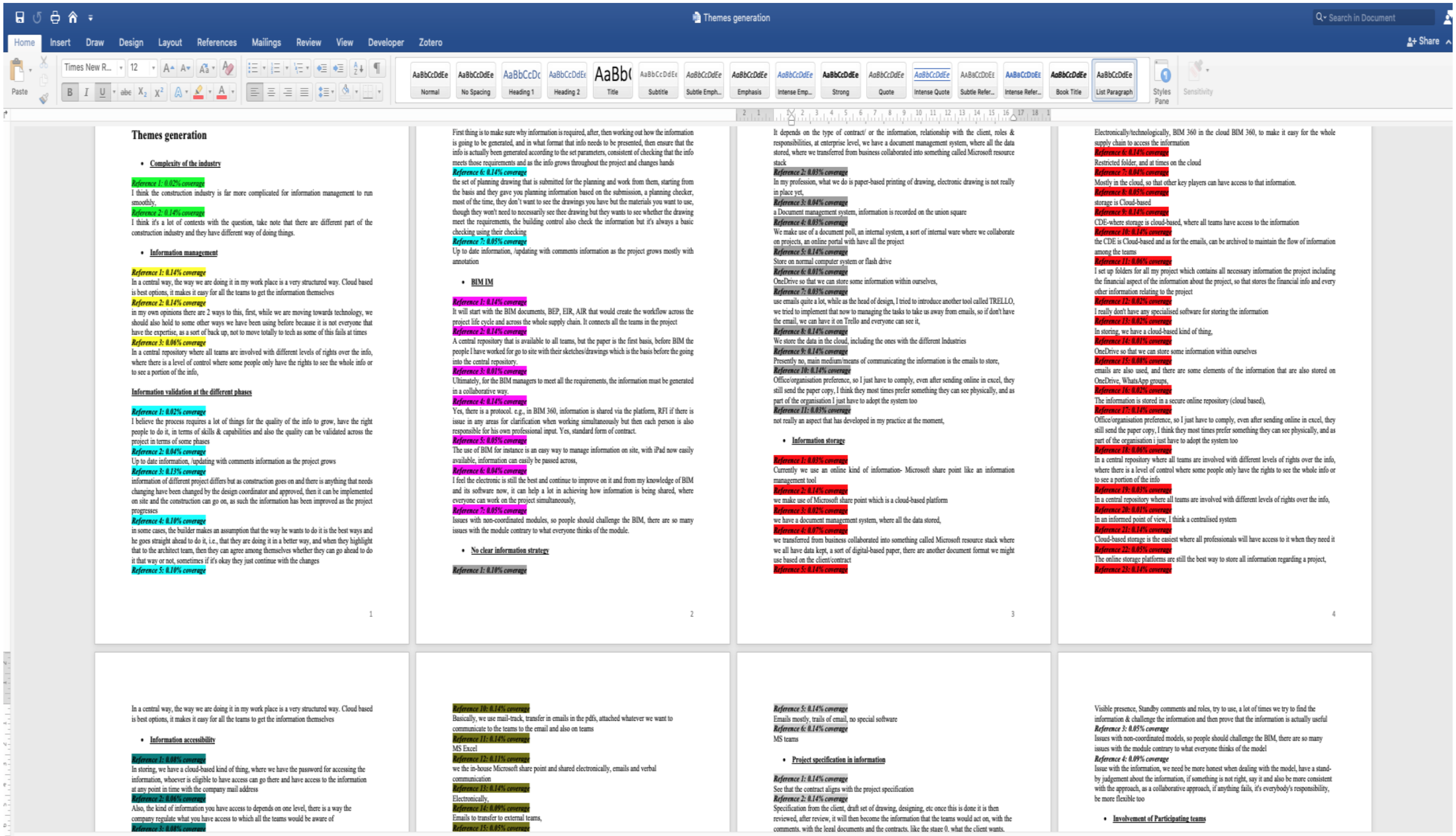


Figure 6. 5: *Organising the codes into themes*

Grouping the themes was also done manually using the labels mentioned above. i.e., the interviewee tag/source, interviewee tag/source, context, keywords, and theme categories. ***The interviewee tag or source*** identifies the interviewee who provided a transcript section. Classification through ***context coding*** helps to recognise the events that bring about a transcript section. Classification by ***keyword coding*** signifies an outline of the key subject matter raised in the transcript section as commented by a particular participant. The keyword classification aids in identifying dominant issues across the transcript and, generally, the participants' interests on the general issue of BIM information management in the industry, as in the case of this study. Finally, the ***theme categorisation*** demonstrates the major theme captured in the transcript section. This will be fully discussed in the next chapter.

6.5.2 Assessing credibility and trustworthiness

According to Lincoln & Guba (1988), the trustworthiness of qualitative research is assessed by its credibility, transferability, dependability, and confirmability. The steps they outlined that are most relevant to this study for qualitative data analysis include conducting stakeholder and peer reviews for building credibility and auditing the research (data comparison of the study's interpretations and findings) to ensure dependability. In addition, the research design was not just evidence-based to improve the qualitative study's methodological credibility, but, the semi-structured interviews' data were also merged and compared with the literature review findings. Combining these approaches helps ensure that the desired phenomenon is adequately explored.

To ensure interpretive validity, codes indicative of the initial words and terms used by participants in the study were used, which improves the general dependability of the whole process as suggested by Guest *et al.* (2011). As suggested by Creswell (2003), an external audit system in which the study's evaluative assessment was conducted by someone not affiliated with the study, was also implemented to improve credibility. Other methods to assure credibility in the study include checks on the clarity of categories, and stakeholder or member checks, a check on the overall coding procedures to test and clarify if the correct text is assigned to the categories or themes and to allow other study participants to comment on or assess the study's results, findings, interpretation and conclusion.

6.5.3 Ethical considerations

Ethical consideration focuses on the ethical issues observed in the study, especially during the data collection procedure. Ethical considerations are linked to the safeguarding of research participants (Merriam, 1998). All protocols were observed before the study was approved to ensure that participants' safety, rights, well-being, and dignity were guaranteed throughout the research. The study accurately referenced all peer-reviewed articles used, as well as the sources of data obtained from the literature. Due to Covid-19-related concerns, the interviews were conducted online via Microsoft Teams. Fundamental ethical principles were adhered to when obtaining consent and permission from the participants, informing the participants about the study, and protecting their privacy. The consent form with the participant information form detailed all information about the study, including the right of the participant to participate or not. The participants' informed written consent was obtained through a signed consent form before participating in the interview. The research does not require any external ethical consideration. As the findings are not related to any specific participants or their firms, no information about the participants, their businesses, or organisations was known. As a result, confidentiality was assured. The management and storage of the research data ensured that only the researcher had access to it.

6.6 Chapter Summary

The chapter gave an overall view and justification for the collection of data in the adopted qualitative research, the study's analytical techniques and ethical issues. Information was gathered from thirty-six (36) purposefully sampled semi-structured interviews with participants who represented the experts in information handling for BIM projects in the construction firms of the four case studies.

Chapter 7

7 Qualitative Study and Analysis

7.1 Chapter Overview

The analysis of the exploratory qualitative research employed in this study is presented in this chapter. The analysis of the methods was all discussed, including the semi-structured interviews and document analysis. The results and findings from all qualitative sources led to the creation and development of the information management schema as presented in the subsequent chapter.

7.2 Qualitative Study

A theoretical assessment of the existing literature and case study investigation were explored as part of the qualitative studies adopted in this research. To accomplish the study’s goals, the literature review aids in synthesising and summarising the theories and arguments of earlier studies that have been published in the field of information management. Additionally, the case study presents information about the study in real time and enables verification of the facts as a supported course of growth, either positively or negatively. The case study strategy's use of a semi-structured interview and document analysis further improved the information gathered. The adopted approaches ensured the discovery of critical theoretical data, provided a solid background for the study and offered a realistic setting for examining BIM information management process in the construction firms. The study’s implemented methodologies guaranteed the finding of significant theoretical data, gave the study a robust background, and provided a realistic environment for analysing BIM information management systems in the construction sector.

7.3 Multiple Case Study Strategy

To justify the knowledge from the reviewed literature, the case studies of the four (4) construction firms in the UK were examined. The strategy attempted to broaden the scope of the evidence to include qualitative findings and conclusions as reviewed from the literature. A similar methodology i.e., case study strategy was used for information management studies in previous research by Lee *et al*., 2003; Magub & Kajewski, 2003; Weippert *et al.*, 2002; Andresen *et al.*, 2000 and Opfer, 1997 and in recent studies by Munir *et al*., 2019; Olawumi & Chan, 2019; and Lin *et al*., 2016, among others.

7.3.1 Sampling strategies for case studies

The four (4) construction firms for the case study strategy were selected using "Maximum Variation Sampling" (MVS). Companies A, B, C, and D were assigned to the chosen construction firms. All of the case studies are from the United Kingdom. These four companies are among the top British construction firms, with an annual turnover ranging from £659 million to £1 billion and expertise in BIM. Their specialisation in construction includes civil and infrastructure, consultancy, health care, fit-outs, renovations, build-to-rent, housing, and property services. They partner with various emerging construction industries and small and medium-sized businesses (SMEs). They also work with several research groups at various institutions across the UK to contribute to a variety of research initiatives that benefit the economy.

The unique traits and characteristics of the chosen projects supported the sampling strategy adopted for the study. By choosing unique cases from a limited sample, the maximum variation sampling method, as described by Gentles *et al.* (2015), enables a study to get different insights into social phenomena. For example, the organisations or firms are entirely different regarding project value, type, and company structure. Additionally, the problem of information management is viewed as a universal but significant problem that affects all construction sectors, regardless of their variations (Dunleavy *et al.*, 2006). Thus, the MVS strategy enabled the collection of vital and varying characteristics for each chosen company or firms and at the same time enhancing the study through diverse views and heterogeneity (Koerber & McMichael, 2008).

7.3.2 The selected case studies

The selected case studies were briefly described with a focus on their projects and how they contribute to information management in those projects. However, in accordance with the project parties' agreement to maintain anonymity, essential details that could readily reveal the identity of the project and its funders were purposefully left out of the descriptions. Below is a summary of this information in *Table 7.1.*

Table 7. 1: *Overview of the four case studies*

Company A
Company A is an engineering construction company. Initially, it has a history in house building and mining. Later, the company concentrated on civil engineering and commercial construction projects, offering a wide range of cutting-edge services throughout the whole lifecycle of clients' assets across the UK with the adoption of BIM, modern methods of construction and carbon reduction tools. Some of the company's project includes a waste-to-energy plant at Belvedere, for powering over 68,000 homes in the UK, an over £300 million project for redeveloping London Bridge station to increase its passenger capacity, and a Gas storage plant to serve over 3 million homes in the UK, among others. In addition, company A has been a champion of solving the economic and societal challenges through digital technology and integration across infrastructure, energy, water, defence, highways, rails, and aviation for over 150 years across the UK and beyond.

Area of expertise	Construction, consulting and digital partners in infrastructural projects.
Company's turnover	>£1,1700 million
Employee	>3,300
Company B	
Company B is a leading multi-disciplinary leading contractor that specialises in build-to-rent, student accommodation, civil engineering projects as well as turnkey project solutions for industries. The company have a solid reputation spanning many sectors and a passion for the latest technologies, hence being named the 'Digital-First Contractor'. It is widely known as the top "shed specialist" in the UK but is also recognised as an expert in various other fields, including student housing or accommodation, private rented sector projects, and retail and leisure developments, to name a few. Company B has offered the public standard BIM level 2 for many years. A few years back, there was a significant uptake in the request for BIM on their projects from clients, further strengthening their adoption of innovative technologies in their projects. Those projects include multi-room or retail & leisure projects, industrial warehouses, Fit-out, and Civil & Infrastructure development.	
Area of expertise	Office and commercial, civil & infrastructure, student accommodation, fit-outs works, build-to-rent, sustainable specialist builds, leisure and retail schemes including fulfilling of turnkey project needs
Company's turnover	>£750 million
Employee	>400
Company C	
Company C is a top-tier design, engineering, and project management consultancy. The company provides data-driven expertise that guarantees projects are executed on time and within budget in various sectors, including healthcare, civil infrastructure, energy, housing and resilience. Integrating all stakeholders and utilising data-driven digital technologies redefines the design process to produce better outcomes. Some of its projects include; ITER-Fusion for Energy (F4E) ITER to demonstrate how fusion energy can revolutionise how homes and companies utilise energy, Dubai Opera: A multi-format theatre with 2,000 seats. A14 upgrade, which uses numerous technologies, including 3D modelling and GIS. For the detailed design process, a digital twin—an asset database representing the natural world as a "single source of truth"—was deployed to provide contractors with relevant, meaningful site data. High Speed 2-Rail & Transit (HS2), the UK's most significant infrastructural investment project more than five of Britain's biggest cities, while reducing transit times and increasing the capacity of the network. One of the BIM functionalities employed in this project is the roles and responsibilities (RACI) Matrix to define the roles of each of the engaging parties. In addition, Carbon Management Communication (CMC) plan to provide a coordinated, consistent and informed means of articulating HS2 Ltd. project objectives across the value chain. The Canada Line-a 19km, completely automated commuter rail line forming part of Vancouver's Sky Train network services. Company C uses cutting-edge technologies to assist clients in visualising and obtaining the appropriate information at any stage of a project's lifecycle, helping them resolve problems more quickly and significantly reducing risk. Building Lifecycle Management (BLM), a collaborative strategy that assists the company in planning, designing, creating, running and maintaining an asset utilising an integrated digital mock-up as well as a single set of interoperable data. Thus, optimising the power of BIM applications through the lifecycle of clients' assets management. Utilising unique end-to-end capabilities is made possible by the building lifecycle management strategy. Company C use the various BIM systems early in their projects to communicate the appropriate information to numerous stakeholders throughout the project's lifecycle, including during O&M, when client might have to go back to how a particular thing was created if they wish to replace it or propose changes. Company C employs the BIM use cases in their projects including laser scanning, digital modelling, visual communication, interdisciplinary 3D coordination, quality take-offs, engineering and constructability analysis, 4D scheduling, 5D cost estimation, 6D sustainability analysis and 7D facility and asset management.	
Area of expertise	Health care, infrastructure, and housing projects
Company's turnover	>£2,000million
Employee	>18,000
Company D	
Company D is a group of specialist businesses, delivery construction and regeneration across the UK for the public, commercial and regulated sectors. Company D operates through five (5) divisions. They are Construction and Infrastructure (construction, infrastructure and Architectural and engineering design consultancy), Fit-Out; (property services), Partnering Housing (Lovell partnership) and Mixed-use urban regeneration (Muse Developments). To build distinctive, sustainable, and inspirational spaces for users, company D combines digital and platform design skills with BIM, modern methods of construction techniques, and innovative carbon reduction tools to execute projects.	
Area of expertise	Construction, Infrastructure, Fit outs, refurbishment, housing and property services
Company's turnover	>£1 billion
Employee	>6500

7.3.3 Sampling techniques for qualitative data collection

After the selection of the case studies, the process was followed by the examination of the cases for possible information management challenges in them in their natural setting. The study then used interviews (semi-structured) and documentary analysis to gather qualitative to obtain information from the chosen cases. The interviews and documentation were used to confirm the applicability and relevance of the theoretically stated information management approaches. The study recruited information-rich people who were relevant to accomplishing the research aims using a suitable sample technique. Construction stakeholders that matched with the study's selection criteria were chosen as the interview participants. The following is a list of the criteria used to choose participants for the qualitative phase:

- Participants in the companies chosen as case studies for this study.
- The participant's corresponding experience in the projects of the selected case studies.
- The senior managers in charge of the selected case study projects.
- Implementation of BIM in the companies' projects.
- The participants' experience with BIM projects in the selected firms.
- Team members who are familiar with the organisation of the companies.
- Participants who have been involved in BIM projects being carried out in the firms for several years.
- The willingness of the interviewee to participate in the study.

7.3.3.1 Qualitative data collection methods

(i) Interviews

Moutaskas (1994) asserts that for conducting an in-depth interview, at five (5) people and at most 25 people may be appropriate for examining a phenomenon, or anywhere from five (5) to fifty (50) (Dworkin, 2012). Dworkin *et al.* (2012) further stated that a sample of twenty-five (25) to thirty (30) is enough to reach saturation in in-depth/focus group interviews, which he said is appropriate for a thorough examination or understanding of the study’s features to address the research questions. In keeping with these viewpoints, the study recruited 36 participants who fulfilled the requirements for the study’s selection. The demographic information of the recruited participant is represented in *Table 6.1*. All participants' average work and years of experience are 28 and 3.27 years, respectively. The interview was conducted for seven (7) months. The interview consisted of a substantial number of guided prepared open-ended questions to conform with the characteristics of a semi-structured interview. Notwithstanding, the interviewee was still urged to express their thoughts on issues on BIM information management systems in a free and open manner. Thus, in accordance with Irvine *et al*. (2013), the study accommodated the participants' essential points of view on the topic. The 36 interviews were voice-recorded and lasted 2,070 minutes, averaging 57.5 minutes per participant.

(i) Documentation

Document analysis is another qualitative data collection method adopted for this study. Document analysis or document study indicates a review of written resources by the researcher, which may include personal and non-personal documents of the studied phenomenon from annual reports guides and recommendation, archival reviews, or documents from policy regulation (Russell & Gregory, 2003). It is a crucial research tool and an invaluable component of the triangulation in this study *(Figure 6.1).* Access to related papers to a study can be a tremendous task and is typically thought to be more challenging than the oral interview method. The study depended on the existing contacts established across the case study firms and data created from the analysis of papers and records related to the study to gather various relevant information about the topic. The researcher publicly accessed documents about the case study and their projects. Information was gathered from the company's employees after participants consented to remain anonymous. Other sources like visual documents and the media were also considered. However, before the study extracted information from the documents, the researcher determined and assessed the quality of the documents based on four (4) criteria as asserted by Scott (1990, p. 6) for determining document quality. These are;

1. Authenticity (Is it genuine, complete, trustworthy, and of acknowledged authorship?)
2. Credibility (Is the document error-free?)
3. Representativeness (Can it be said that the available documents are a representative sample of the original records?) and
4. Meaning (Is there a surface or deeper meaning?)

Nonetheless, the study concluded that all documents are genuine, credible, meaningful, and well-represented because the case study companies are highly profiled. This idea corresponds to Bryman’s (2004) recommendation that documents coming from institutions, companies, or organisations meet Scott's (1990, p. 6) standards for quality in terms of authenticity, reliability, and meaning. After evaluating the papers' quality, the study extracted the pertinent and significant notes relevant to the study. *Figure 7.1* illustrates the collection and analysis of data procedures in the study.

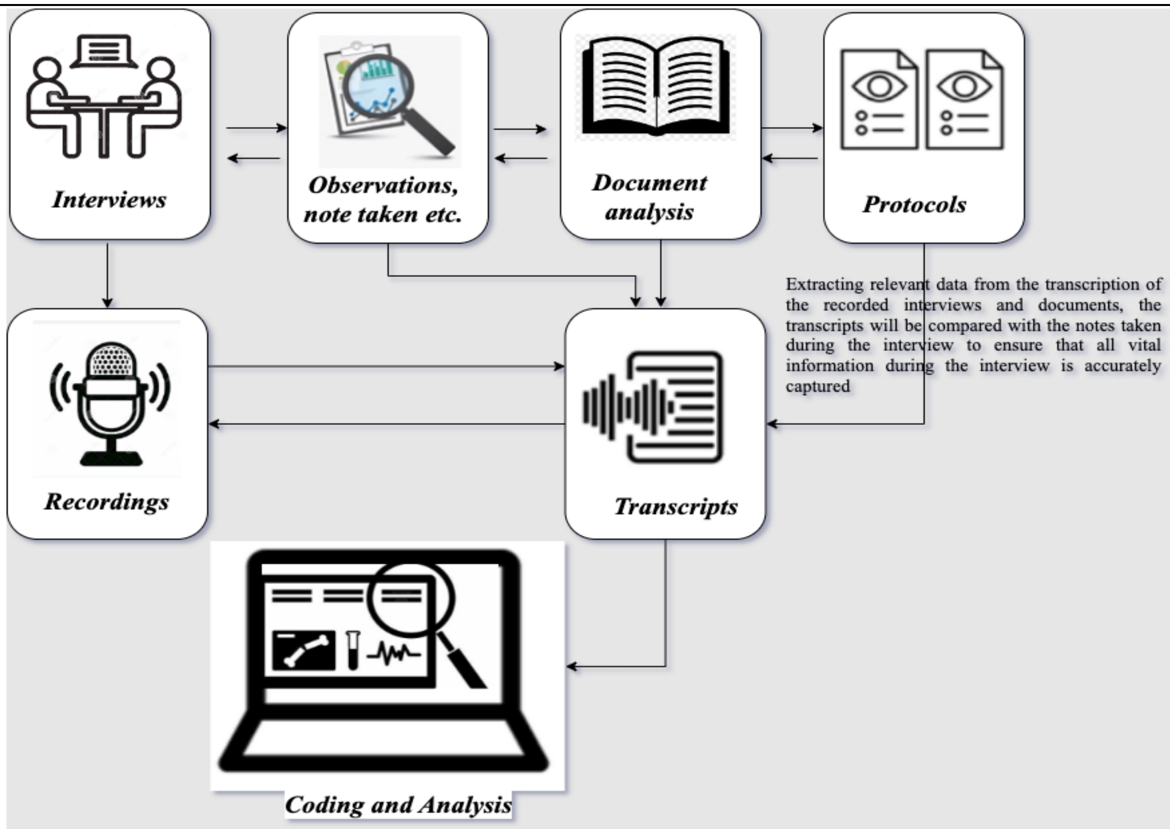


Figure 7. 1: *Illustrations of the study's data collection and analysis*

Interviews were conducted with participants who met the eligibility criteria, and their responses were recorded and transcribed. The analysis procedures started with the transcription of the recorded interview responses and relevant documents from the company's collection. While observing and noting relevant issues to the study, notes taken during the inquiry were compared to the interviews and document extracts. The responses were coded on NVivo software and then analysed after following the necessary protocols to ensure that all vital information was accurately captured as illustrated above in *Figure 7.1.*

7.4 Qualitative Analysis

This study adopted thematic analysis (TA) to analyse the semi-structured interview. First, TA was employed to determine the underlying themes/patterns in the qualitative data. Thematic analysis, a content-driven technique, permits a thorough comparison of the entire qualitative data segments for identifying correlations and schemes among recurrent themes/codes or patterns (Braun *et al.,* 2014) Usually, TA enables researchers to compile the rate of occurrence of particular themes/codes in a dataset and permits interpretation of their implication within particular situations (Clarke & Braun, 2014). Through this method, the underlying meaning of a qualitative dataset is used in combination with the qualitative data interpretation to understand the major themes (Vaismoradi *et al*., 2016). As stated above, this study used NVivo 1.6.2 in chapter 6 (software for qualitative analysis) after transcribing all interview responses to textual data *(Figure 6.3).* NVivo was specifically for qualitative research analysis with extremely rich text-based or multimedia data to perform in-depth analyses on small and big data volumes. Afterwards, the interview transcripts were coded to identify patterns in the datasets (Braun & Clarke, 2014).

The coding was done by taking into account the descriptive terminologies employed by the participants during the interview process. According to Kerr and Beech (2015), this procedure increases the analysis' dependability. Furthermore, the thematic analysis and the coding scheme clarified the various difficulties connected to information management processes or procedures crucial to the study. According to William & Irurita (1998), "a label for the category, the author's explanation of the meaning of the category and an excerpt from the raw data that clarifies the interpretation of the category and demonstrates the sort of word/text that is identified as themes in the category" are the main style for reporting categories that constitute the main findings in the thematic or qualitative or inductive analysis. Thus, the label employed for coding in this study is interviewee tag or source, context, keywords and theme category.

The interviewee tag identifies the interviewee that gave a transcript section. Theme Context coding category helps in understanding the situation from a transcript section or within the quotation segments. Keyword coding category represents a summary of the major issue arisen within a transcript section as commented by a particular participant. The keywords category helps to reveal predominant issues across the transcript and generally the participants' contributions regarding the common or prevalent issue of BIM information management. The theme category displayed the principal theme. *Table 7.2* depict an illustration of the excerpt classification in the transcript section according to the established coding scheme adopted in the study.

Table 7. 2: *Sample quotation classification in the transcript segment based on the developed coding scheme adopted in the study*

S/n	Quotation	Interviewee tag or source	Theme Context	Keywords	Theme category
	"The new concept is to work collaboratively in all aspects of the project life cycle. Collaborative tools commonly being used now are Autodesk BIM 360 and the CDE, although there are other ones, such as datum 360. Even when working collaboratively, some work needs to be done by some of the teams before others can perfect their own, i.e., ***despite working collaboratively, one output affects others' inputs, so the information has to be consistent."***	Interviewee 2	Collaboration across all project life cycles	Collaboration	Collaboration and information consistency
	"There is a ***quality system that is followed across the board in creating the information in documents****, but in terms of information management, it is more* ***project specific."***	Interviewee 4	Project specification in information quality	Quality systems	Quality assurance
	"I think the construction industry is far more complicated for information management to run smoothly*. Also, every rule has an exception, and one must agree on each change as the project progresses. Some need to be changed immediately, and one starts doing them right away, while some need to be changed later and agree on information exchanges and requests for information. Where the information is stored and needs many contacts, the review process agreed upon in the EIR and the BEP also differs for every project. So, no hard rules in information management procedures on site.* ***Rigidity is an enemy in construction, be as flexible as the project allows, and be able to accept different methods of doing things."***	Interviewee 11	Industry and project complexity	Complexity, rigidity and flexibility	Information rigidity and flexibility
	"Eventually, what to note *when generating information is the goal for which the information is generated****, which will decide what the quality of the information will be and whether the information meets the goals for which it is generated. So therefore, we put together workflows that ensure that we can check and verify the quality of the information. There are two ways this is done. First, provide the teams with a checklist (a manual process). If one is generating any information, the team is requested to tick the boxes before they can share the information. Outside that,*** *we deployed software that can check through information models to ensure that certain fields of information are filled in within the information that has been provided* ***and also checks what the format of the information is and ensures that it meets those contractual requirements."***	Interview 22	Goals for which Information is generated for.	Information generation and verification	Information generation and verification in the model
	*"The construction industry is very complicated, so it is difficult to explain the information options or process in one go****, but it usually starts with the architect submitting his drawings on the CDE. The other designers would use his designs to prepare their drawings or models, which would also be uploaded onto the CDE; the contractor would now take the drawings and provide the price/budget based on the drawings. Sub-contractors are brought here to see if they can build at that price. All the drawings and the models are submitted the same way. This goes back to the*** *design team/client/contractor after the subcontractor's price is based on those drawings, who either approve or disapprove of the subcontractor's price****. If approved, then the drawings would be used for the project. The process/protocol is not rigid or fixed and goes back and forth. It is not done***	Interviewee 12	Process of information management is complicated	Information complexity	Complexity of information management system

	by a specific body but goes to various specialists for approval. "				
	"There are issues with the non-coordinated models, so people should challenge the BIM. There are many issues with the models, contrary to what everyone thinks of them. For example, regarding the issue with the information, ***we need to be more honest when dealing with the model, have a stand-by judgement about the information.*** *If something is not right, the concerned participating team should say so, and be more consistent with whatever approach is adopted. As a collaborative approach, if anything fails, it is everybody's responsibility.''*	Interviewee 17	Honesty and fair judgement in dealing with information	Honesty and fair judgement	Uncoordinated information in the BIM model
	"*In practice, we* **set up folders for all the projects, that contain** the information necessary on the project, including the financial aspect of the project, so we store the financial information *and every other piece of information relating to the project.* ***We do not have*** any specialised software for storing the information, *but anytime the need arises to communicate the information to the other parties We communicate with the client and email the information to them. However, the company information is archived as a soft copy. "*	Interviewee 24	No clear information management strategy	Specialised information storage strategy	Siloed information according to departments. As such, no defined information management strategy
	"***For transferring information, we have a particular process as a project manager in my company to transfer information. For example, from the lead project manager to the sub-managers****, it is like a mail track where one can see whatever has been sent and responded to. Any corrections or additional information that a team member requires will be displayed in the mail track, and the recipient of the information will be indicated in red, so they will be aware that it is intended for them and needs to take action on it. The information is copied to everyone, but the person concerned to take action is denoted in red."*	Interviewee 27	Information transfer is specific to individual company	Information transfer specificity	Transferring information
	"***Currently, we use an online kind of information Microsoft share point like an information management tool for the in-house staff for the creation of the information by each consultant or participating teams****, where the information can be downloaded after being given access to the teams in need of the information. Collaboratively, we tried to get the supply chain involved earlier and the specialist so that we could make a decision earlier."*	Interviewee 29	Early involvement of participating team in information creation	Information creation	Specific Information creation procedure

7.5 Results and Discussions

The detail of the results of the semi-structured interview is discussed in this section. All the respondents state that BIM is utilised in their organisations for a variety of tasks, including the creation of 3D drawings, engineering, clash detection, laser scanning, constructability analysis, digital modelling, interdisciplinary 3D coordination and quality take-offs, scheduling (4D BIM), cost estimation (5D BIM), and sustainability analysis (6D BIM). Although a few people in the industry use BIM in manufacturing, it should be noted that the interview responses showed that just a tiny percentage of the respondents clearly understood how important BIM was to their projects in the manufacturing phase. Every respondent asked about the use of BIM in some contractor organisations stated that the client/employer have considerable authority on the projects. As a result, if a client does not know about or appreciate BIM, the contractor organisation has no demands on BIM or BIM information management processes.

Most respondents' answers emphasised the clients' lack of knowledge on BIM requirements. However, the responders emphasised that BIM provides advantages in problem-solving practices. The respondent noted that when it comes to problem-solving, BIM, mainly 3D modelling and clash detection, supported collaboration between the consultants/sub-consultants and the engaging actors, and improved engagement between the final users and client/owner in numerous ways. Additionally, BIM was considered to be effective in prioritising, organising, and minimising design errors. It was also beneficial in identifying faults and correcting them quickly. In terms of potential application, interviewers noted that BIM could be divided into information and materials, where it has the potential to be used in various areas of manufacturing, logistics and planning.

Some interviewees noted that, although there are already rules guiding the information procedures, there should also be flexibility in how the information is handled and requested by the participating team. To manage, monitor, and observe the process to ensure compliance throughout the project life cycle with respect to the rules, and to meet the quality assurance process. This is reflected in one of the interview responses as evidenced below:

"Since ease of accessibility is granted to all the teams, they have access to the information that should be available. This way, there would be flexibility to enter or edit any information or data to manage, monitor, and observe the process. It also ensures compliance throughout the project life cycle with respect to the rules to meet the quality assurance process. There is a caution to all these so that, for example, suppliers or manufacturers do not edit information in the design phase, which in the real sense should not be, so there is a rule in place to guide the process. As such, the information manager would be dealing with the people and the information because it would be part of the verification process at the end. Moreover, ensure it is the correct data to the right people rather than having everyone access everything" (Interviewee 14).

Another thing that was mentioned is the complexity of the industry as it affects the information management procedures. This is noted in the excerpt below:

"The construction industry is very complicated, so it is difficult to explain the information options or process in one go, but it usually starts with the architect submitting his drawings on the CDE. The other designers would use his designs to prepare their drawings or models, which would also be uploaded onto the CDE; the contractor would now take the drawings and provide the price/budget based on the drawings. Sub-contractors are brought here to see if they can build at that price. All the drawings and the models are submitted the same way. This goes back to the design team/client/contractor after the subcontractor's price is based on those drawings, who either approve or disapprove of the subcontractor's price. If approved, then the drawings would be used for the project. The process/protocol is not rigid or fixed and goes back and forth. It is not done by a specific body but goes to various specialists for approval "(Interviewee 12).

Participants also commented on the non-coordinated BIM model. Every participating team has their way of doing things since the numerous parties involved in building projects all have different backgrounds, histories, and goals for the project, as shown in the following statement below. So, honesty and fair judgement should exist in dealing with information in the model.

"*There are issues with the non-coordinated model, so people should challenge the BIM. There are so many issues with the model, contrary to what everyone thinks. For example, regarding the issue with the information, we need to be more honest when dealing with the model and have a stand-by judgement about the information. If something is not right, the concerned participating team should say so and be more consistent with whatever approach is adopted. As a collaborative approach, if anything fails, it is everybody's responsibility" (Interviewee 17).*

Another respondent noted that as an industry, there should be a way to attest to the level the information is growing in the industry to be able to manage the information effectively within the different projects as evidenced below:

"As an industry, we should attest to how information is becoming more crucial to manage it effectively within the projects we deliver. However, we still need to appreciate that as an industry that is growing very quickly in the digital space and going forward, if we are not careful about the way we are putting together information and ways of generating or managing information in our projects, we will quickly find ourselves back again in an environment where the construction industry is siloed under different specialisms simply because of the level of information that we are generating. If there is no collaboration in generating this information, how is it then shared and used? Otherwise, we will find ourselves with masses of information that we cannot use, generated for purposes unrelated to anything that benefits the project we deliver. So, there is certainly also a future out there that we need to be thinking about, in how what we do now, what information we

structure for this project, is going to meet the requirements of the future generation of information management of the building and infrastructure that are been put together at the moment" (Interviewee 30).

Also, the interviewees acknowledged that the client had enormous power and that BIM would not be implemented if clients did not demand or seek its usage in construction projects. They pointed out that using BIM information management is typically expensive for some projects, and contractor companies pay significant expenses when clients on these projects do not want 3D modelling or BIM on their projects. Other respondents believed that clients frequently lack BIM knowledge and skills, which leads to a lack of BIM requirements. Therefore, information management in the BIM process does not arise if BIM is not requested to be employed in a project. Most respondents noted a lack of expertise and knowledge in terms of information management in BIM, particularly regarding the usage of BIM in construction and operations. The interviewees noticed a lack of information technology (IT) knowledge within the AEC sector. Several respondents noted that the industry lacked experience and knowledge of information software, and they identified various knowledge gaps, such as the client's and consultant's lack of familiarity with information management practices and internal organisation competency.

The respondents also mentioned how challenging it was to collaborate across functional lines and share information and knowledge among several players involving varied disciplines, knowledge, and practices. According to one interviewee, comprehending the different parties in construction projects is often challenging to because each one has a unique context, history, and project-related ambitions. Given that the type of information submitted or the information introduced into the models is occasionally unclear, some respondents claimed that this lack of knowledge impedes a comprehensive information management system. Furthermore, as shown by the following statement, there is no clear definition of how information in some firms should be transferred or managed, i.e., no clear information management strategy exists.

"*In practice, we set up folders for all the projects, containing all the essential information on the project, including the financial aspect of the project, so we store the financial information and every other piece of information relating to the project. We do not have* any specialised software for storing the information*, but anytime the need arises to communicate the information to the other parties we communicate with the client and email the information to them. However, the company information is archived as a soft copy " (Interviewee 24).*

According to some respondents, moderate construction firms cannot afford to invest in BIM, including its information management strategies. Some interviewees pointed out the cost of BIM education and training as well as investments in hardware and software as part of challenges in BIM IM. In addition, it is also challenging to predict the expenses associated with BIM information management in a construction project even if the industries are willing to embark on it. Other respondents claimed that despite the usage of BIM in construction and operation, they did not see a clear benefit and that investing in BIM was not a good idea if the value was not evident from a financial perspective.

Furthermore, some interviewees argued that BIM information management software is highly complicated and challenging to use. The process became more complicated because multiple actors had to be familiar with various software platforms other than the traditional method. However, several respondents stated that skills in various BIM software would soon be resolved. But they also observed that a lot of consultants lacked access to the software as well as the technical know-how to use it. The respondents also mentioned the need for processing power and capacity for BIM software, which meant that investment in computers would be necessary to have a robust BIM information system. Many respondents also commented that the company's internal organisational structure inhibited the creation of a BIM information strategy and its use within the company. They observed that having a project to work on was significant for standard-size contractors, leaving the organisation with less opportunity for long-term and strategic planning of information management practices. Another respondent claimed that the majority of large companies had more roles to fill than other contractor firms since they had fewer resources, which meant that there was not enough time and room to learn additional skills and how to utilised the BIM-specific information management methods and requirements as captured in the following statements:

"Right now, I am working for the main contractor, but my role spans the whole project delivery life cycle, right from the first contract we get from the potential client. After that, the project is to be delivered through the BIM process. So, my role is on the business development side of things, looking to do work for the potential client, selling our services to attract new clients, and working on how BIM will contribute to acquiring the client's satisfaction. In addition, we are sometimes invited to tender on a project on the side. I work with the contractor to give the client a general requirement in response to the client's information requirements and go into specific detail about how the contractor and the supply chain will ensure the client's project is delivered and satisfied.

Moreover, to make sure that everyone in the team understands as far as the requirements of the client are concerned, they need to pull together the processes to ensure a successful project, monitor the developed design on the site to satisfy the client's requirements, and deliver a design to the site that is buildable as far as the information side of things is concerned. Furthermore, when handling over, the sets of information satisfy the client requirements and ensure that the information is useable in the operation phase" (Interviewee 26).

Along with the concerns mentioned above, a notable trend in the construction market is the overemphasis on the key financial ratios of projects while paying little attention to issues with information management and ways they might be streamlined. Other issues brought up include the unwillingness of participants to embrace new techniques of managing information, the legal implications of BIM, the lack of standardisation and interoperability, collaboration, data security and information inconsistency.

7.5.1 Data triangulation and confirmation of evidences through the qualitative studies

It was necessary to triangulate the data underpinning this study retrieved from the interview data after identifying the key themes relating to information management. Using two or more methods, theories, data sources, and researchers increases the credibility of qualitative studies involving multiple perspectives. Triangulation is one such technique that also allows for understanding an event at various levels, taking into account the complexity of the group being studied (Flick, 2011). Denzin (2009) discusses triangulation as a technique for validating research that may be used in four different ways. The first relates to data triangulation, utilising several sources of data that can be generated at various times, locations, or with varieties of individuals.

The second strategy is investigator's triangulation, which uses various researchers to reduce subjective distortions caused by a single person. The third, the triangulation of ideas, is one in which a particular phenomenon is addressed and analysed in light of many perspectives or ideas to learn more about the subject being researched. The fourth and last option is methodological triangulation, which can be employed within one technique (intra-method) or between several methods (inter-method). At least three triangulation methods to ensure credibility, reliability, and assurance of greater research rigour, according to Denzin (2009), were employed in this study. To assess the reliability of the coding scheme, additional supporting information was gathered through triangulation from various independent sources (Richards, 2014; Taylor *et al*., 2015).

For instance, evidence from the company records about each of the case studies was used in this study as confirmation evidence to verify that the themes were consistent with the gathered interview data. The study created a coding system to analyse the project documents in a way comparable to that employed for the data collected from the interview. The study then goes over the recorded data to identify aspects where the themes and coding match up with the findings from the interview. According to researcher like Creswell & Miller (2000) and Miles & Huberman (2004), this analysis technique requires a long period of time for checking, affirming, and reaffirming/disconfirming. As a result, the study demonstrated substantial convergence on information management issues previously retrieved from the literature and by merging the interviews data with the document analysis findings. The verified BIM information challenges from the qualitative investigations are presented in *Table 7.3.*

Table 7. 3: *Data triangulation and evidences confirmed through the qualitative studies*

S/n	Challenges of BIM Information Management (literature review)	Case Study A		Case Study B		Case Study C		Case Study D	
		Interviews	Documents analysis	Interviews	Documents analysis	Interviews	Documents analysis	Interviews	Documents analysis
1.	Inaccurate or incomplete information along the project workflow	✓	x	✓	x	x	x	x	✓
2.	Lack of expertise in information management strategy	✓	✓	✓	✓	✓	✓	✓	✓
3.	Insufficient information needs/requirements	x	x	x	✓	✓	x	x	x
4.	Undefined information exchange plan	✓	✓	x	x	x	x	x	x
5.	Unspecified information according to each of the project phase	✓	✓	✓	✓	✓	✓	✓	✓
6.	No information management strategy	✓	✓	✓	✓	✓	✓	✓	✓
7.	Information deficit specification due to complexity of projects	x	x	✓	✓	x	x	x	x
8.	Undefined organisational structure	x	x	x	✓	✓	✓	✓	✓
9.	Unclear pre-planning and design phase information	✓	✓	✓	✓	✓	✓	x	x
10.	Insufficient information in the construction phase.	✓	✓	✓	✓	✓	✓	✓	✓
11.	Inability to access essential information for operation, maintenance and handover phase	✓	✓	✓	✓	✓	✓	✓	✓
12.	Interoperability issues and lack of data standardisation	✓	✓	✓	✓	✓	✓	✓	✓
13.	Unspecified cloud-based information storage	✓	✓	✓	✓	✓	x	x	x
13.	Non-early involvement of all participating team all through the project phases	✓	✓	✓	✓	✓	✓	✓	✓
15.	Non-coordination of information in the BIM model	✓	✓	✓	✓	✓	✓	✓	✓
16.	Complexity of information management process	✓	✓	✓	✓	✓	✓	✓	✓
17.	Siloed information according to the department that created the information	✓	✓	✓	✓	✓	✓	✓	✓
18.	Information rigidity	✓	✓	✓	X	x	✓	✓	✓
19.	Lack of human knowledge/expertise in information management process	✓	✓	✓	✓	✓	✓	✓	✓
20.	No information management tool	✓	✓	✓	✓	✓	✓	✓	✓
21.	Insufficient information in the project workflow	✓	✓	✓	✓	✓	✓	✓	✓
22.	Lack of collaboration and information inconsistency	✓	✓	✓	✓	✓	✓	✓	✓
23.	Lack of honest and fair judgement in dealing with the generated information on site	✓	✓	✓	✓	✓	✓	✓	✓

24.	Unestablished goals for the generated information	✓	✓	✓	✓	✓	✓	✓	✓
25.	Inadequate quality checks and assurance along the project workflow	✓	✓	✓	✓	✓	✓	✓	✓
26.	Ineffective site inquiries and interactions	✓	✓	✓	✓	✓	✓	✓	✓
27.	Unmanaged information in the early project phases for availability in the subsequent phases	✓	✓	x	x	x	x	✓	✓

The above table summarises the challenges identified in the reviewed literature and confirmed by the semi-structured interviews and the document analysis. According to the interviewee, challenge "1" was evident in case study "A," where the information for the designers, for example, was accurately represented as agreed in the contract. Hence, challenge "1" was well-represented in the documents analysed for case study "A" but a challenge according to the interviewee analysis. For case study "A", this implies that the information was not accurately represented, and the parties were not well-informed about the needed information during the project to efficiently carry out their work. Hence, in the above table, inaccurate information along the project workflow was a challenge according to the interview analysis in Case Studies "A" and "B" while it was not for case studies “C” and "D." On the other hand, the other challenges such as 4, 5, 9, 10, 11, 13, 14, and 15 were clearly identified as challenges in both the interview and document analysed in the four case studies, as shown in the above figure. These challenges were all considered in the development of the schema.

7.6 Chapter Summary

The qualitative (exploratory research approach) study used in this study was discussed in this chapter. The study started with a review of the literature to identify various information management challenges in BIM. Next, the findings of the literature review were confirmed with a multiple-case study strategy. These include case studies of four construction companies in the UK, semi-structured interviews, and documentary information from the companies. Each of these approaches was discussed in this chapter, including the methods of collecting and analysing data.

Chapter 8

8 Development of the Information Management Schema

8.1 Chapter Overview

The chapter examines the development of the proposed BIM information management schema to improve information management on construction sites. It addresses information requirements, information exchange, and information delivery during the preliminary design, design, preliminary construction/construction, handover and close-out, and operations and maintenance phases of a construction project in a BIM environment. These components of information i.e., information requirement, exchange and delivery are crucial to the proposed information management schema. The terms used throughout this section have been discussed in Chapter three (3) of this study including BIM information management terminologies and procedures. By being aware of these information components, the administration and request of information throughout the construction project life cycle would be enhanced and improved. The chapter also offers a strategic perspective on BIM information management systems.

8.2 Information Component at the Project Life cycle

The BIM model uses a variety of formats to provide information about a project at various stages of its life cycle. DWG, DXF, RVT, and IFC are a few examples of this type of format. By representing the overall information digitally in a data repository throughout the project life cycle, BIM is viewed as a tool for efficiently using information from the beginning to the completion of a project. The subsequent sections explore these stages.

8.2.1 Information components at the pre-design phase

The initial phase of a project's development is the pre-design or programming stage. The principal players at this stage are the owner, the architect, and his design team. After examining the client's brief, the architect and owner determine the requirements for the project's development. This phase's main objectives are to develop a thorough grasp of the project's constraints and a plan for the project's implementation. The architect and his design team assess the project's chosen site during the pre-design phase. They thoroughly assess any applicable zoning regulations or restrictions regarding the project's construction, and they consult with the client to decide the programs or uses that would be included into the design. The design team better understands the project's capabilities and restrictions due to this initial information-gathering process. The initial goals of the design would be established using the data gathered. The information component in this study is divided into four (4) parts. They are site survey, geotechnical data, zoning and preliminary building codes, and information about the project and scope, as presented below in *Table 8.1*.

Table 8. 1: *Components of information at the pre-design phase*

Information Components at the Pre-Design stage			
Site Survey	***Geotechnical information***	***Zoning and preliminary building codes***	***Information about the project and scope***
Site selection	Geological conditions	Zoning analysis	Owner-architect agreement
Land survey	Topography	Existing building assessment	Specification and procedures
Site analysis	Access points for water, gas and electricity	Laws and regulation	Construction scale
Environmental policy	Economic and technical indicators	Government services and limitation	Cost structure
		National and local policies	Structural form

8.2.2 Information components at the design phase

This stage's information component includes what goes into the design. The activities that take place at the design phase have a considerable impact on the information components at this stage. Through the use of the model, this design stage information is anticipated to show the intention of client about the project he wants to develop, including the functional needs and project standards. To ensure the client's goals are maximised, all stakeholders associated with the project must work collaboratively across disciplines. The stage comprises those activities in which the owners plan, create, bid, and contract out the project, as well as sign the bid and the contract documents with designers, consultants, supervisors, contractors, and other parties involved. It also calls for conducting hydrogeological investigations and supplying design guidelines, schedules, and budget estimates. The information components at the design phase are classified into three groups in this study depending on the design content. As stated in *Table 8.2* below, they are information regarding survey and design, information regarding bidding and contract, and information regarding finances.

Table 8. 2: *Components of information at the design phase*

Information Components at the Design Stage		
Information on survey and design	***Bidding and contract details***	***Financial details***
Investigation of Hydrological data	Prequalification documents	Human, material & machine resources
Technical and design documents	Tenders for survey and design	Design estimates
Schedule and specification of the design	Contract for survey and design	Construction budget
Auditing information of preliminary and technical design	Work force /labour details	
Construction drawing review information/details		
Designs of different professionals		

8.2.3 Information components at the construction phase

As a result of the dynamic nature of construction management and guideline, a vast amount of information is included in the implementation phase or construction information components. Since it is essential to accurately and successfully execute the design, the plan of work at this stage frequently takes the longest. The owner, designer, supervisor, contractor (general and subcontractor), suppliers (material and equipment providers), and related government departments are typically involved. As shown in *Table 8.3* below, the information produced by these activities is diverse and complex. It is divided into six (6) categories such as basic information, resource information, construction information management, ecological/environmental information, technology information/IT details and details of related projects.

Table 8. 3: *Components of information at the pre-construction/construction phase*

Components of information at the construction phase					
Basic Information	***Technology information/IT details***	***Construction information Management***	***Resource information***	***Ecological/Environmental Information***	***Details of related project***
Departmental Laws & regulations	Construction logs and records of quality assurance	Site layout and construction plan	Demand and allocation schedule	Natural environmental information	Structural/construction scale/form
Technical standards	Organisation structure for construction	Notice of site meetings	Material and equipment supply schedule	Legal environmental information	Budget structure
New process & technology information	Technical knowledge	Negotiation records	Payment and material information consumption records	Physical environmental information	Treatment effect and geological conditions
Environmental information	Planning and construction management	Construction schedule/specification	labour, materials and equipment charge	Economic environmental information	
Engineering solutions	Main materials, components and equipment test report	Contract and actual cost		Cultural environmental information	
Architectural, structural, plumbing, electrical designs	Standards and construction technology	Cost analysis and control plan			
Bidding & contracts documents	Construction quality assessment	Security details			
		Health/safety checks and measures			

8.2.4 Information components at the operation phase

At this stage, the information component includes details regarding operating and maintaining a construction project or the built asset. The information not only provides owners with a stylish and relaxed environment but also ensures the efficiency of construction components and accomplishes sustainability of the process. During this operating phase, information components were generally made up of the key activities at this stage, which can be classified into three types. They include general, construction, and facility management information, as shown in *Table 8.4* below.

***Table 8. 4**: Information components at the operation phase*

Information Components at the Operation Phase		
Basic information	***Construction-related information***	***Facility management-related information***
National and local policies and regulations	Property and technology from contractor	Information on owners' meeting and committee members
Regulations issued by the relevant department	Rental and property management agreements	Information about the facilities' internal environment
	Conventions for filing and fee payments	Information about residential facilities and vehicle management
	Records of meetings and complaints	Information for buildings maintenance
	Personnel files, additional papers	Information on the configuration, specifications, and operations of the equipment.
	Information about the construction (spatial structure performance and general layout)	Daily facility management, equipment upkeep, and maintenance
		Building maintenance schedule/plan
		Real value information
		Assessment of facilities and equipment,
		Property cost information, payment and receipt
		Security scheduling plan & regulations for managing public security
		Information about fire channels and escape routes

8.3 Information Requirements

The client first defines the information requirements in a BIM project. ISO 19650 specifies these information requirements, as discussed in chapter 3. ISO 19650 states the information requirements for a project's establishment, input definition, and all procedural directions in the BIM process. Each organisation and project must develop sound information requirements to acquire higher-quality information delivery and to design and construct better. The components of the definition of "Information Requirements" are explained below. The definition broadly considers information flow and exchange, and information delivery as essential for the information requirements of project life stages.

1. The information requirements outline the tasks that the provided information is used to complete.
2. Establishes the event for which the information is supplied, which can be a project milestone's deadline, in which case, the information requirements must be established as soon as possible.
3. The format in which the information would be conveyed in terms of format, content, and presentation is defined. The information requirements would be set up so that automated checking rules could be implemented.
4. The recipient of the information which could be a group, an individual, or a company. The appointing party/the lead appointed party receive information from the appointed parties.

According to information requirement in the BIM process, the above definition is explained under 3 topics as discussed below.

The information required for the clients' organisation: The requirements for the client's organisation outline the data required to support facility management at the organisational level. AIR is created from OIR and informs the PIR, as seen in *Figure 8.1* below, as discussed in Chapter 3 of this study. According to ISO 19650, the OIR describes the organisation's asset management system and other organisational functions that gives inputs to the AIR, making it the only source of input to the AIR.

The information required by the organisation under contract describes the OIR for external contractors involved in the project. The AIR and the EIR are detailed information requirements for construction projects, also known as the "appointment information requirements" (ISO 19650-1). The EIR outlined the data project teams were to produce along with the procedures to be used for construction projects. In connection to a particular asset or assets, AIR lays forth the project-specific details about external contractors and internal participating teams.

The information requirements from the contracted organisation: The AIM and PIM perform different functions, as explained in chapter 3. An AIM is a single source of digital information related to a facility in the O&M phase of a project, while PIM information is related to a facility in the planning and development phase of a project (design and construction). While the PIM information is generated for the new construction assets or the modification of existing assets, the information needed to create the AIM is defined in AIR, which determines the AIM's content, structure, and methodology.

Organisations require OIR information to function at the organisational level; AIR and AIM information to function at the asset level; and PIR, EIR, and PIM information to function at the project level. This is shown in *Figure 8.1*, comprising the components that define information requirements throughout the project life cycle.

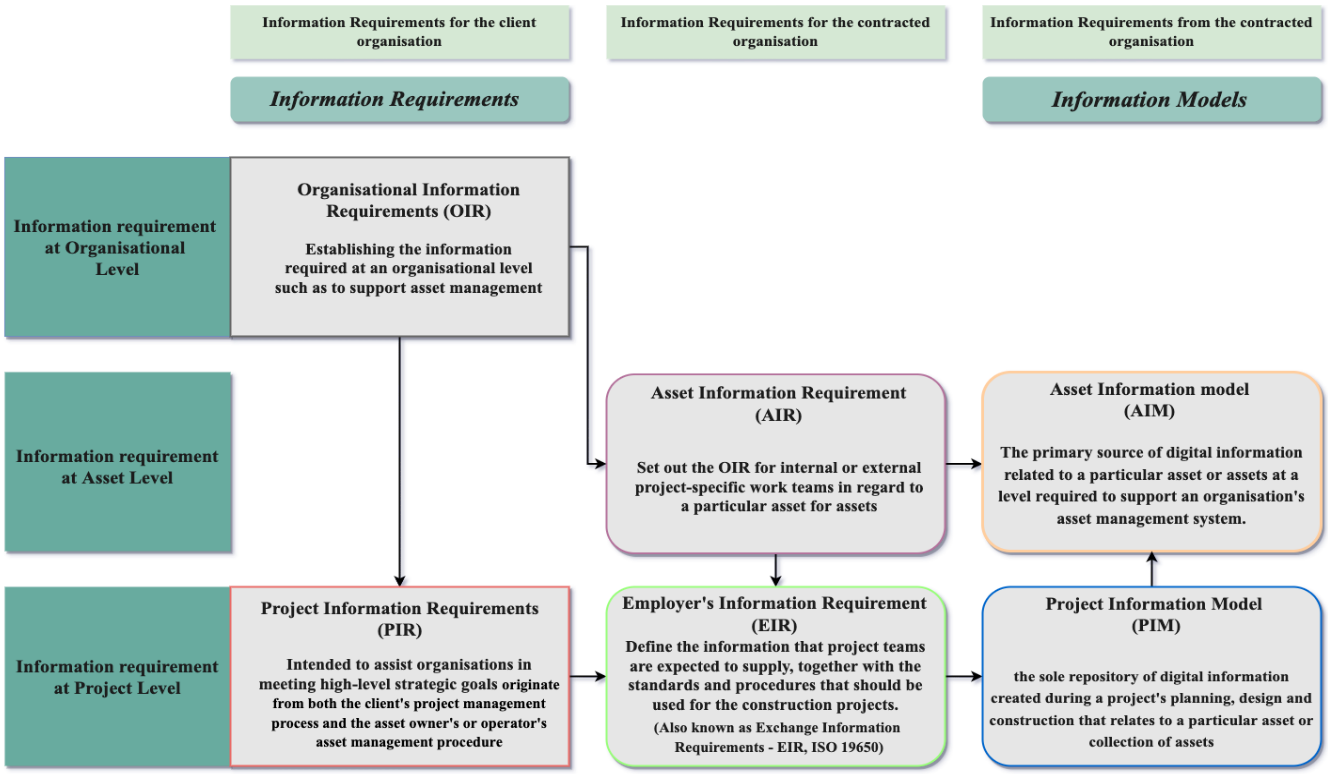


Figure 8. 1: *BIM information requirements at the project life cycle as defined by PAS 1192-2:2013*

8.3.1 Information requirement development

Due to the collaborative nature of BIM, it is critical to obtain the input of all interested parties at the information requirements stage throughout the project life cycle. The reviewed literature and case study investigations highlight the challenges in BIM information management. Among the challenges is interoperability, and if the information requirement stage is effectively defined, this issue could be avoided. The relevant parties require a representative with sufficient BIM experience to ascertain and update these requirements.

8.4 Information Flow and Exchange

When working on a BIM project, many issues frequently come up. This paper has discussed a few of the issues. Whether it was the architect who was at fault for altering the original design concept or the engineer who was at fault for producing a model with excessive complexity at a relatively early design stage is uncertain. It is challenging to provide a satisfactory response, but the planning of information exchange throughout the project life cycle is at the root of the issue. A simple definition of *information exchange* is transferring and distributing information from the information model to the various participating teams. PAS 1192-2: 2013 defined information exchange as "structured information gathering with a predetermined format and level of fidelity at one of many pre-specified project stages" (PAS 1192-2:2013). The EIR would specify the points of information exchanges by referring to the established stage and gateway terms. The information contained in the information model would be shared and exchanged in a multidisciplinary setting and per the purposes for which it is to be used to express its worth (Hattab & Hamzeh, 2013). The flow of information/information flow throughout the project life cycle improves information exchange from a specific project stage to the next. As such, information flow and exchange involve exchanging ideas and instructions across the project life stages. Therefore, information flow and information exchange will be discussed simultaneously in this study. This section discusses information flow and exchange during the project life cycle in the BIM process.

8.4.1 BIM objectives for the project

Before determining BIM uses, the project team outlines the project objectives by defining the value of BIM adoption on the project and any potential connections to the implementation of BIM. The objectives of the project would be project specific, quantifiable, and aimed at enhancing facility planning, design, construction, and operation success. For example, one type of project goal or objective might have to do with the project's overall performance, such as reducing the project's timeline, cutting expenses, or enhancing the project's overall quality. An instance of such a goal is shown in *Table 8.5.*

Table 8. 5: *An example of goals in BIM projects (Adapted from Messner et al., 2011)*

	Project Goal Priorities [1- most important, 3-least important]	Possible BIM or Model Uses
1	Maintain high standards for the all-design documentation and design	Design authoring, reviews/3D coordination
1	Organisation of the access of the asset's occupants.	4D modelling
2	Maximisation of the installation of field productivity	Design reviews, 3D Coordination
2	Accurately monitoring the development of the construction	4D Modelling
2	Creating an exact record of the final design of the project for use in prospective renovation initiatives.	Record Modelling/model, 3D Coordination
3	Review the modification of the cost implications accurately and promptly.	Design Authoring, Cost Estimation

Before defining the information exchanges, the team would first comprehend the type of information required to deliver each use of BIM. A typical example of BIM use or model use cases all through the project life cycle is discussed and shown in chapter three *(Table 3.10)* of this study.

8.4.2 BIM or model use

Through industry expert interviews, case study analysis, and a literature review, twenty-four (24) BIM or model use cases were discovered and improved, as shown in *Table 8.6* below. There are more likely uses of modelling applications that might be used on a project, so team knowledge should not be limited to the ones in this study. Also, it is essential to keep in mind that while some or all of the mentioned model uses are being used on projects, very few teams would use all of them. The model used in the National BIM Guide for Owners has been incorporated into the identified model used in this study. The team should strongly consider implementing these uses.

Table 8. 6: *BIM or model uses as adopted in the study*

Project plan	Project design	Project construct	Project operation
Modelling of new or existing project condition			
Estimating cost	Estimating cost	Estimating cost	
Programming			
Design authoring	Design authoring		
Design/plan reviews and records	Design/plan reviews		
	Energy analysis		
	Structure and engineering analysis		
	Phase planning		
	3D coordination	3D coordination	
		Site utilisation planning	
		BIM-to-field	
		3D planning and control	
		Record modelling	Record modelling
			Project maintenance schedule
			Project system analysis
			Management of space and tracking
			Asset management
			Disaster planning

8.4.3 Describing the BIM uses

The description of the BIM usage follows the establishment of the uses. It is specifically available for all BIM execution project. As this is a standard set for BIM projects, the study would adopt the same description. The standard descriptions gave a quick overall view to the project party unfamiliar with BIM use and further details that might be useful to the party throughout the selection process. Each individual description contains a summary of the BIM use, possible advantages, necessary team skills, and other means that may be consulted for more details on the BIM use. A typical example of BIM use description is presented by Messner *et al.* (2011) as shown below in *Table 8.7*.

Table 8. 7: *Example of descriptions of BIM uses for cost estimation (Adapted from Messner et al., 2011)*

BIM Use: Cost Estimation
Description of the BIM use: • A method where a BIM model can provide an acceptable and accurate quantity take-off and estimate of cost earlier in the design stage, as well as cost effects of modifications and improvements with possible cost and time reduction to avoid budget overruns. This procedure enables designers to see the cost implications of their changes promptly, which can help reduce unnecessary budget overruns due to modifications of project.
Possible Value: project or process improvement • Precise quantities estimating material to create a quick cost revision. • Be within the budget limit with constant preliminary cost estimates throughout the design progression. • Improved visual project image and construction components that should be costed/estimated and taking off • Providing improved/better cost information to the client earlier in the design process to make a timely decision • Concentrate on added value activities in the estimation process, such as establishing construction assembly, creating costing, and eliminating risks necessary for quality estimation before taking off. • Defining various design alternatives and ideas in line with the stipulated client's budget. • Reducing the estimator's time to focus on other vital issues in the estimation process as quantity take-offs can be automatic. • Quick access to determine the cost of precise/unique objects in relation to the client's choice
Required Resource: • Software for the estimation • Software for design authoring • Project cost details/information
Required skills • Skill for defining the exact design modelling procedures to yield reasonable information for quantity take-off • Capability for quantities identification for correct estimating level • Capability to manipulate the models for the required quantities for the estimation process

8.4.4 Designing the BIM process

After the BIM uses are identified and their descriptions provided, the BIM process design would highlight the scheduling/sequencing and coordination of the various BIM uses in the project. The participating teams could understand how their work processes is related to the other team members. Additionally, the points of information flow and exchange are identified. A typical information flow through a BIM implementation project is adopted in this study for the development of the schema.

8.4.5 Defining the information exchanges

It is important to explicitly identify the information exchanges between project participants after defining the BIM implementation process for the project. Each information exchange interaction necessitates a thorough detail of the relevant information by the participating parties, most especially the sender and recipient. An example of the information exchange table, called the information exchange worksheet, is displayed below in *Table 8.8*, which allows for the definition of information content for the exchange.

8.4.6 Information exchange worksheet

An information exchange spreadsheet is created to specify the information required to deliver each BIM use or model use. A blank instance of the information exchange worksheet (IEW) in Microsoft Excel format is shown in *Table 8.8* below. After establishing and detailing the BIM process, the IEW need to be done early in the project to avoid complications during the deployment of each BIM or model use and defining the required model components. The information-sharing worksheet can be developed in several ways. The procedure for establishing a typical IEW is provided below.

i) Establish the information exchanges by applying a standard BIM process.
ii) Select a model element breakdown structure (CSI Uniformat structure or OmniClass) such as it is in the example shown below in *Table 8.9* to use in the process, which could be described in terms of the work's structure, such as a sub-structure or super-structure.
iii) Determine the information requirements for each input and output exchange, including the model file type, model receiver, and information.
iv) Assign responsible parties to author the necessary information, such as an architect, a contractor, a civil engineer, or a structural engineer *(Table 8.10).*
v) Determine the input and output information requirements to be compared for consistency.

Table 8. 8: *A blank example of the information exchange worksheet (Adapted from Messner et al., 2013)*

	Information Exchange
	Information
A	Accurate size and location includeing materials and object parameters
B	General size and location with parameter data
C	Schematic size and location

Discipline (OmniClass Table 33)	
11	Planning
21	Design
25	Project Management
31	Surveying
41	Construction
55	Facility Use Disciplines
81	Support Discipline
99	Other Discipline

BIM use title	Phase planning		Energy analysis			Cost estimation			4D Modelling		
Project stage	Design		Design			Construction			Costruction		
Time of exchange (conceptual design, schematic design, detail design, construction)											
Responsible party (receives the information)											
Receiver files format											
Application and version											
Model Breakdown Structure	Responsible party	Notes	Information	Responsible party	Notes	Information	Responsible party	Notes	Information	Responsible party	Notes
01 Sub-structure											
10 Foundations											
10 Standard Foundations											
20 Special Foundations											
20 Sungrade Enclosure											
10 Walls for Subgrade enclosure											
40 Slabs-On-grade											
10 Standard slabs-on-garde											
20 Structural slabs-on-grade											
30 Slab Trenches											
40 Pits and bases											
50 Slab-on-Grade Supplimentary Componenets											
60 Water and Gas Mitigation											
10 Building Subdrainage											
20 Off-Gassing Mitigation											
90 Substructure Related Activities											

Table 8. 9: *A Blank instance of the Model breakdown structure based on Uniformat II (Adapted from Messner, 2013)*

Model Breakdown Structure									
01	Sub-structure								
		10	Foundations						
				10	Standard Foundations				
				20	Special Foundations				
		20	Sungrade Enclosure						
				10	Walls for Subgrade enclosure				
		40	Slabs-On-grade						
				10	Standard slabs-on-garde				
				20	Structural slabs-on-grade				
				30	Slab Trenches				
				40	Pits and bases				
				50	Slab-on-Grade Supplimentary Componenets				
		60	Water and Gas Mitigation						
				10	Building Subdrainage				
				20	Off-Gassing Mitigation				
		90	Substructure Related Activities						

Table 8. 10: *Responsible parties in the study*

Responsible Parties	
CLI/OWN	Client/Owner
ARC	Architect
CON	Contractor
CE	Civil Engineer
FM	Facility manager
QS	Quantity Surveyor
SE	Structural Engineer
TC	Trade Contractors

8.4.7 Software and information exchange formats

BIM uses standards such as IFC, COBie, XML, IDM, MVD, IFD, and so on to facilitate information exchanges and ensure that all parties are coordinated *(Figure 2.14).* As a result, applications that can collaborate are required in information or data exchange (Pauwels *et al.*, 2017; Kim *et al.*, 2015; Pauwels *et al.*, 2011). Interoperability via exchange formats greatly influences the ability of diverse programmes to transmit data. Interoperability encompasses the exchange of meaning between the data and the data itself. The data provided comprises, in addition to images, energy charts, quantity, material, and cost tables, structural designs, and geometrical components. Direct and parametric modelling could be employed to create information models (Tommasi, Achille and Fassi, 2016).

Parametric modelling conveys information in the form of a nD BIM object-oriented/generative model (iBIM). Representation of objects that are presented by algorithms are present in generative models. In order to address challenges that may occur, object-oriented models employ techniques to describe items with related outlines but variable orientations and locations. Object-oriented modelling is premised on pre-made elements libraries to provide information about a model's physical, mechanical, energy, and other properties. The completed BIM model delivers information to everyone involved for the required purposes and is linked to an information database. BuildingSMART, an international organisation, is in charge of standardising BIM processes, workflows, procedures and adopting and developing data format technologies all through the life cycle of projects. BuildingSMART shows these ISO-certified standards, which cover every level of interoperability in the BIM environment. IFC, an interoperability and data exchange file format may be utilised to access data created by several program, including Revit, Archicad or Allplan making it possible to move the information/data or open it via a separate operating system with another software (Yalcinkaya & Singh, 2015).

The above standard, i.e., IFC, defines the various levels of interoperability. Understanding the interoperability environment requires matching the relationships between the data exchange formats. In the interoperability environment, relationships between model producers from the same or different professions, those employing the same or separate workspaces, and those not using BIM software may exist (Succar, 2009; Bryde, Broqentas, and Volm, 2013). Because of the powerful connection that limits or facilitates the efficient sharing of information, interoperability is a critical prerequisite for BIM deployment in projects (Grilo & Jardim-Goncalves, 2012; Cerovsek, 2011; Goedert & Meadati, 2008). Unfortunately, there are still instances of data loss and inaccuracies (Jeong *et al.*, 2009), which this study aims to improve. As a result, software and information-sharing formats and forms for information transmission between the various parties were designed for each BIM used in this study. The CDE is required for information exchange so that all parties involved can access the information. The exchange format criteria were considered to include both the output formats and those supported by the software (i.e., rvt., IFC, and COBie). Because most software used during project stages requires a BIM model as an input, accounting for this is critical to eliminating interoperability challenges. The output format is also crucial for the parties who will get the outcome of an action. The following list of considerations is provided for each phase.

- ***Pre-design Phase:*** The parties' BIM-based design modelling tools should be compatible, OpenFormat such as IFC.
- ***The Design Phase:*** This is the same format for delivering the pre-design phase.
- ***The Construction Phase:*** The software employed for construction may vary depending on the project. BIM-to-field, 3D coordination, 4D simulations, and other uses are examples. A project may have a variety of software alternatives for each field. According to Sacks *et al.* (2018), it is critical to specify the software used for each BIM application to check the permitted formats. If one party, such as the design team, accepts an open format such as IFC, it must be declared in the deliverables for that team. Furthermore, responding to the requests for information (RFIs) should be prompt to avoid delay and agreed upon by all parties involved during the construction.

- ***Handover*:** The handover would use the same format in which the as-built model would be provided.
- ***Operation and Maintenance:*** The format to configure the system and establish whether it will receive COBie data is used in operation and maintenance. However, if this is not the case, a new mechanism for transferring data and information from the BIM process to facility management systems should be defined. In that case, the appropriate party would be appointed to manage the information linkage, and if the programme changed, the relevant training might be considered.

Although different types of data are exchanged during project phases, it is critical to agree on and establish an agreement on information exchange formats with parties to avoid losing the accuracy of the information.

8.5 Information Delivery

Each lead appointed party and appointed party is responsible for delivering information. Plan of action should be produced to acknowledge the information requirements of the appointing party that would represent the scope of the appointment across the entire project life cycle. Each information delivery method would consist of the following components:

- The information that is necessary to meet AIR or EIR standards
- The information that would be provided
- The information that is delivered at the time it is required to provide the information, first in terms of project phases or asset management milestones and later in terms of the precise delivery dates.
- The party in charge of distributing the information
- How the information is integrated with information from other appointed parties is defined.
- The party who will receive the information

The processes indicated above are part of the information delivery planning that takes place before the appointment by the appointed party/lead-appointed party. It is also a component of the appointing party's assessments. If the appointment is established as part of mobilisation and the information requirements or delivery team are altered, the information delivery procedure normally requires additional clarification. Predefined information exchanges would be used to deliver information. Sharing of information is part of the role of the appointing, the lead appointed parties and the appointed parties. One of the conditions for completing the information management activity would be the distribution of the information. Each data container would be linked to one or more predefined data requirements. The PIM helps with project information delivery and contributes to the AIM *(Figure 8.1)* to help with lifecycle information management operations. A schedule for information distribution would be developed for the entire project or the project's short and medium terms, depending on the timing and appointment of the parties. In more complex cases, this would be accomplished by integrating the delivery plans for each project activity. Each information delivery plan would include the time of each information delivery and references to project life cycle management schedules, wherever available. A responsibility matrix or model production delivery table (MPDT) is created as part of the information delivery need *(Figure 2.12).* As applicable, this would include information management functions, information management responsibilities, or information deliverables.

8.6 Information Management

Information management is vital to the proper functioning of construction projects. It facilitates the collection, storage, dissemination, archiving, and deletion or destruction of data. Efficient information management ensures that the appropriate personnel gains access to the appropriate information within the appropriate timeframe, allowing for wise decision-making. It is usually delivered continuously and remotely and allows participants to schedule and manage their time and resources most efficiently to achieve the specified goals. As discussed in this study, clients/owner, consultants/subconsultant, contractors/subcontractors create massive amounts of information during construction projects, necessitating the use of information management systems for standard protocols/automated systems-generated information.

The initial phase of information management is the development or gathering of information, which includes documenting the demands of the clients and other teams engaged, exchanging the information thus produced, and distributing the information to achieve the desired goal. The Construction Project Information (CPI) documents, which are used to manage information, are created via the Construction Project Information Exchange (CPIx). In addition, PIP, TIDP, MPDT, MIDP, and BEP are used for information management, as discussed in Chapter three. The management requirements include the standards for information management, the functions and duties of each party, the quality control procedure, the owner of the BIM model, the BIM uses, and the project output.

- *Information management standards*

The appropriate standard in BIM projects would guide this study *(Table 3.8).* The goal is to provide a standardised approach for ensuring that all parties follow industry standards. The adopted standards must be consistent with the project's location standards and guidelines. *Table 3.8* of this study provides a summary of the standards. The responsible parties *(Table 8.10)* would ensure that the approved standards are consistent with the implemented standards.

- *Party responsibilities*

For each phase of the project, each party's responsibility for each task in the information flow and exchange is established. An MPDT, or responsibility matrix, is created for the work *(Table 2.12).* It is vital that the parties agree on and set explicit duties when starting the project to avoid conflicts with task ownership/BIM model ownership.

- *Quality checks and verification*

A model and data coordination system would be established to guarantee the quality of the exchanged information (section 3.4.4). Throughout asset management, the model and data, as well as other agreed-upon and required information, are delivered to the parties to fulfil their tasks, particularly the facility managers and contractors. The processes, responsible parties, and quality control milestones are stated in the specifications to ensure the success of the information used and operated during the construction and operation stages. Various types of verification and checks to ensure the quality of the model information have been covered in Chapter three, as mentioned in section 3.4.4.

- *The BIM or the model uses*

The BIM applications for the project stages are determined at this phase to establish any additional requirements, such as necessary exchange formats, the responsible party, and necessary BIM models. *Table 8.6* indicates the BIM use cases used in this study.

- *Owner of the BIM model*

The agreement in the contract should state who owns the models, who has rights to them, and how they can be used. The ownership of the information, ownership of the BIM models, authority to use the model, authority to update the model, and responsibility for the information on the models should all be identified. All parties' ownership would be publicly acknowledged to avoid disagreements before and after the project. In addition, the agreement would specify whether models might be altered for the construction project and who could do so. *Table 8.11* below summarises the information management activities and authorities of the different parties in the project management process.

Table 8. 11: *Information management and exchange of activities in the delivery process as defined by PAS 1192-2:2013*

ACTIVITIES						
Information Manager	**Project delivery manager**	**Lead designer**	**Task team manager**	**Task Information Manager**	**Interface manager**	**Information originator**
Establish a common data environment to ensure reliable information exchange.	Ensure that information exchanges are appropriately delivered	Delivering all design information in a coordinated manner	Design outputs that are pertinent to a task that is time-based, package-based, or discipline-specific are produced.	Manage the creation of task information in accordance with processes and standards	As a task team representative, the interface manager will be in charge of spatial coordination.	Create specific tasks according to the individual components of the information model.
Supervise and accept data into the Information Model	Authorise vendors' capacity to deliver information requirements.	Control the production and approval of information.		Adopt agreed-upon systems to control the establishment of task information.	Provide-solution for trade coordination conflicts	Production of project output
Permit coordination and data integration inside the Information Model.		Confirmation of the design outputs				
Establish project information outputs		Overall leadership and management administration				
Choose a format for the Information Model's information exchange.						
AUTHORITIES						
Accept/reject the exchange of information in the CDE	Accept/reject the information exchange in the CDE	Approve the quality information for distribution inside the CDE	Deliver verified information within the CDE	Verification of suitable information for issues in the CDE	Resolve suggested clashes	Information Model ownership
No legal power or right to give instructions		Approve proposed design alterations to overcome clashes.				

- *Project output*

Each project's output would include information delivery format, level of development, information demands or requirements, data type, and delivery stages.

8.7 Information Management Schema

The proposed information schema would be created to establish the information management systems as mentioned above, incorporating the information components, requirements, flow and exchange, and delivery. They are divided into layers: the information component layer, the information requirements layer, the information flow and exchange layer, and the information delivery layer. These four layers are considered critical to the development of the information management schema. Each of the four layers will first be discussed in detail to show their components. The subsequent sub-topics discussed the components of each layer and how they contribute to the schema development in the project. *Figure 8.2* represents the graphical representations of the developed schema. The graphical representations act as the legend employed in the development of the schema.

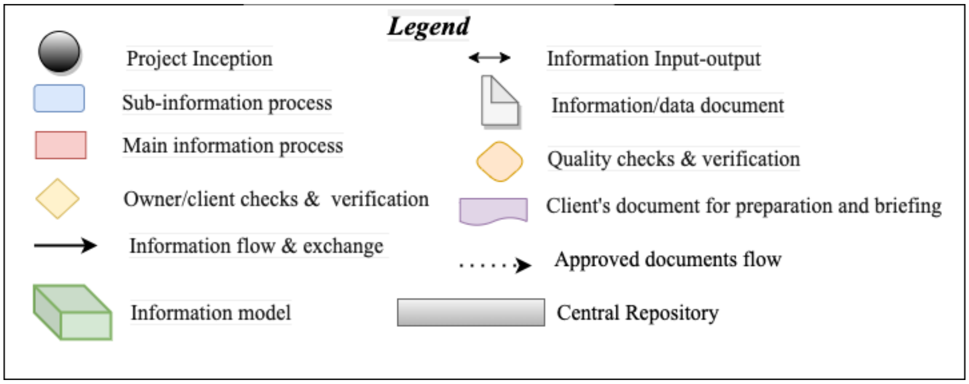


Figure 8. 2: *Graphical representations in the schema*

8.7.1 Information components layer

The information component was generated at each level based on the established information in each stage, as shown in *Table 8.1.* As BIM is viewed as a tool for efficiently using information from the beginning to the end of a project by representing the information digitally or data repository containing all project life cycle information, the schema would be established from the programming/pre-design (preparation and briefing) stage. Establishing the information components earlier in the project phases would provide a clear indication of the information that must be satisfied before the client approves the project. This would allow the architect to develop his design concept based on the approved project site data provided by the owner or client. At this stage, all participants are involved, but the architect and the client are the main players. As indicated in *Table 8.1*, the information component at this stage consists of site information, including site surveys, geotechnical information, zoning and preliminary building codes, and information about the project and its scope.

Each piece of information would be verified to ensure that the architect and the design team, including other designers such as structural engineers and MEP engineers, had accurate information to develop the concept design. As seen in the diagram below, verification occurs after each information point *(Figure 8.3).* This would ensure that all essential information is provided at each level before proceeding. This preliminary programming or assessment not only provides a thorough knowledge of the limit and implementation plans of the project but also includes a detailed analysis of all applicable zoning regulations and project's capabilities and constraints. The procurement method and the requirement for specialist contractors/subcontractors, and suppliers for project design and execution are advised or recommended to the client at this stage. Considering an IPD procurement strategy in this study, all project participants are invited to participate in this step. With the information requirements and information exchange style, each participant's role is set early in the project.

The pre-design stage (preparation and briefing) *(Figure 8.3)* began with a site survey to ensure the site was suitable for the proposed project. Next, numerous site analyses are done to verify that local rules, laws, and regulations are in place. At this time, all stakeholders are involved in determining the project agreement, specification procedures, construction scale, cost structure, and structural form of the proposed projects. Other investigations may be required to decide the viability of the client's requests. As shown in *Figure 8.3*, the information from each information point is established to serve as the basis for the design stage and the approved information from the pre-design stage. *Table 8.2* depicts the information components at this stage, which include information regarding the site survey, the design, the contract, and the cost. Financial information, including cost estimation, begins at the information component layer.

During construction, massive amounts of data are identified and collected by construction information professionals. Since it is vital to correctly and accurately execute the design, the work plan at this stage often takes the longest. The first column of *Table 8.3* establishes the basic information confirmed at the design's completion stage. Additional construction information components at this time include environmental information, technical information, resource information, construction information management and past project information. Past project information is one of the issues identified as a primary contributor to poor information management systems. As previous lessons are rarely documented, the same mistakes on projects are frequently repeated. Many information management challenges could be avoided if this information was established earlier in the project. The primary information components at the operations stage are construction-related information and facility-related information. The diagrams below *(Figure 8.3)* show how information is exchanged from the design phase, construction phase to the operation phase. At these stages, the information component represents the client's vision on the ground and includes, among other things, information for asset maintenance, equipment configuration, specifications, and operations, building maintenance plan, and actual value information.

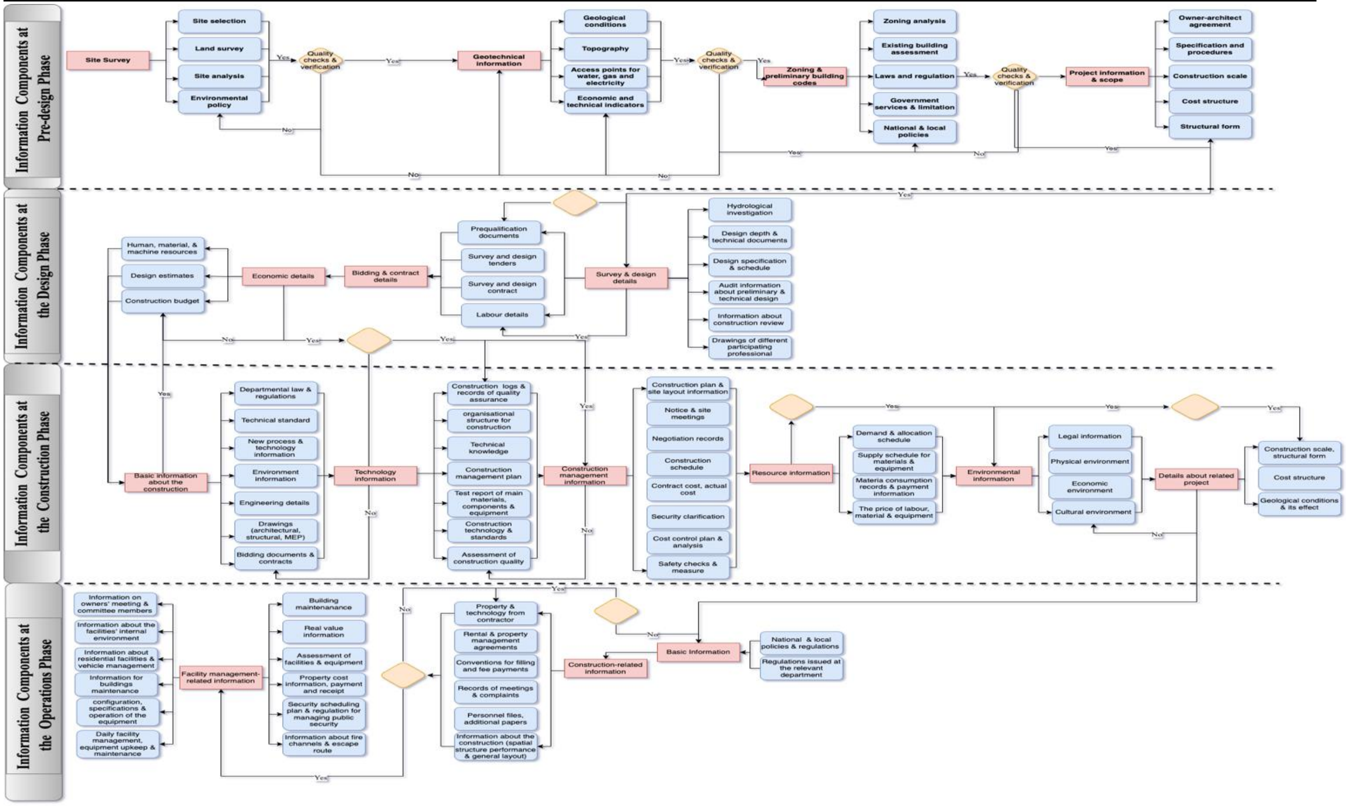


Figure 8. 3: *The information components layer*

8.7.2 Information requirements layer

The parties participating in a project establish the information requirements. This is the next stage in the developed schema after defining the information components at each stage. This information has been validated, and the teams involved now have access to the data needed to plan the project. The client defines the information requirements first, as specified in ISO 19650 *(Figure 8.1)*. This standard outlines the client's and other parties' unique information requirements. This standard guides every procedure throughout the project life cycle. Each organisation and project create reasonable requirements for quality information delivery and better design and construction.

Most industries in the construction sector did not appropriately define these requirements, which often led to information management issues. However, these requirements are essential, as failure to do so could result into a negative implication on the overall success of the project. Decision-making delays, inefficient information sharing, inefficient onsite inquiries and interactions, time overruns, and unclear task roles among project teams are just a few examples. As established in the previous section *(Figure 8.1)*, this layer comprises the required information at various levels. According to the ISO standard, this information is necessary at three different levels: organisational (OIR), asset (AIR and AIM), and project (PIR, EIR, and PIM) levels. They provide the information to carry out the tasks of the different parties, as shown in *Figure 8.4* below.

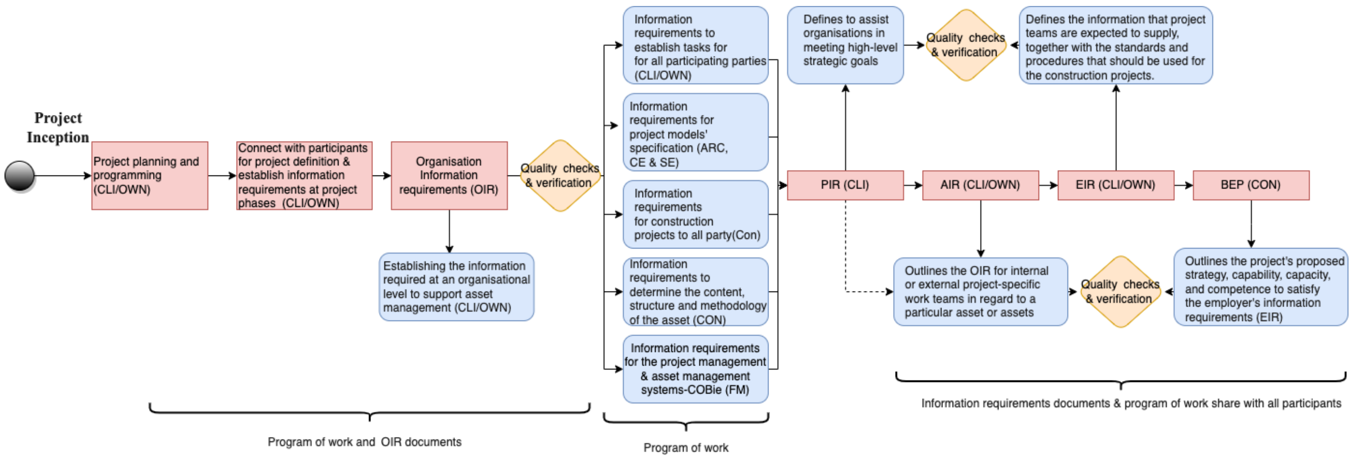


Figure 8. 4: *Components of the information requirement layer*

Establishing these requirements aids in the model's use and the development of the BIM process. As stated in Chapter 2, the IPD procurement approach was adopted as an example of the procurement method in this study as it encourages the involvement of all project participants from the start. All participating teams contribute to the information requirement layer, as shown in the figure above. This is to inform the requirements and decide what information need to be included in the PIR, AIR, EIR, and BEP. The information requirements of each participant differ, emphasising the importance of determining the level of growth and information requirements early on by all parties. The advantages are that the already agreed-upon information requirements and exchanges will allow the succeeding stages to proceed successfully. As a result, the likelihood of a party acquiring a partial information model is minimised.

As a reminder, the owner creates and distributes a worksheet containing the programme of work as a reminder to ensure that all participants receive the correct information. The programme of work focuses on what has to be done, what needs to be considered, lessons gained from previous projects, required standards, and areas for participants to focus on that can affect the job. The programme of work could also include the standards and software versions to be employed by the participants for their activities during the planning stage and how the information model is delivered to the designer or how the overall design model is established for the contractor.

The program of work for construction could comprise the task breakdown structure (TBS) for the model or work breakdown Structure (WBS) or space breakdown structure (SBS) (Lee *et al.*, 2018), the measurement processes to be followed, requirements for modelling, the type of categorising system that would be used to link the model, cost estimates/quantities, and essential criteria for 4D and 5D BIM. The operation team's program of work could include the types of operational documents that would be checked, the parameters that the designer and contractor should include in the operation documents or continue to update for the operation phase, asset management requirements, and the construction operation documents that are required, such as COBie. The contractor developed the BEP to outline the project's proposed strategy, experience, ability, and competence to satisfy the EIR after compiling all of these requirements, adding more details to the specifications, and sharing them with all involved parties.

8.7.3 Information flow and exchange layer

Information flow and exchange are discussed within this layer based on the different stages of the project's life cycle, including operations, occupancy, and end of life. Information flow and exchange make sure that the appropriate information is created in a suitable format at the right stage for better decision-making.

8.7.3.1 Information flow and exchange at the design phase

From the diagram below in *Figure 8.5*, the architectural concept design in the BIM environment commences with the information flow and exchange layer. The architectural concept design deliverables are incorporated into the BIM information model. As it is a BIM environment, the engineers (structural or civil) do not have to wait for the architect to finish his design before proceeding with their own. Sharing is facilitated via a cloud platform (i.e., a CDE such as BIM 360) such that each designer completes their job simultaneously, as seen below. The individual single design model is incorporated into the central BIM model, sharing real-time input-output information between the various designers. Designers can also receive just-in-time information on any changes to the combined information model, and the client or owner can provide earlier input on the design. The required deliverables or output can be obtained from the model at any moment in the progress phase, reducing the need for late decision-making and acceptance or rejection of the design.

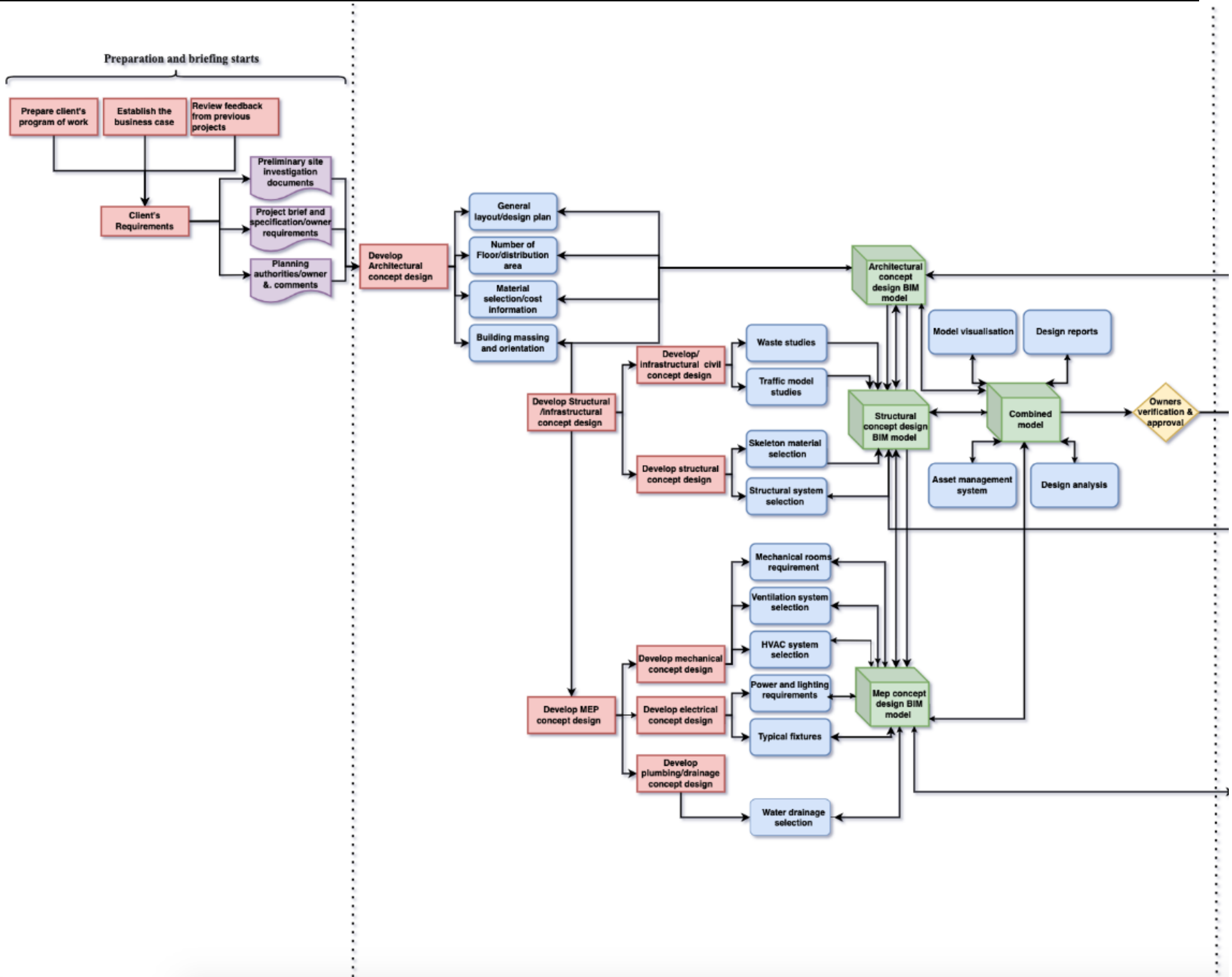


Figure 8. 5: *Information flow and exchange at the conceptual design stage*

In most projects, after the client has given his brief, he rarely works with the designers to ensure the concept design meets his needs. Instead, he re-appears once the designers have completed their conceptual design. The designer would have to either start over with the design concept or reassess the design before moving on to the next design phase if any changes are made now rather than earlier, as is practical in the design phase. As a result, the issue of time overrun is limited. Following the completion of the conceptual design, the designers add more detailed information to the model to create the schematic design process as shown below in *Figure 8.6*. This is in accordance with the schematic design stage's needed LOD. *Table 3.12* of this study gives an illustration of the level of development at the various design stages.

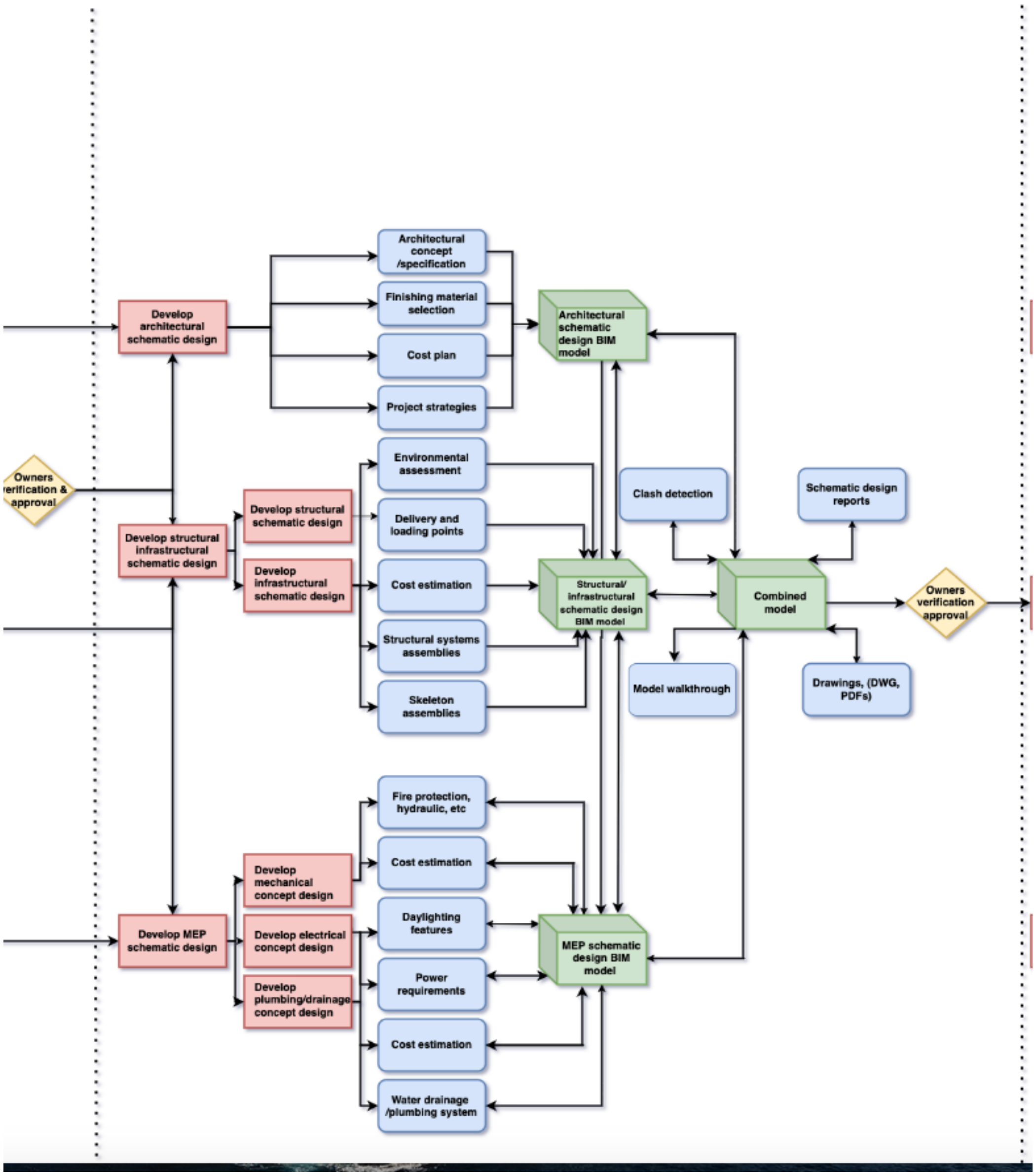


Figure 8. 6: *Information flow and exchange at the schematic design stage*

Further elements are added to the schematic design to develop the information model for the detailed design phase as shown in *Figure 8.7* below. This procedure follows the same logical sequence throughout the design phase. Early in the project's development, the client provides input for acceptance or rejection of the design at various stages. This saves time throughout the design process and gives the contractor or construction team access to the design information needed to start the construction process. As a result, waste is eliminated from the project's delivery processes.

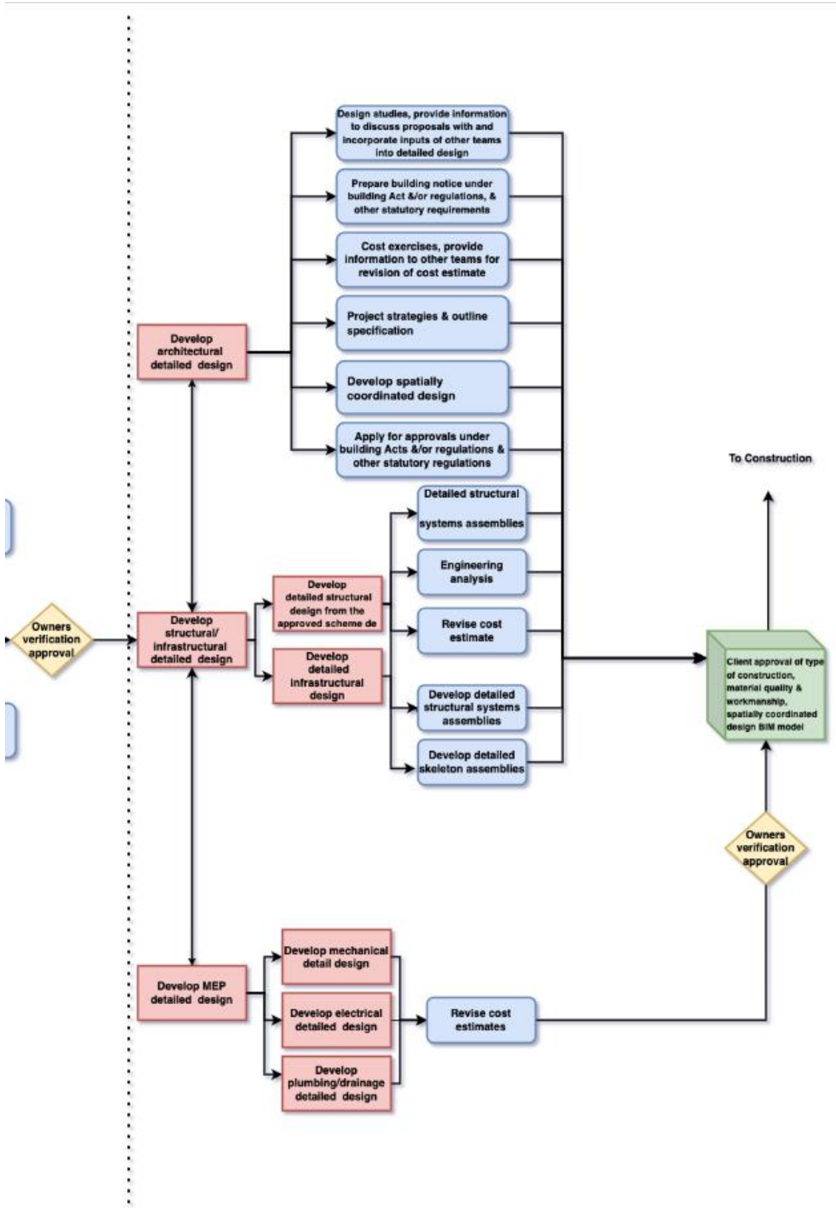


Figure 8. 7: *Information flow and exchange at detailed design stage*

This information flow and exchange process give a clear design visualisation that improves interaction among the involved project's parties and allows for continuous information flow. Some of the study's highlighted challenges could easily be resolved if the design stages were handled in this manner, as information during the design phase is key to the success of the entire construction process. For example, establishing information flow and exchange layer would enable quick information transfer among participants, and the design model could be integrated at any time during the design process. As a result, this information is always current, allowing for real-time changes and improvements.

Likewise, including the owner or client as the design progresses and asking for his consent reduces design decision-making and guarantees that the client's value is accurately expressed throughout the project. In this way, the design quality is also increased. Furthermore, as the model evolves, the owner's verification and approval are included, allowing the milestone objectives to be met, checking for any significant errors, verifying the existence of parameters as agreed on the BEP, ensuring compliance with naming file conventions or that standardised names are compatible and ensuring information model verification. This technique can be automated and facilitated by programming information verification into specialised software. This stage is crucial as the design team incorporates the information that would be useful to other participants in subsequent phases.

Participants' collaboration also encourages inputting data from everyone, resulting in everyone's having an all-inclusive image of the client's design purpose. In this approach, the architects and engineers collaborate to create a higher-quality shared design. Designers also utilise BIM to investigate other options, value engineering, and designs optimisation. The design phase model is utilised as a basis for obtaining data for various application and/or tools in the process and to manage construction project design phases in terms of cost, time, and project resources. The authors of the models would further create simulation models to analyse the efficiency of managing the design quantitatively as well as to measure possible budget and time savings realised from using BIM on projects. These models translate static process models into dynamic process models. The user may instantly witness changes as the process progresses while at the same time interacting with the model. The client can interact and participate simultaneously. The overall design phase is represented below in *Figure 8.8.* The phase progresses to the construction phase.

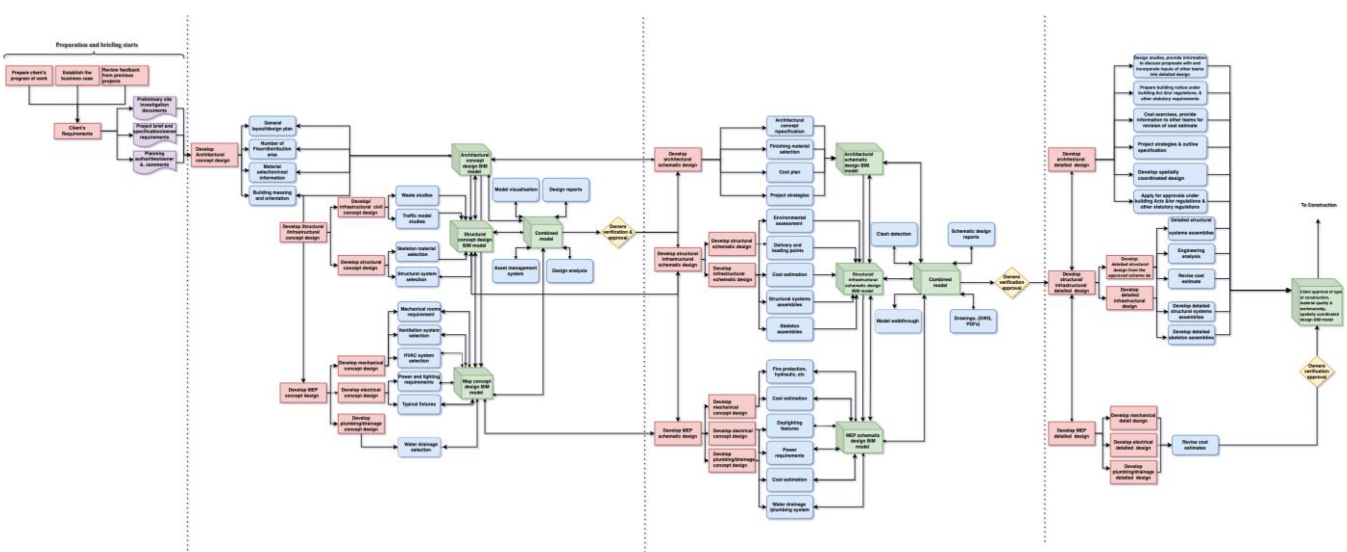


Figure 8. 8: *Overall design phase for the information flow and exchange layer*

8.7.3.2 Information flow and exchange at the construction phase

Construction planning (pre-construction) and the construction process are both addressed as the construction phase in this study. The proposed schema combines these two processes. The employed BIM is used for construction scheduling, cost estimation, 3D coordination, 3D cost control and planning, and for field and record modelling *(Table 8.6),* all of which are used at different phases of the pre-construction/construction process. This includes everything from site logistics to the early construction phase, cost validation, and construction completion (Harding & McCool, 2015). The model's quality and consistency determine the accuracy of the findings in the construction phase. For efficient usage of the model in this phase, the model would adhere to the measurement standards, modelling requirements, and how things must be modelled as previously agreed upon by the participants. Quantity surveyors or cost consultants are the primary responsible parties for cost planning, quantity take-off (QTO)/cost estimation, and other costing activities. The basic information evaluated for quantity take-offs is as described at the start of the project, unit specifications for each service, and measurement standards. The bill of quantities in the accepted format is the information created at the end of the quantity take-off.

The construction deliverable is validated at the end of this phase by the contractor who would use the information. This validation as a requirement is to ensure that the information given is organised and accurately defined for use in this phase and meet the expected objective. After the QTO, as seen in *Figure 8.9*, a BIM cost estimation/parameter, i.e., 5D BIM, is next. Integrating the model with construction expenses (5D) necessitates using previously agreed-upon software and model rules for information accuracy.

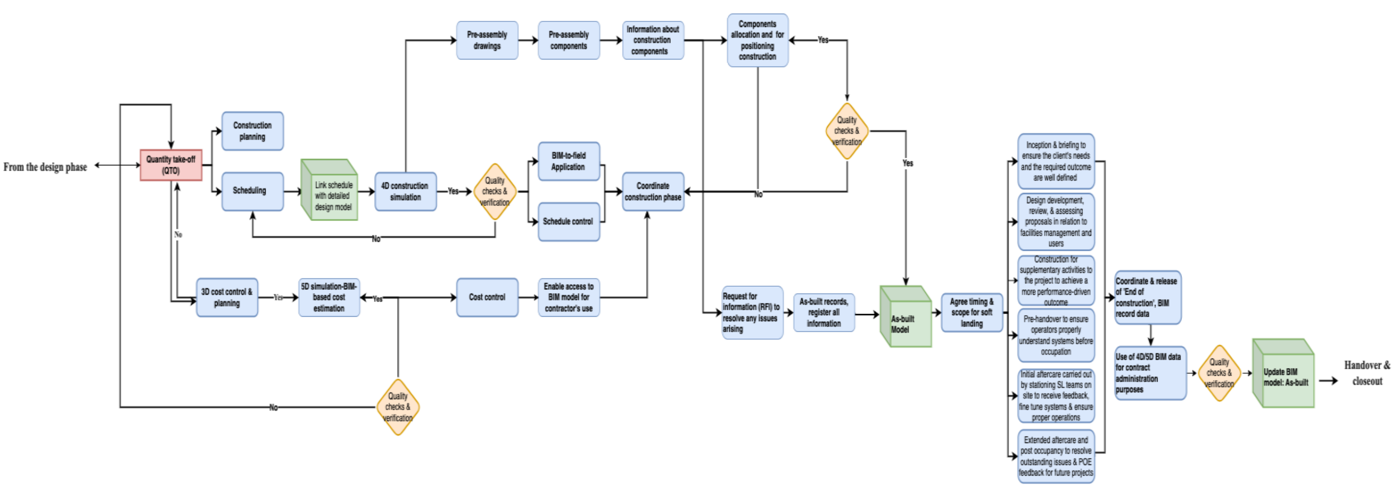


Figure 8. 9: *Information flow and exchange at the construction stage*

The benefit of this integration step is that it directly links the information, reducing the possibility of information loss along the delivery path. Furthermore, the ability to get an immediate response is promoted for cost analysis and simulations based on the design options. Finally, the whole construction budget is the output. Another implementation in construction planning is simulation, which is ascribed to the contractor as the major responsible party for construction. For the simulation, the simulation software should be compatible with the schedule format to reduce labour-intensive and the possibility of data entry errors. The schedule could be inputted into the software and connected directly to the information model. By linking the schedule with the model, any errors in the schedule become apparent. But verification is necessary to review the scheduling process. After this verification, the simulation is generated for the construction phase and shared to the participants. The BIM model application. construction planning and costs, schedule control and construction simulation, are this stage process's primary focus. This process's resulting outputs or deliverables are used for planning the construction phase.

As illustrated in *Figure 8.9,* the construction phase deals with two activities related to applying the model for construction: using the model for assembly or BIM-to-field. The concept behind assembly is to use the models and the actionable information inside them for assembly processes. Clash issues would have been resolved during the design phase, and assembly factors would have been considered when designing to facilitate the assembly process. The design team and the subcontractor working together on this process would agree on the format of the model delivery in advance. Nonetheless, an initial agreement on a model delivery format would facilitate a smooth process in the construction, whatever the format used: either an open standard one like IFC or a native format. The subcontractor would have informed the contractor about the status of the components and the mode of delivery before assembling them. Such data can be integrated into a platform for the information management and connected to the contractor on the job site so that he can use it to manage the work.

This stage can improve information organisation, allow better communication, and increase onsite coordination of the components. The model is primarily used on the construction site for construction coordination. BIM-to-field takes into consideration the BIM information model as the input at this step. The contractor/subcontractor would choose a BIM-to-Field solution that permits entry into the model to assists with coordination. BIM-to-Field enables using accurate digital data in an information model to inform accurate construction and operations on the site. To prevent interoperability issues, the BIM-to-Field application use open formats or application formats and the agreed-upon modelling software at the project’s inception. The construction drawings and model are employed onsite to coordinate the construction. The objective is to have accurate details or other information, preferably on onsite screens. This makes it simpler to ensure that the most recent version of the project is used and that no errors occur in the version.

The scheduled information exchanges on the construction site communicate issues and requests for information (RFI) amongst all parties on the CDE. Instructions about the project for the designers, information about the project shared among the contractor team, requests about the project to the construction team/subcontractor, and quality checks/validations with the client or employer are just a few of the exchanges that can occur on the RFI. The RFI is a cloud-based information management platform operated in the CDE, i.e., BIM 360. Thus, all parties have access to this information when it is required to overcome delays in decision-making. In addition, information can be tracked if any doubts regarding a previous judgement exist. Therefore, adopting a suitable information management platform on the site can offer an effective and well-organised trail of information sharing for future consultation by the parties.

However, most project participants are unfamiliar with the cloud-based information management platform, contributing to some information sharing and management challenges. Other large construction corporations have a unique cloud-based system that makes it difficult for third parties on the project to use the platform efficiently. As a result of the project team working in several environments and with numerous vendors, information flow is delayed, information does not reach its intended users, and data security is compromised. This study's proposed approach is to improve access to information to support project implementation. Security is another challenge on the RFI, where those that should not have access to specific information gain access to them. As the security of the industry is ever-changing, and most organisations find themselves growing rapidly, the industry needs to build a security strategy for the future rather than for the present or its current projects.

Another activity during construction is the as-built information register for asset management. If the model is to be used for a subsequent stage, like operations, additional information as well as modifications to the original project would be recorded. For simplicity in this process and increase efficiency, the schema suggested centralising all model information and the information contained in them, whenever possible, linking supplementary information to the model, the documents and the CDE. These could be represented in various formats in the CDE, such as jpeg, doc., or pdf format. The information management platform, on the other hand, must support and ease this process. It would reassure the facility manager that he is receiving up-to-date information in an orderly manner. This task could be regarded as the contractor's obligation, as he is the party in charge of transitioning the information model from the construction operations stage to the operating. The BIM information model from the earlier phases would also need to be restructured or updated regularly during this process to guarantee that the client/owner receives an up-to-date model. The suggested schema assumes that the as-built model process includes the information at the construction and handover stages. The design team or a third party in the design terrain involved in the project may be allocated the responsibility of updating the BIM model.

The participant overseeing this activity must be approved or decided upon in the contract/agreement. This participant may be the designers, the consultant/contractor, or another individual from the collaborating teams contracted to execute the activity. Nonetheless, who would be responsible for carrying out the work must be decided upon from the start of the project. The modelling tool to be utilised and whether the designers will provide the model in the native format must be decided upon. If any of the provided formats is used, it should be specified in the contract that it will be used from the very beginning of the project. If this process is not handled correctly and not well agreed upon, it could incur significant losses to the parties involved. Another necessary process to consider in a BIM project from the construction phase to the handover phase is soft landing (SL) *(section 2.6.6.1).* Adding SL to the proposed schema aims to restore the smooth transitioning process from the construction phase to the operating phase. *Soft Landings* is a construction delivery method that extends from project inception to completion. This ensures that all choices created during the project are centred on enhancing the construction project's operational performance and achieving the client's expectations (Gana, Giridharan, and Watkins, 2018).

8.7.3.3 Information flow and exchange at handover

Following the timing and scope for soft landings, the entire process is documented and disseminated among participants, as shown in *Figure 8.10.* The handover and close-out phase follows the construction phase on the schema, during which information from the construction project would be given to the appropriate party for operations. Following the distribution of the updated as-built model, a quality checks and validation process is added to ensure that the model was updated entirely to the as-built conditions and that it contains all of the information that the asset operating manager would require. Once confirmed, the model and construction documents will be submitted to the facility manager.

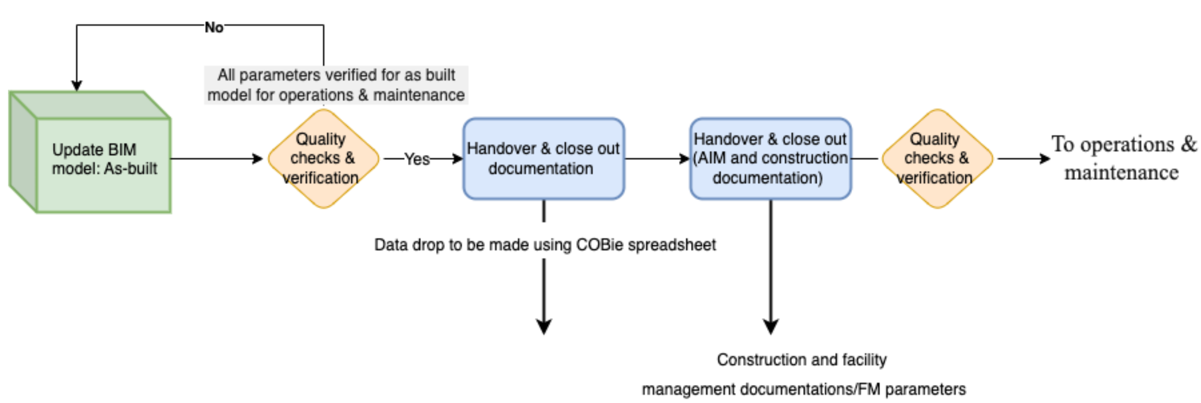


Figure 8. 10: *Information flow and exchange at handover & close out phase*

8.7.3.4 Information flow and exchange at operation and maintenance phase

The As-built model served as a basic information about the project for all parties involved in the asset use. It provides the O&M manager with detailed operations information arranged/organised in a database connected for model visualisation. One of the most pressing concerns in information exchange is to transfer the information obtained during construction to operation with little data loss, according to one of the identified challenges in the study, i.e., challenge arising when transitioning to the operation phase. The model, however, offers data that can be evaluated for facility/O&M management. As such, the format for distribution and LOD are established for the O&M/facility manager to employ the data in his system. The proposed method is to create a connection from the model to an external database using either the COBie format or a script.

The specification of this format is determined by the software utilised by facility management and the form of database the programme can comprehend. For example, if COBie is employed as proposed in this study, this can be established from AIM and connected/linked to the facility management system to add model data/information into the database. Also, the database is connected to the model to allow the facility management to utilised the data in the format in which it is available in the database and to attach further information. This information is connected to adequately capture the operations and management software information. As a result, the facility manager might continue to use the software to operate the facilities. This is incorporated into the schema during the operation phase, as seen below in *Figure 8.11.*

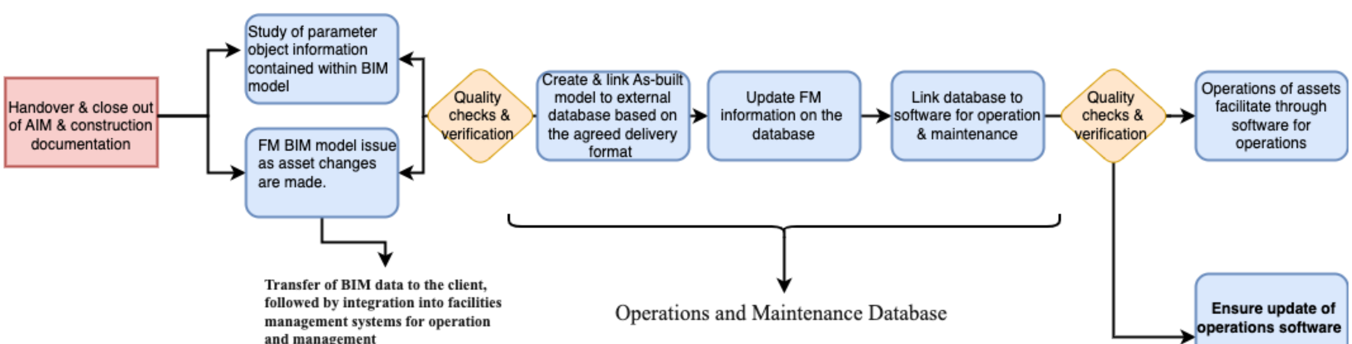


Figure 8. 11: *Information flow and exchange at the operations and maintenance phase*

Furthermore, the BIM process would involve the facilities manager all through the project life cycle to successfully transfer data to the O&M team for accuracy and quality information. The project would keep on operating after the information model has been delivered by the construction team to the operation team. The operations would continue as the model and construction database links are connected, and all data added to the database. When all these phases are presented this way, the objective is to have a transparent view of the exchange of information that takes place in all the processes. Therefore, participating parties could deliberate and decide on several matters right from the inception of the process to avoid any challenges occurring.

8.7.4 Information delivery layer

The information delivery layer, as depicted in *Figure 3.8* of this study, investigates the delivery process of a construction project's whole life cycle in accordance with PAS 1192-2: 2013. It addresses the information assessment and needs/requirements, procurement, post-contract award, mobilisation, production, and AIM maintenance. The delivery process starts with 'CAPEX' and concludes with handover. "CAPEX start" denotes either a project’s start time with no prior information or a project’s start time hinged on an evaluation of prior information from an asset/facility file.

8.7.4.1 Information assessment and need or requirements

The delivery document in the information assessment and needs consists of the EIR, which outlines the requirements for information exchange and collaboration among the parties. The supplier would include the EIR in their project execution strategy. The EIRs' content would be aligned with the employers' decisions, project stages, and tender documents. This would allow the vendors to create their initial BEP, outlining the project's planned approach, capabilities, and capacity. In addition, the EIR would deliver the project's information management, commercial management, and competence assessment strategies.

8.7.4.2 Procurement: pre-contract award

At this information delivery point, the details of the bidders’ strategic plan to project IM is submitted which is sufficient enough to determine the supplier's planned approach, competency, ability, and skill to satisfy the EIR.
The initial BEP generated above during assessment and need would allow the client to decide whether the project’s requirements/needs in the EIR are doable, and if possible, leave room for adjustments or negotiations of the capabilities/competences of the supply chain. *Section 3.6.5* highlights the content of the pre-contract BEP (PAS 1192-2:2013). During the procurement point in the process of delivering the information, the pre-contract BEP, project implementation plan (PIP), supplier's information technology and supplier's resource and BIM assessment form, and supply chain capabilities outline documents are delivered. At post-contract award, the supplier resubmits the BEP to the employer, validating the capabilities of the supply chain and the MIDP. This guarantees the participating parties have committed themselves and agreed to the BEP.

8.7.4.3 Post-contract-award

At this point, the supplier ensures that the data provided by their supply chain complies with the EIR which has been provided to their supply chain partners at specified intervals throughout the project. The BEP post-contract documents include everything required in the EIR, management information, planning and documentation, standard operating procedures, and IT solutions for the project *(Table 3.9).* This delivery point also includes creating the MIDP and TIDP. The project delivery manager (PDM) defines the MIDP which confirms the resource availability and capability of the responsibility matrix developed, identifies education needs (training) if applicable, and collaborates to establish the MIDP using the TIDPs of each team members. The PDM would use the MIDP to manage information delivery during the project and identify the project's information output/deliverables in addition to specifications, drawings, equipment schedules, room data sheet and models. Furthermore, each task team manager defined and assembled the TIDPs as part of the delivery layer to specify their milestone. It would be used to communicate the delivery of information from each supplier, the alignment of milestones to the project design within each TIDP, the responsible party for each deliverable, the preparation of project document transfers, and the appropriate model sequence for the work packages created for used in the project. At this time, the project delivery team's roles, responsibilities, and authority are clarified.

8.7.4.4 Mobilisation

In the delivery layer, mobilisation is a critical task. This takes place before beginning design work and enables the project delivery team to ensure that the IM solution works. This involves ensuring that the essential documents are provided and decided upon, that the IM processes are established and that the project team have the necessary abilities and capabilities. It also ensures that the technology support aligns with the project requirements and enables standard information management. Interoperability issues between the various BIM solutions used in a project should also be addressed here. Typically, any data/information would be produced in the native format of the solutions being used. Furthermore, the project teams agree on the description of the number of data and rigorously test them to ensure interoperability. At this point, the education needs (training) of all project delivery team members who are engaged in the generation, analysis, and evaluation of the PIM are examined, and suitable plan is taken, if necessary, with specific opinion to the content of the BEP outlined above.

8.7.4.5 Production

The production throughout the delivery process progressively developed the PIM and supplied it to the employer via a set of information exchanges as defined in the EIR, such as the CIC scope of services, on crucial times to correspond with the decision-making processes of the employer as described by the EIRs and the CIC BIM Protocol (2013). Level 2 BIM requires the PIM to include a collection of federated building information models other than a single integrated building information model, non-graphical data and documentation. As authorship flows from providers for the designs to construction suppliers and their supply chains, the PIM evolves from a design intent model to a virtual construction model.

PIM is created in line with the MIDP and consists of graphical and non-graphical data documents as defined in the MIDP. Data/information delivery at this stage includes data entities such as native (product-proprietary) file formats, COBie, or PDF to conform with BIM Level 2. The CDE forms part of the production point and ensures that all process of production information at each individual information exchange is accurate, appropriate, and unambiguous (section 3.5.1). The development, exchanging, and issuing of production information occur in the CDE so that information is maintained and shared on time. The information classification system delivered at the production point is represented below in *Table 8.12.*

Table 8. 12: *Information classification for the delivery layer as defined by PAS 1192-2:2013*

Information	*Classification and Delivery format*
Conceptual cost information	NRM1, CESMM
Developed cost information	NRM1, CESMM
Conceptual design information	Uniclass - entities, spaces, element tables
Detailed design information	Uniclass - elements, systems tables
Construction/manufacturing information	Uniclass - systems, work results and product tables
Assembly information	Uniclass - products tables
As-built information	Uniclass - systems, products tables
Operations design information	Uniclass - systems, work results, products tables
Operations & maintenance cost information	NRM 3

8.7.4.6 Asset information management (AIM)

The data created during the delivery phases mentioned above and the commissioning information are expected to constitute most of the information delivered at the end of the project. In the UK, COBie is the approved information exchange format. If additional information is required, such as 2D or 3D models or other data properties, these alternative formats will be described in the EIR at the beginning of the project. The successful movement delivers a significant value in structured information between asset lifecycle stages. The EIR contains formal handover protocols that are documented to ensure an effective process. The framework, process, and substance of the information to be shared are defined in the document. This forms the basis for operational contract documents. To ensure the as-constructed model's completeness, laser scanning is proposed in this study. Laser scanning in construction is further discussed in the next section. As explained above, the documents for the delivery layer are interconnected to ensure a successful delivery process. These delivery documents also ensure the effective information management of construction projects. *Figure 8.12* below depicts the component of the information delivery layer, as discussed above.

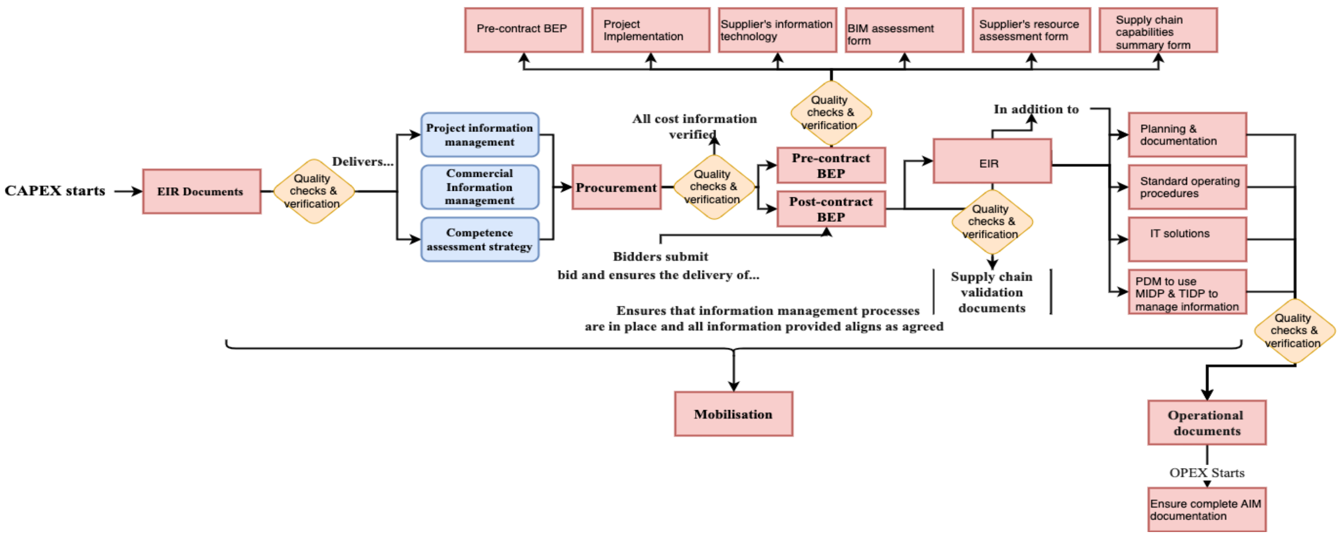
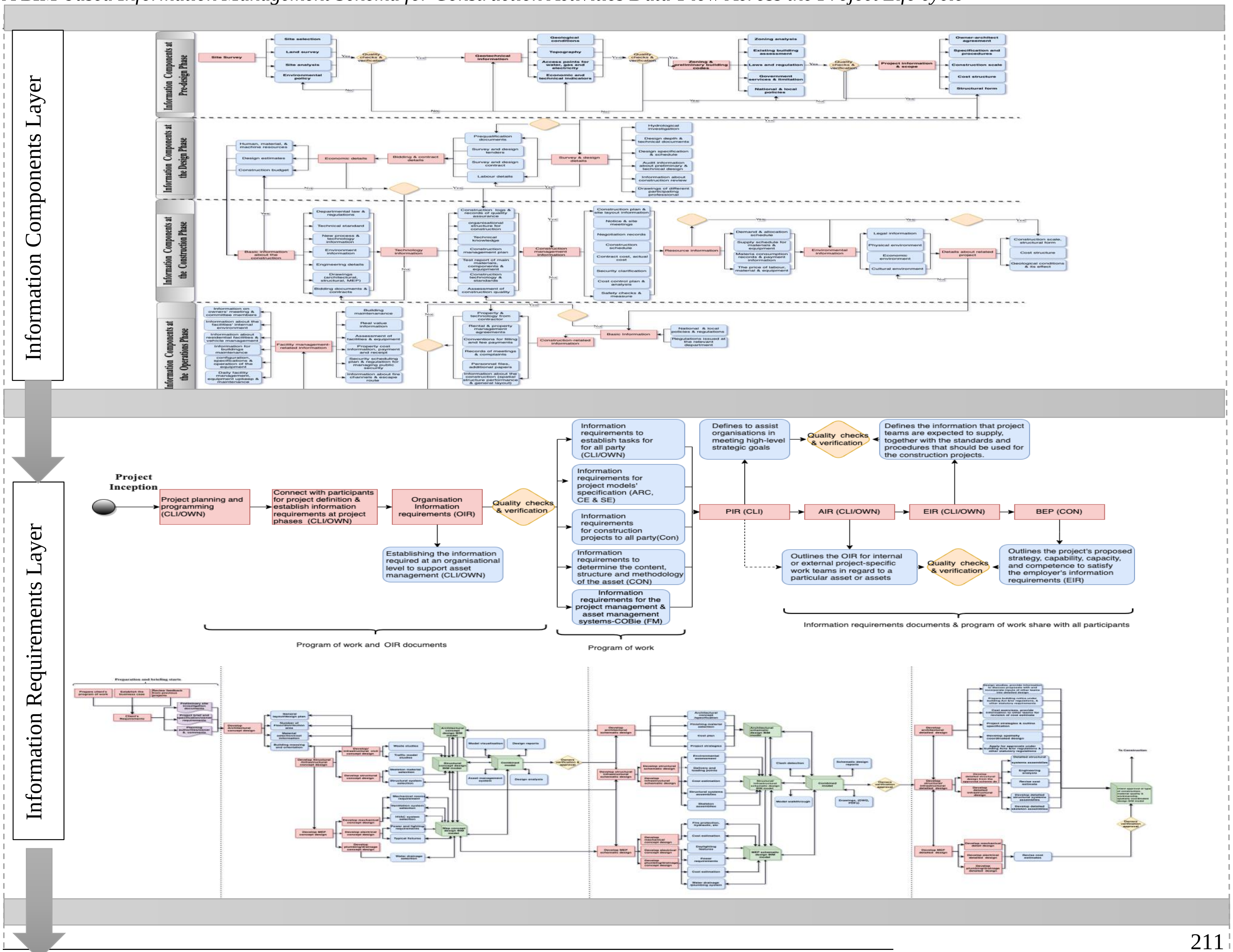


Figure 8. 12: *Components of information delivery layer*

8.7.5 Schema development

The entire development is depicted below in *Figure 8.13*. This comprises the four layers discussed above, with the core activities represented in each layer. Presenting the schema in these layers makes it easier to comprehend the entire process of BIM-based information management. Furthermore, it also provides an understanding of the interaction among the participating parties, with the information components related to each construction phase and task. Information flow, exchanges, and delivery and how they are linked with the entire process were also examined. The schema provides a strategic view of how information management could be improved in the BIM context. It could be adapted to improve information management of projects' life cycles in the construction industry.


Information Components Layer
Information Requirements Layer
Project Inception
Project planning and programming (CLI/OWN)
Connect with participants for project definition & establish information requirements at project phases (CLI/OWN)
Organisation Information requirements (OIR)
Quality checks & verification
Establishing the information required at an organisational level to support asset management (CLI/OWN)
Information requirements to establish tasks for for all party (CLI/OWN)
Information requirements for project models' specification (ARC, CE & SE)
Information requirements for construction projects to all party(Con)
Information requirements to determine the content, structure and methodology of the asset (CON)
Information requirements for the project management & asset management systems-COBie (FM)
Defines to assist organisations in meeting high-level strategic goals
Quality checks & verification
Defines the information that project teams are expected to supply, together with the standards and procedures that should be used for the construction projects.
PIR (CLI)
AIR (CLI/OWN)
EIR (CLI/OWN)
BEP (CON)
Outlines the OIR for internal or external project-specific work teams in regard to a particular asset or assets
Quality checks & verification
Outlines the project's proposed strategy, capability, capacity, and competence to satisfy the employer's information requirements (EIR)
Program of work and OIR documents
Program of work
Information requirements documents & program of work share with all participants

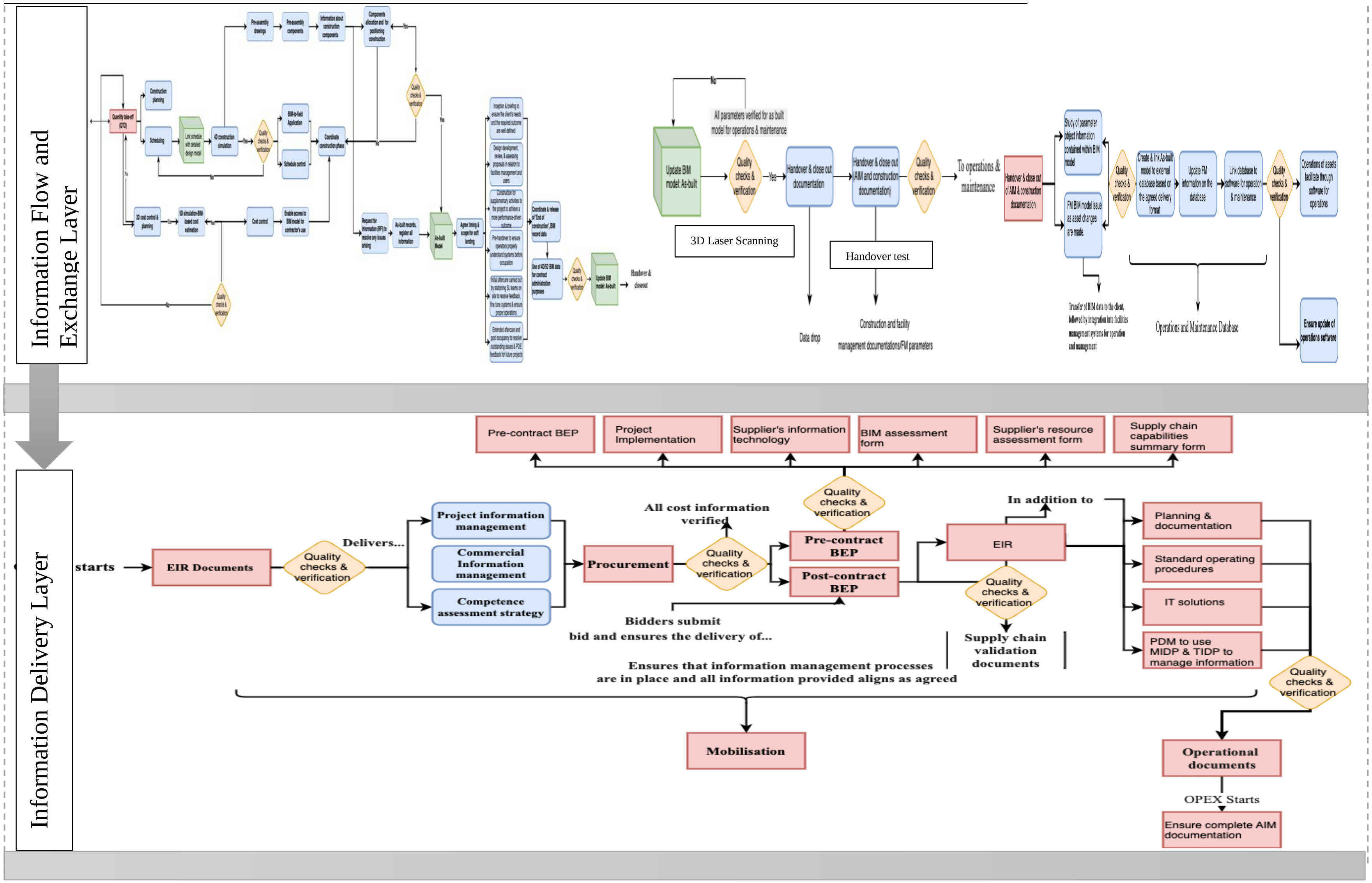


Figure 8. 13: *Information management schema*

The central repository as adopted in the developed schema collects stored data or information from existing databases that have been integrated into it so that it may be shared, analysed, or updated across the industry. It is consequently constructed practically by combining data/information from all relevant sources. Storing all the information in one place enables easy management, evaluation and data safeguarding. According to this study, the amount of data organisations collects, store, and manage quickly expands in the construction sector. As such, more efficient methods of managing this data are required. The size and complexity of data threatens the quality and accuracy of projects, necessitating connectivity. When management bases essential decisions on the non-accuracy of data, the results could be fatal, making inaccurate data useless and harmful to the industry. Some of the benefits include centralising the storage and maintenance of data, increasing data quality and accuracy, reducing time-consuming updates and redundancy, maintaining data history, i.e., learning from previous projects, enhancing decision-making and generating a higher return on investment (ROI).

i) Centralises data storage and maintenance

Information management via a central repository/central database enables users to modify the information and reflect those modifications all through the organisation (Thomas & Praseetha, 2020). As a result, individual department in the organisation can function within a centralised work plan by providing numerous users with access to data in real-time.

ii) Increases data accuracy and quality

According to the data warehousing institute, poor quality of data costs construction businesses billions of dollars every year. Investigating trends and developing strategies for business success could be achieved by analysing data. A central repository provides reliable data for accurate trend analysis in projects (Banzi *et al.*, 2019). In addition, the data is continuously updated and standardised across departmental databases, which accounts for improved quality and accuracy (Thiele *et al.*, 2008).

iii) Reduces time taken to update and eliminates redundancy

The record of creating and collaboration minimises and, in many cases, eliminates redundancy. Removing unnecessary information minimises the time required to review and make decisions, resulting in increased productivity (Murray, 2006; Ardini *et al.*, 2014). This enhanced cross-departmental cooperation ultimately gives the organisation a competitive edge by saving decision-makers time.

iv) Maintains data history

A central repository houses enormous quantities of historical data, adding a previous intelligence component to making decision and creating an easier way to recognise patterns and make more informed decisions (Kim, 2018).

v) Enhances making informed decision

Making decision impacts the performance of the whole industry, and management is better able to make decisions effectively and ensure they are carried out quickly and consistently when they have access to accurate and organised data (Sidawi & Hamza, 2012). In addition, making blind decisions in the industry is avoided by having all the data in one place.

vi) Generation of a higher return on investment

The investment costs of implementing an IM strategy may appear high initially, but when compared to the costs of poor quality of data, incorrect information, and uncoordinated decision-making, the advantages are obvious and enormous. According to the literature, companies with developed central data repositories have produced higher income and saved extra money than those that have not. As data is considered an essential asset to an organisation, efficient management of data and its quality is essential to the companies' survival and success (Wallis, Roland & Borgman, 2013). These numerous advantages of a central data repository result in improved decisions, added productivity, improved efficiency, and more knowledgeable people in a company. Employing a central data repository largely allows a company's core operations to run more efficiently.

8.8 Chapter Summary

The processes for developing the information management schema are examined in this chapter. The schema is divided into four (4) layers: information components, information requirements, information flow and exchange, and information delivery. The four layers were first discussed separately to understand the components in each layer for the management of information throughout the project life cycle and later combined for the developed schema.

Chapter 9

9 Validation and Analysis of Findings

9.1 Chapter Overview

In this chapter, the developed BIM-based information management schema was evaluated using two real-life projects as case studies. The chapter explains how the validation process was accomplished. The results of the validation outcome were analysed and discussed to assess the developed information management schema. The validation process was accomplished with the construction company's and staff's support. In addition, ethical consideration was duly observed on the part of the researcher and the participants.

9.2 Validation and Analysis Process

Validating the schema examines its components, quality, suitability, and usefulness to improve information management systems in the construction industry. Furthermore, it helps to address the project's shortcomings and prevent basing the study's findings on inaccurately represented data, validating aids in ensuring data details, accuracy, and clarity (Choi & Ha, 2022). The purpose is to make informed judgments about the study's outcome, improve the effectiveness of information management in a BIM context, and achieve the intended learning results. The schema was validated qualitatively using a case study approach and semi-structured interviews with experts from the two case studies chosen for the validation process. These two case studies are from the UK construction industries with proficiency in BIM. For the validation procedures, two of their projects were evaluated.

9.2.1 Case study planning

Participants from the two case study companies were further invited for interviews to validate the proposed schema. The objective of this section was to understand how the developed schema met the requirements of information handling and management in the two case studies. Two projects from the companies were used as examples to represent the company’s information management experience. Interview questions were project-information-related questions prepared to comprehend the information processes in the two projects. The interview questions helped to guide the flow of conversation with the participants. The discussions were based on BIM information management processes and challenges in the selected projects. The projects were labelled Project ‘A’ and project ‘B’.

Project 'A' is an institutional structure in the North-West of England. The project is a completed project which lasted for 30 months. It is a seven-storey building. In line with the existing structure of similar use, BIM level 2 was used for the whole project. The client is a higher institution, and the procurement method was not mentioned. The intricate mechanical, electrical, and plumbing (MEP) design was coordinated using 3D modelling. The owner was liable for verifying the information quality in the project, while a third party was responsible for the construction project's information management and ensured it was in line with the client's needs/requirements and standards.

Project 'B' is also an institutional building in the South-West of England. Although the project is now completed, the interview started when the project was still under construction. The client is the institution where the project was constructed. The output/deliverables and level of information for the project were stated at the start by the owner. BIM was utilised throughout the design and construction phase. The development of Project 'A' progress very fast because of the urgency of the building in the institution while adapting to all the design coordination in the project.

9.2.2 Interview with the industry participants

The participants for the interview were experts with proficiency in BIM construction projects. The interview was conducted to collect data that would be used to validate the proposed work. Open-ended questions were used, and the interview responses were recorded and reorganised in accordance with the interview flow. The questions were designed in accordance with the pertinent subjects in the proposed schema for the validation process. The idea behind these questions was to confirm any challenges the adopted research methods found to validate the possible solutions proposed in the information management schema. Appendix C comprises a sample of the questions used as the basis for the interview. Although there were pre-planned interview questions, some extra ones came up in the discussions. The interview discussions outlined the overall view of the goals and development study.

9.2.3 Pre-design phase

9.2.3.1 Project brief, planning and programming

All the participants are involved right from this stage in the proposed schema. As proposed, the involvement of all the participating parties helps to ascertain the specific roles of every project team member. In addition, it enables them to understand the project brief and develop a thorough grasp of the project's constraints and a plan for its implementation. The EIR was developed by the client, owner, or someone from the project management team, as claimed by the participants in the interview (which was not specific). The appointment of the information manager and the site surveys and tests, zoning and building regulations *(Table 8.1)* also form part of the preparation at this stage. The responsibility matrix is also developed at this stage. From the interview response on the project used for validation, it appears that this phase is not as pronounced as it should be in planning. The entire process combines preparation, procurement methods, and other pre-design activities. As proposed by the study, this phase should be made a priority and adequately addressed in the development of any project. If this phase is carried out as it should be, then minimal errors will be recorded in the information management process. As such, the participants agreed with the information at this stage in the proposed schema.

9.2.3.2 Procurement method

In most cases, the proposed project determines the procurement methods as confirmed by the participant. However, the proposed schema considers IPD as the chosen procurement route to have early participation from all participants throughout the project. Abd Jamil and Fathi (2018) claim that IPD is the most effective procurement strategy when using BIM. Although it is determined to be the best strategy for BIM projects, legally, as confessed by the interview participants, it is challenging to implement. While the proposed schema considers the method, the procurement method adopted for the projects according to the participants was determined by the type of the project or construction type. According to interview participants in the two projects, it can be challenging to gauge each participant's involvement level or potential contribution to the project when using the IPD procurement route.

Nevertheless, the participants emphasised that the most crucial factor in choosing a suitable procurement method is the type of construction project. As such, a good contract and mutual trust are required among the companies and should be done early in the project with the involvement of all parties. So, the early involvement of all the participants in the proposed schema is considered a good option by the interviewee. However, for the projects, the interviewee claimed that one should be flexible in adopting the project's contract type. This was also mentioned by some interview participants in the initial interview for the study. Although the participants did not rule out the adoption of IPD, they emphasised that this should be done according to the project type. From the discussions on procurement methods in section 2.4, it is clear that DBB is the most well-known major construction contract because the apparent flow of data enables professionals or participants to track the BIM models established by others participants. Nevertheless, for anonymity purposes, the interviewee did not disclose the adopted contract methods for their projects.

9.2.3.3 Responsibilities of the project teams throughout the project life cycle

The proposed schema considers the contributions of all parties throughout the project life cycle. In both projects used for validation, the contractors played an active role in the design. The reason given was that the length of time between the design and construction most often determined the degree of this participation. This interaction, as pointed out, was crucial for the project's success as they could represent and actualise the client's intention. The participation of the facility manager was also mentioned at the beginning of the project. The participation of all stakeholders contributes to quality improvements and budget reductions for the project. As such, the stakeholders' participation in the design phase of the developed schema was considered valid.

9.2.3.4 Responsibilities of participating teams in the development of the EIR and the AIR

The developed schema considers the participation of all participating team at the project's start and, as such, also contributes to the development of the EIR and AIR because the tasks to be carried out by them are outlined in the EIR. The reason is that it enables all parties to be aware of what the information requirements are. Again, the interviewee claimed that the contribution of the various parties' involvement in any project differs and depends mainly on the contract type. They stressed that since the project manager is now involved in most projects, the project management team developed the EIR requirements based on his consultations with the other parties. They further stated that since the project manager's participation is from the beginning of the project to the end, it is an option considered in most of their projects. However, as the participating teams' involvement was considered in the proposed schema, this option was validated.

9.2.4 The design phases (conceptual, schematic and detailed or technical design)

9.2.4.1 Roles of the responsible parties at the design stage

The developed schema reflects the contributions of all parties during the design stage, as shown in *Figure 8.8.* In the project, the contractor participation throughout this process was very effective as confirmed by the interviewee that "the participation of all the parties including the contractor was active", i.e., the design team, the client or owner, the project manager, and the legal team. The process in the design phase was managed by the lead architects and engineers and a BIM manager who assisted in establishing the collaboration and methodology on the cloud platform, i.e., CDE. The participants' contributions in the design phase of the proposed schema were validated.

9.2.5 Pre-construction and construction phase

9.2.5.1 Quantities and cost estimation

The respondent's responsible party for the quantity take-off was either the quantity surveyor or the cost consultant on their projects. It was mentioned that the size of the project determines whether a quality surveyor would oversee this exercise or a cost consultant. Due to the size of the project under consideration, the responsible parties for the two interviewed projects referred to a reputable but unnamed cost consultancy firm. In addition, it was stated that the contractor controls these cost exercises and budget from the project inception. As such, he works together with the costing team on the project. Additionally, the contractor offers all modelling requirements and measurement guidelines in the BEP necessary for accurately taking off the quantities and creating cost estimates. This is regarded as a component of the milestone for validation. This is well-represented in the proposed schema in *Figure 8.13.*

9.2.5.2 Time-cost management and software adoption (4D & 5D)

The architect, structural or civil engineer, MEP, BIM manager, quantity surveyor, construction manager, facility manager, and contractor are the parties in charge of the 4D BIM uses (not just visualisation) and 5D. Some of the 4D BIM uses stated during the interview include site layout, clash detecting, scheduling, safety, constructability and environmental management, and monitoring. These uses are managed by the responsible parties mentioned in the study *(Table 8.10).* As claimed by the interviewee, the 4D BIM, together with the digital project documents, is a valuable source of knowledge and assists in project decision-making. This is also represented in the proposed schema.

Nevertheless, a vital thing that should be noted is that some aspect of the 4D BIM uses exist during the design phase, however the main field of implementation is during pre-construction and then the 4D monitoring in the actual construction. All models (architecture, structure, civil, and MEP) are well-established and detailed at this stage. All the data at this stage is bounded by management of time in regarding planning with an estimate of time and construction resources required. This is all converted into precise construction schedules, including tasks, elements, and dates, as well as the construction firm, equipment, and material requirements. The responsible party in the proposed schema is the QS or the cost consultant for 5D BIM cost considerations. The contractor is also responsible for the QS’s duties. As such, all the QS costing procedures would be managed the contractor. The participants mentioned that the responsible party for individual activities would vary in accordance with the project's contract/procurement route and other form of agreements.

The software for the 4D and 5D is also of interest to the contractor to connect the software and the model. The contractor should be duly licensed to use the 5D software. This should be made known in the BEP. Unless the company does not use 5D software, then a resolution for the integration traditional software the contractor uses can be applied to the process. The study mentioned using Openformat to enable a seamless connection between the costing software and the model. The contractor could either acquire 5D BIM software or resolve to link the model with the parties' applications. Additionally, this needs to be discussed earlier so that more options can be explored and any rework or overruns can be avoided. This issue was considered in the information management schema.

9.2.5.3 Interoperability between software

When employing software for quantity take-off or linking software that requires IFC, the interviewee believes that the quality of the IFC model must be validated. This is a significant challenge mentioned in the paper when exporting to IFC. It was noted that when the IFC is developed internally, it is easier to ensure its quality because established templates and standards are employed in the model. They claim this can aid in the correct generation of the IFC. However, when dealing with models from third parties, controlling the integrity of the information becomes more difficult. The respondent suggested that exporting data from the original software to a spreadsheet/ database, such as Structured Query Language (SQL) and later linking it to the cost documents could be a solution. They stated that no known solution exists but that each case should be examined and resolved as it arises. The study's proposed option is to adopt an open format such as IFC, nonetheless, additional training and skills to implement it are required for it to perform well and without substantial difficulties. This could be delegated to the contractor. The study considers quality assurance and validation to guarantee that the IFC will be tested for compatibility as the project progresses.

9.2.5.4 BIM-to-field

The schema considered coordination for the model's use on the site, including visualisation, design interpretation, and health and safety issues. For simulation, cranes, the installation of elements, and the defined different areas, the Revit 3D model phasing technique was used. The interviewee mentioned that this process allows for model checking. For the proposed schema, the most notable advantages of the use of technology on the site are ensuring updated models and correct revisions. In addition, the proposed schema considers construction coordination and simulation during construction. Another consideration in the proposed schema is BIM-3D laser scanning integration. According to Isa & Lazoglu (2017) A *laser scanner* is a technology that uses particular laser light and image sensors that are strategically assembled on a moving structure, which is often positioned and structured on the ground with a tripod support in front of an object or area to be scanned.

BIM-3D laser scanning integration is yet to gain popularity in construction practices. However, significant benefits in managing information in construction could be realised by adequately integrating BIM with data from 3D laser scanners (Pica & Abanda, 2017). Evidence of 3D-laser scanning integration for different BIM applications in construction has been explored in the literature (Isa & Lazoglu, 2017; Bosché *et al*., 2015; KIM et al., 2015; Mahdjoubi *et al.*, 2013; Xiong *et al.*, 2013), but none of these bodies of literature explains its applicability in managing information for construction projects. Therefore, one of the ways it could be deployed for information management is proposed in this study, as shown in *Figures 8.13 and 9.1*.

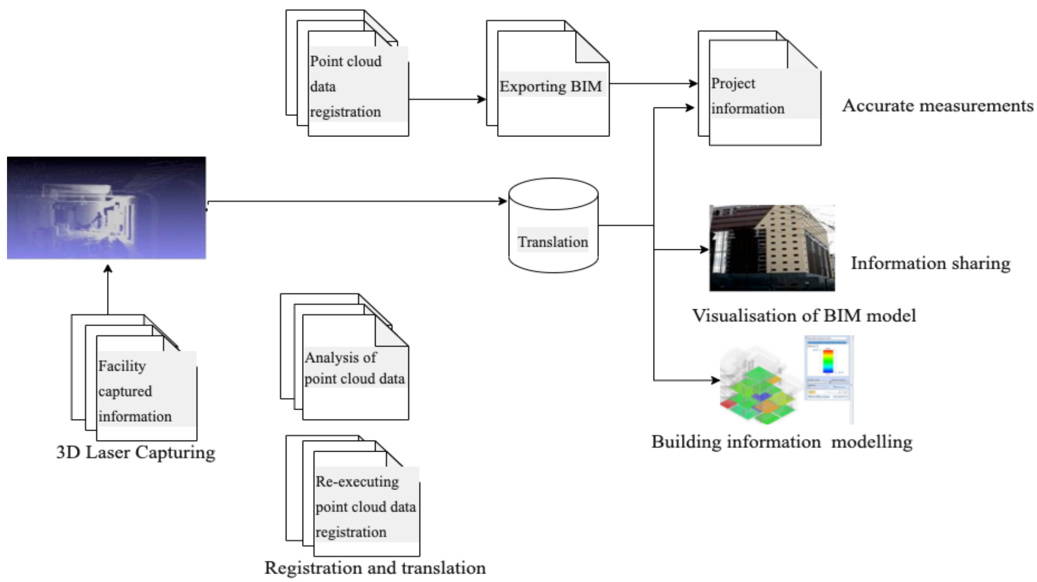


Figure 9. 1: *Integration of laser scanning into the developed model*

Software considerations are also a priority in the use of laser scanners for information management. The software would integrate seamlessly to allow easy viewing and measurement of the point cloud as well as export standard industry file types. An interviewee in project 'A' explained that the adoption of laser scanning in their project enables the accurate coordination and design of new elements within the existing structure. Thus, it enables them to get accurate information needed for the new project. Another simple and valuable laser scanning application involves scanning in the construction phase to guarantee that the work is executed as planned. In the absence of the context of yet-to-be-installed construction elements, most construction challenges cannot be discovered by ordinary viewing. Therefore, it is a technique considered to be the fastest and most accurate way to capture the complete job site so work can be evaluated. This consideration was proposed in the schema and considered viable by the participants.

9.2.5.5 Drawing consultations on site

During the conversation, the generation of drawings in conjunction with the models on the site came up. The possibility of drawing generation on site was stated to be a possibility. From their perspective, it would be challenging to eliminate paper completely from the construction site. However, the industry is gradually moving in that direction. As a result, they stated that designs are still essential for construction. They confirmed that those who construct still require standard details to be followed during construction rather than spending time on the model every time. Paper drawings were visible on the project's "B" site, particularly in the installation sections. Although the proposed schema gave little consideration to this, it is hoped that adopting digital technologies such as conversational artificial intelligence (Conversational-AI) and immersive technologies (such as augmented, virtual, or mixed reality) would tackle this problem. For example, by employing conversational AI, construction teams can communicate verbally with the BIM model for faster decision-making and collaboration.

The engagement of participants is facilitated via CDEs such as BIM 360. The information management platform prioritises requests for information (RFI). According to the interviewee, the primary difficulty with the RFI is inefficiencies caused by poor communication and misunderstanding. The study advised creating reports with the RFI. These reports would also be uploaded to the platform, allowing the relevant party to respond and document them. A key aspect is that standard forms, such as the usage of graphics, could be used to improve RFI operations. Images and a brief explanation could be included as additional comments to avoid misunderstanding. The proposed schema considers consolidating information from BIM projects into a single platform. This would enable speedy interaction on the management platform between the site, project teams, and other infrastructure on the site.

9.2.5.6 BIM information model documentation

According to the participants, the industry's most prevalent method for documenting as-built documents is taking photographs of the construction activity using a digital camera. The employment of a laser scanner in this process is also quite beneficial. As a result, this process could be enhanced by scanning the site with a laser scanner at each milestone delivery. The points cloud and model could be compared, and any disparities could be evaluated and modified as needed. This is a faster approach, but the contractor must agree to get the as-built data in the same format. The created schema proposed a laser scanner.

9.2.5.7 As-built model update

The responsible party for the as-built model should be agreed upon previously in the contract. This could either be the contractor or the design team. According to the interview participants, the contractor was the responsible party for the as-built model. The participants further justified that the model authorship/ownership should be well-defined in the contract, thus, after the completion of the design, the contractor takes charge of the model for establishing/constructing the construction model. In the event of an onsite adjustment, the contractor would put it into the model, update it, and then validate it. The requirements in the proposed schema were to specify obligations, as well as the as-built model's responsible party. Furthermore, the contract should clearly define who is responsible for each task so that any inconsistencies in the software for the information exchange process may be corrected. The proposed schema also outlined the tasks for each responsible party.

9.2.5.8 Soft landings initiatives

According to the participants, a "soft landing" was considered the project performance enhancement process in the UK construction industry. This has been discussed in Chapter 2 of this study. However, the two case study projects did not consider soft landing initiatives. As a result, its inclusion in the proposed information management schema was considered a reasonable option.

9.2.6 Handover and closeout

9.2.6.1 Handover planning and process

The proposed schema also took into consideration the handover of the asset information model and construction papers by the contractor to the O&M/facility manager at handover. Participants specifically mentioned the developed designs, as-built model, and O&M instructions as deliverables during the handover phase. They added that the information at this stage/phase is typically delivered with the CDE acting as the delivery medium and is subject to review and approval by the client or the BIM manager. For example, in project A, where a laser scan was performed on the project, a lot of questions arose regarding the disparities between the laser scanning result and the as-built model. To correct the differences, the contractors had to update the model. Validating the modified as-built model in the proposed schema was considered necessary during this step. The verification at this stage ensures that all model parameters are consistent with the site updates. Laser scanning could be introduced as an extra layer of assurance for the client or project manager, as adopted in this study.

9.2.6.2 Project delivery format

The proposed delivery and handover information model also considered all information components, requirements, flow and exchange as they were considered in the pre-design through to construction. As such, the participants considered the introduction of information components at the various construction phases as task lists for the information expected in the models at these phases to be a reasonable alternative. However, it was suggested that the format for the delivery should be agreed upon from the project inception as mentioned in the previous stages to have a smooth delivery process and to enable software interoperability with the operating systems. They also emphasised the need to adopt the agreed-upon format throughout the process.

9.2.7 Operation and management phase

9.2.7.1 Information linking and management

The contractor was charged with linking the information model to an external database in the proposed structure. This database was supposed to be integrated with the operations software. In terms of the responsible party, it was suggested that it could be someone who understands key options, such as the BIM manager or the client. According to the explanation, the person responsible for this function should comprehend the strategy for how the project will be maintained and the associated responsibilities. This concern was also taken into account when developing the schema.

9.2.7.2 Information exchange software for facility management

The contract should outline the format of exchange as well as the compatibility of the BIM model with the operating systems. For example, in the information model, the customer or owner would specify how he wants to get the information. One interviewee, for example, indicated that while specifying the information that would be accessed from the model, a PDF with a link to each object in the model was prepared. The PDF format provides the owner with complete project details, including warranties, asset operations, and maintenance. Thus, the particular information need not be displayed on the model but will instead be available via a link.

In contrast, the second interviewee stated that the information in the model is accessed from the model in addition to the COBie format as the accepted standard for information sharing during the operation phase. Another point raised was the unusual issue of employing COBie. Nonetheless, COBie has been used in several successful applications. So, the most important thing is to ensure that the way of recording information at this step is appropriately specified from the start of the project and adjusted for 'handover testing' to identify, predict, and overcome any issues. This idea is incorporated into the developed schema.

9.3 Chapter Summary

The chapter explained the qualitative approach used for the validation process. It then proceeded to discuss each of the topics addressed in the schema in connection to the study's findings. Each topic was evaluated based on how it related to the perspectives of the interview participants and how they were handled in the projects for the case study. These were compared to the components of the developed schema to identify any flaws in its design. In addition, a summary of the validation of the schema was reviewed.

Chapter 10

10 Conclusion and Recommendations

10.1 Chapter Overview

This is the concluding chapter of the study. It summarises the entire study, from the background, the aim and objectives, processes, and requirements of BIM IM, collection and analysis of data to the results and findings. The research design and methodological techniques were also covered including the adopted methods to align with the aim and objectives as presented in the chapters. How the chapters were organised to develop an information management schema to improve BIM IM systems in the construction industry were also considered. The study concludes with a discussion of its study's limitations and suggestions for future research.

10.2 Summary of the Study

The information exchange throughout the project life phases has nevertheless remained a significant challenge in the industry because of the diversity of the construction sites, the project complexity, and the fragmentation of the construction sector. This study examines these challenges to improve BIM information management practices. Due to the challenges identified in this study, various methods were used to investigate the study to align with the aim and objective of the study. In addition, the advantages and disadvantages of each philosophical school of thought for the study's objectives were evaluated to conceptualise the study within the proper worldview and epistemological perspectives.

To achieve the aim of the study, the study started with a literature review, with similar studies on information management. The study further goes on to conduct a critical analysis of research methodologies, or research strategies, to establish the appropriate strategy for the study before identifying the most suitable methodological viewpoint. The appropriateness of the various research methodologies for this study was then determined. Several approaches to research design, including quantitative, mixed-method designs and qualitative were further examined. The study then discussed induction as the research approach, a case study as the research strategy, and a qualitative methodological approach, including a semi-structured interviews and document analysis, as the research choice.

The study provides an overview and justification for the qualitative research data collection procedures, analytical techniques, and ethical issues. An overview of the four (4) construction companies selected for the case studies was also provided. The findings from the literature review were justified using the multiple case study strategy:

semi-structured interviews and information from documents (document analysis) of the four construction companies. In the semi-structured interviews, information was gathered from thirty-six (36) purposefully sampled participants who represented the experts involved in information handling for BIM projects in the four construction firms. Thematic analysis was adopted for analysing the collected data. From the results of the qualitative data analysis, the study identified 26 challenges of BIM information management systems. Based on these identified challenges, a BIM-based information management schema was developed across the project life cycle.

The processes for developing the schema were examined in the study. The study divides the schema into four (4) layers: information components, information requirements, information flow and exchange, and an information delivery layer. The four layers were first discussed separately to understand the constituents in each layer all through the project life cycle and then combined to develop the schema. A qualitative approach, which involve a case study of two real-life BIM construction projects in the UK and semi-structured interviews with the experts in the project was used to validate the developed schema. The schema was validated using these two real-life projects as case studies and interviews with experts on the projects as participants. The study explains how the validation process was accomplished. Finally, the results of the validation were analysed and discussed to evaluate the information management schema developed to provide support and enhance the IM processes of activities in the UK construction industry and beyond.

10.3 Study’s Key Findings

This section discusses the key findings of the study to align with the aim and objectives that the study was set to achieve. The first objective observed the needs for and benefits of information management, which formed the first part of the discussion in this section. The second objective examined the BIM principles and standards governing information management across the project life cycle. The study used a qualitative (exploratory) data collection and analysis research design, a multiple case study strategy of four UK construction firms, semi-structured interviews with experts on their projects, and document analysis. The third objective discussed these qualitative studies, which make up the third part of this section. Finally, the results and findings from the developed schema and its validation process completed the discussions as reflected in objectives 4 and 5.

10.3.1 Needs and benefits for information across project life cycle

Information management is the focus of this study for better decision-making, efficiency, and effectiveness, as well as for raising the quality, standard, accessibility, and prompt delivery of the created/generated information. As such, establishing information needs and benefits in the project life cycle would contribute to raising the standards of the final output of the study. The study reveals that information is tied to knowledge, which is critical to solving problems, innovating, and making sound decisions. In the construction sector, IM is equated to information needs because it improves the quality, availability, and timely transmission of information generated of construction projects. The study concludes that information is crucial in developing any industry and must be carefully managed for optimum efficiency. Furthermore, hands-on skills, employee experiences, special or technological expertise, instructions on dealing with complex challenges, best practices of team members, project leaders' expressions of opinions, and feedback from clients or project managers constitute tacit knowledge in the AEC industry.

10.3.2 Guiding standards and principles of BIM information management of construction project life cycle

The flow of data through the design, construction and O&M phases is essential to managing BIM information, and what will make this possible is to explore standards linked to data interoperability and other standards in the information flow and exchange, and management of BIM projects. The study reviewed these standards to provide a comprehensive understanding of BIM information management criteria to achieve the objectives of the study. Topmost among those reviewed are the BS EN ISO 19650-1–5, PAS 1192-2, 3, 4, 5, and 6, BS 7000-4, BS ISO 16739, and BS ISO 55000, among others. Other guiding terms to BIM IM are IM requirements: OIR, EIR, AIR, & PIR and their corresponding model, i.e., AIM & PIM, collaborative practices, interoperability, IFC, DPoW, COBie, BEP, TIDP, and MIDP among others. All these provide the necessary understanding of BIM IM and the terms associated with managing information in a BIM project to achieve the objectives of the study.

10.3.3 Multiples case studies for identifying challenges of BIM information management

The findings from the literature review were justified using the multiple case study strategy. The adopted multiple case study strategies employ document analysis and semi-structured interviews with experts from the construction industry in the UK to obtain their views on information handling in their respective BIM projects. Four case studies were selected and analysed in the study, and the participants for the semi-structured interviews were selected from the case study companies. The findings reveal 26 challenges, and a table showing the results of the adopted strategy was presented in the study. Some of these challenges include non-early involvement of all participating teams all through the project phases, inaccurate/incomplete information along the project workflow, insufficient information needs/requirements, undefined information exchange plan, unspecified information according to each of the project phases, no information management strategy, information deficit due to complexity of projects, undefined organisational structure, unclear pre-planning, and design phase information, insufficient information in the construction phase, inability to access essential information for operation, maintenance and handover phase, and interoperability issues and lack of data standardisation among others.

These challenges were identified in the reviewed literature and confirmed by the semi-structured interviews and the document analysis *(Table 7.4).* According to the findings, challenge "1" (inaccurate/incomplete information along the project workflow) was not a challenge in the documents analysed in case study "A". For example, the information for the designers or the contractor was accurately represented as agreed in the contract. Hence, challenge "1" was not evident in the documents analysed for case study "A," while for the interview analysis, it was a challenge. This implies that the information was not accurately represented, and the parties were not well-informed about the needed information during the execution of the project to efficiently carry out their work. Also, inaccurate information along the project workflow was a challenge in Case Studies "A" and "B" in the interview analysis while it was not for Case Studies “C” and "D." Likewise, the other challenges such as unspecified information according to each of the project phase, no information management strategy, insufficient information in the construction phase, inability to access essential information for operation, maintenance and handover phase, interoperability issues and lack of data standardisation, non-coordination of information in the BIM model and complexity of information management process among others was evident and were clearly identified as challenges in both the interviews and documents analysed in the four case studies *(Table 7.4).* These challenges were addressed in the development of the schema.

10.3.4 Schema development for construction activity management of projects

Based on the identified challenges and aim of the study, a BIM information management schema for construction activities data-flow across the project life cycle was developed. The processes for developing the schema were examined in the study. The study divides the schema into four (4) layers: information components, information requirements, information flow and exchange, and an information delivery layer. The four layers were first discussed separately to understand each layer's constituents throughout the project life cycle and then combined to develop the schema. The layers were established to address the identified challenges. For example, the information component was generated at each level based on the established information in each phase. As such, the information components layers identified the information constituent at each of the project phase i.e., from pre-planning and programming to operation of the asset. Establishing this information enables each lead responsible party to know the needed information for the particular phase and accurately work towards ensuring that this information requirement is fulfilled for that particular phase. Thus, addressing some of the identified challenges concerning unspecified information according to each of the project phase, unclear pre-planning and design phase information, insufficient information needs/requirements across the project phase and unestablished goals for the generated information.

Likewise, the information management requirements layer defines the various parties and their roles in the project responsible for establishing the information requirement and what those required information needs to achieve in the project. The information in this layer is established while carrying along all project participants including the FM, QS and the legal teams. The information requirements layer also addresses some of the identified challenges including Lack of collaboration and information inconsistency and non-early involvement of all participating team all through the project phases. Furthermore, quality checks and verification at strategic points in the project workflow tackles interoperability issues, lack of standardisation, information rigidity and insufficient information in the project workflow. As such, the developed schema addressed each of the identified challenges to achieve the aim and objectives of the study.

10.3.5 Validation process of the developed schema

The analysis of the validation process was based on each of the phases within the project life cycle. The process started with the pre-design phase, which examined the project brief, planning, programming, procurement method, and responsibilities of the participating teams from the onset of the project and in the development of the information requirements at this stage (i.e., the EIR and the AIR). The results of the validation processes confirmed the validation of the schema as this information is well-represented in the developed schema. However, some very important points were emphasised during the validation process. First, regarding the procurement method, the study reveals that although the IPD procurement route was proclaimed by various studies as the most effective strategy when using BIM, its implementation is very challenging. It thus concluded that the procurement method should be according to the project type or construction type or as agreed to be adopted in the project. Although from the findings, the adoption of IPD as proposed in the study was considered appropriate. The second point raised during the validation process concerns the involvement of all parties in developing the requirements at the pre-design phase. The project management team and not the client, developed the information requirements at this stage based on his consultations with the other parties and therefore helped to contribute to quality improvements and budget reductions for the projects. Also, the study suggests that this particular phase should be prioritised and well-addressed in developing a project to record minimal errors in the information management process. The reason being that the information created during this phase is essential throughout the project life cycle. This information was included in the suggested schema, which also clearly outlined the information components for each phase.

The design, pre-construction, and construction phases were addressed on the basis of the defined criteria in these phases. From the study's findings, these criteria include the involvement of all responsible parties throughout the design phase, quantities and cost estimation processes, software adopted for 4D and 5D BIM, coordination and simulation processes, interoperability among software, BIM-to-field, consultation of the construction drawings on site, BIM information model documentation, as-built model, and transitioning of the facility model to the owner, Also, as signified in the study are the soft landing initiatives, handover and closeout, and the delivery of the deliverables to the user. At the design stage, the proposed schema reflected the participation of all responsible parties. However, it highlighted the management of the phase by the designers (i.e., the architects and engineers), and supported by the BIM managers to establish the CDE and collaboration. As the establishment of the above information during this phase coincides with those confirmed in the projects by the interviewee, the findings from the validation process considered this information viable at these stages.

The pre-construction and the construction were considered simultaneously in the schema due to information overlap in these phases. Various information was included at these phases, including the quality checks and verification at more strategic points during these phases than in other BIM construction operations. The validation process helps to guarantee that IFC compatibility can be tested as the project progresses to avoid the issue of non-compatibility of software during the information transfer process or interoperability The digital technologies such as conversational AI, immersive technologies, and laser scanning during this process was considered viable by the study. However, according to the interview conducted, it is an area that is the most challenging to most construction firms. Additionally, technology is constantly changing which makes it even more challenging. Construction industries, therefore, need more expertise in implementing construction projects especially concerning information management strategy.

The validation process was concluded by analysing the information regarding soft landing initiatives, handover and closeout, and the delivery of the as-built model. The interviewee considered the inclusion of the SL initiatives very practicable, despite not specifically considering it in selected case studies. However, because most current construction projects give little consideration to SL initiatives, this explains why many challenges still need to be addressed during these phases. As such, apart from the validation of notable information in the BIM model in the developed schema by the study, it suggests consideration of the SL initiatives and other criteria, such as consideration of the information components to outline the exact information needed at each phase of the project life cycle and the participation of all responsible parties including the client and facility manager, from the onset of the project. Other information include the adoption of technologies (which is considered an area to be fully explored in information management), defined quality check and verification, most especially to resolve issues arising from interoperability, a responsible party to lead the various projects phases while consulting and carrying the other parties along, the establishment of a program of work to ensure that each participant is aware of the information to issue or receive and acted upon, and the management of this information via a central repository. However, data security would be a priority if the repository is managed by a third party.

10.4 Implication for Practice

The findings from this study substantially impact different types of projects across the project life stages of preparation and briefing, pre-design/design, pre-construction/construction, handover, O&M. While the project type influences the procurement procedures for any project, the study discovered that IPD is the preferred option for BIM projects. It was regarded as a viable alternative in the literature even though it is extremely challenging to implement due to the challenges involved in bringing all participating teams from diverse backgrounds together. Furthermore, in an IPD procurement approach, identifying the level of participation of each party or how much they can contribute to the project is frequently challenging. The study discovered that involving all parties from the project's inception helped to determine the unique tasks of each project's participating team. It also enables them to understand the project brief and establish a complete understanding of its limits and implementation plan. However, this phase is not often addressed as thoroughly as it should be. The study concludes that these should be prioritised and adequately addressed in the creation of any project because they are critical to information management. Furthermore, the industry should not leave anyone behind, and the 3Ps (people, process, and product) must be their watchword. However, champions at all levels are required to make the most of information, from the lowest level to the Chief Executive Officers.

Simplifying the tasks/roles and responsibilities of the project parties is necessary at the beginning of the project to reduce the information management challenges. This primarily ensures that all parties have access to the necessary project documents and that each team understands their roles and responsibilities (responsibility matrix). Another essential consideration in information flow and exchange for efficient management is software compatibility. Although the software employed and the method of transferring information would have been specified in the BEP, the investigation discovered that the software used for information exchange in most projects is incompatible. Instead of using the agreed-upon software, the parties involved employ their preferred software, which is frequently the source of interoperability challenges. As a result, the findings propose that IFC should be assessed for compatibility continuously as the project progresses, as well as focus on information accuracy and interoperability of various systems employed. The study also revealed the importance of data quality verification and monitoring. Defining data validation processes is crucial throughout the project operations, especially when changing milestones.

Another significant revelation in the study is the challenges surrounding information or data security. Storing information in "dropboxes" constitutes many risks to the information and may put the organisation in a hazardous situation. Some organisation even brings their information into the actual work, which brings a lot of risks to the operation management. As such, a single system and a universal set of security standards could be used where compliance could be achieved. Data security also goes beyond security. It is also about ownership of the data. It relates to access to the data, and companies should be mindful of who owns the data. For example, operation teams in asset management sometimes own the asset but not the asset management information in the model. Some companies in the construction industry manage contract information management alongside the actual work, which brings a lot of risks to the operations and limits the ability to optimise and innovate in the process. In addition, information is a living system. It requires ongoing improvement, and the requirements change. It requires or demands continuous change, and technology evolves swiftly as industries are constantly altering technology. As a result, getting all aspects of the information management strategy in one go takes a lot of work. As such, the industry should be prepared to continue to innovate and optimise to obtain the full benefit BIM information management system across the project life cycle.

10.5 Implication on Policy

The government and its subsidiary authorities in various countries such as Singapore, United States, Australia and Finland have played a key role in demanding and encouraging the adoption of BIM, albeit through different approaches, strategies, and initiatives. In the United Kingdom, BIM policies range from a firm mandate of Level 2 BIM, which corresponds to '3D collaborative BIM,' in all publicly procured projects beginning in 2016, to other encouragements and support initiatives through legislative changes. As a result of the UK government's action, the adoption of BIM in the construction industry has accelerated in recent years, and this goal is on track to be met. To propel this initiative forward, policy makers have continued to improve on previous BIM protocols in order to create better guidelines and new protocols/mandates. Because this study is based on BIM information management throughout the project life cycle, it will benefit policymakers in a variety of ways. For example, the outcomes of the study could aid in the development of new BIM information management protocols in terms of the involvement of the participation parties be involved in the project from the start to completion of the project and quality checks and verification at various points along the project workflow to address interoperability issues. This study also contributes to the parties' understanding of an improved BIM IM process, the role of technology in the process, and a comprehensive understanding of the policy's impact. Furthermore, by incorporating project carbon information into the developed schema, the study will contribute to the government's initiatives to digitalise the construction sector and its transition to net-zero carbon.

10.6 Limitations of the Study

The scope of the study is limited to projects in the UK construction industry. As such, the main limitation of the study is its scope. The study's data collection was restricted to UK BIM information standards and frameworks and was conducted entirely in the UK. Therefore, the findings of the study should be interpreted in the context of the BIM environment in the UK. Even though the study used a multiple case study strategy and achieved triangulation, which is unique to a mixed-methods approach in quantitative research, generalisation could not be predicated in other countries other than the United Kingdom.

10.7 Direction for Future Research

It is particularly challenging to "investigate everything" about study. For continuity, there is always a section that requires additional exploration/investigation. This study is not left out. Although the study critically examines the challenges in BIM information management, there are still areas that require additional research. To enhance IM control and use the generated information all through the whole process of design, construction and O&M, future research could look into information management techniques with a focus on each project life cycle, particularly to accomplish a more comprehensive study into the techniques involved in every part of the project phase.

For example, the information components in the preparation and briefing (pre-design, such as site investigations and analysis, among others) are external to the BIM process. Future studies could delve into the concept of bringing in BIM specialists in this field. In addition, BIM applications during the procurement and commissioning stages could be created among the BIM uses or model uses. This would provide more excellent information on these phases as they relate to the overall BIM construction process. Furthermore, future investigation could look into the relationship/connection between the model's element classification systems and the contents of the bills of quantities. Finally, the characteristics and needs of the asset information model could be addressed during the handover. For example, asset management ownership sometimes owns the asset but not the asset management information in the model. This is another area that could be investigated.

Furthermore, studies on how to proceed with data security (in connection to data ownership), data quality, and compliance verification could be relevant areas for future research. Data security and quality have been revealed to be critical issues on BIM projects, and guidelines for ensuring that the model is well protected with the necessary design, LOD and information would be helpful for future research. Finally, the study is a qualitative inquiry conducted in the UK. As a result, this study is limited to studies undertaken in the UK, while the modules presented here could be adopted and applied in other nations. Further research could broaden the study's scope beyond residential structure, generalise its findings, and improve its dependability.

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Appendices

__Appendix A 1:__ Sample Consent Form

Research Title: A BIM-based Information Management Schema for Construction Activities Data-Flow Across Project life cycle

Consent Form

This form's objective is to ensure that you have received all the necessary information concerning the research project and wish to participate. So, please read the following statements carefully. If you are happy to participate in the interview on the above-named research and all information points have been covered, please sign and date the form in the spaces provided below. You will be given a copy to keep for your records. If you are unclear on any point, please ask the researcher using the address below.

Consent statement

I have discussed the purpose of the research with the researcher. I have read the information sheet and have asked questions to understand what I need to do if I participate. I have:

- Read the participant information sheet and the UWE Policy Notice before being asked to sign this form.
- The opportunity to ask additional questions related to the study.
- Satisfactory answers to all my questions concerning the research.
- Agree to the use of anonymised quotes in the study's final report.
- Permission to withdraw at any time without giving any reason.
- Agreed to take part in the research.
- Permission to refuse to answer any question during the interview.
- Permission to withdraw my contribution from the study at any time as indicated in the information sheet
- Given my permission to the researcher to take notes, audio recordings, photographs, and video to be used for research purposes.
- Agreed that you could contact me again.

I consent/I do not consent.

Participant's information

Name (Print)…………………………………………………….………………….

Signature…………………………………………………………Date……………….

Contact number..……………..………………………….

Email: ....……………………………….

If you have any questions about this study, please contact:

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If there are any concerns about taking part in this study, please contact Researchethics@uwe.ac.uk, the Faculty Research Ethics Committee.

Appendix A 2: *Semi-structured interview questions*

I appreciate your coming for the interview. I am a PhD student at the University of the West of England, in the Faculty of Business and Law, Department of Business and Management. My research interest is focused on construction informatics. The interview today aims to obtain your views on how information is managed and handled on construction sites across the project life cycle to facilitate effective construction consistency on site.

The responses will be anonymised, and no part of them will be used to identify you. The responses will strictly be used for academic purposes, and all responses will remain confidential. You are free to opt out at any time.

1. What is your role, discipline, or position in the industry?
2. As a/an--- (role). What are your responsibilities?
3. How long have you been in the industry?
4. Can you give examples of information created during construction activities or across the project life cycle?
5. Where is each of this information created? How are they created? Is it by consultations, discussions, or meetings among the participating teams? Individually or collaboratively?
6. If collaboratively in 5 above, do you use any collaborative tool? If so, which one?
7. Who is the information created for?
8. Is there a particular protocol or process you follow when creating or transferring the information on sites?
9. How does information move across the project life cycle? Verbally/technologically-electronically/paper-based? or email.
10. If technologically/electronically above, what technology do you use to communicate?
11. Presently, do you use any technology for creating or transferring information on your construction sites, electronically or otherwise? If so, how do you store the information? One drive, WhatsApp group, or email to transfer and archive? Cloud-based?
12. Can you give reasons for your answer to question 11 above?
13. Does collaboration enable remote working? Or how did you cope during the lockdown periods?
14. How is the information shared during COVID-19, and how has it impacted or improved your information management structure?
15. In your own view, what do you think are the best ways to manage information on construction sites? i.e., how best could you create the information? Stored? Transfer? Used? Reused? Is the information secure?
16. How is the information validated? When the information is created, how is the quality of the information validated? Who validated it? Some information is created onsite during the execution of a project. How is this kind of information validated?
17. How does the quality of the information grow?

18. How do you relate or include information relating to zero-carbon or sustainability across the project's life stages?
19. Any additional comments that you think may be useful to me for completing the project?

Thank you for your help!

Appendix A 3: *Interview questions for the validation process.*

I would first appreciate your coming again to be interviewed. The purpose of the interview is to obtain your views on information handling in your BIM projects in order to validate the proposed management schema developed in my doctoral research. Your responses will be anonymised and no part of them will be used to identify you. The responses will strictly be used for academic purposes, and will remain confidential. You are free to opt-out at any time.

The researcher began by providing a brief overview of the purpose of the interview and what the participants could expect if they agreed to participate.

1. What is your role, discipline, or position in the industry?
2. As a/an--- (role), how do you contribute to information handling in this project?
3. What are the criteria that determine the competency of your teams to participate in a project?
4. Do you develop the responsibility matrix for this project? If so, who developed it, and what procedure did they follow?
5. Who develops the EIR and the BEP in your projects?
6. Do all parties participate in the BEP development of a project? Does the development of the BEP specific to a particular participating party, or did you contract it to a third party?
7. Do you have a BIM manager? If so, what are his responsibilities?
8. Who is in charge of specifying the BIM requirements? Is it specific to a particular participating party?
9. Who, in your opinion, should contribute to establishing the BIM project requirements? Is it all participating parties (designers, owners, contractors, subcontractors, and facility managers)? Is the establishment of the requirements a prescribed procedure or a collaborative effort?
10. Is setting the requirements based on specific guidelines or rules, or is it project-specific?
11. What type of procurement route/contract did you adopt on this project? In your own view, what is most commonly used in BIM projects? (DB, DBB, or IPD) Do you believe the contract or procurement method impacts the information handling of projects in the BIM process?
12. Do you believe that the requirements should be more generic or specific?
13. How do you create the CDE for the project? Is it a requirement of the employer or BIM manager? If so, do you have the opportunity to express your thoughts when setting the CDE?
14. Is it possible to have only one CDE throughout the IM process? If so, who do you think should be accountable for it?

15. How is the CDE for each type of your project created? Is it a requirement of the employer, or do all parties have the opportunity to express their thoughts?
16. Do you request information that will be used in the operation phase from the commencement of the project? When, in your opinion, should this information be required?
17. Do you agree that the facility manager should be engaged in the AIR definition?
18. Who established the LOD?
19. Do all parties agree on the type of software, software version and interoperability format? If any interoperability issues occur, how is it resolved?
20. Do all parties agree and adopt OpenFormat (IFC) as the exchange format? If so, what are the benefits? If not so, what do you usually use in your project?
21. Is Cobie used as an exchange format in the project? If so, what are its advantages? If not so, what do you use?
22. How do you manage the information once you have defined Cobie as an exchange format (Excel or XML)?
23. How is data or information secured in this project? What kind of security is in place for information handling in your BIM projects?
24. Do you have a procedure for dealing with a problem such as software incompatibility, clash detection, information gap, or quality assurance that arises on site?
25. Who is in charge of carrying out the clash detection? How are the results of the clashes communicated to the rest of the project parties?
26. How do you develop the TIDP? Who develops, oversees, and ensures its appropriateness to the project?
27. Is there a Master information delivery plan in place for the project? How do you decide on the information delivery?
28. Is each team responsible for delivering a single model?
29. How do you define the owner of the model?
30. What are the challenges you faced in the different phases of this project?
31. Is the breakdown structure of your work defined at the project inception according to the BIM uses? Is this the responsibility of the contractor as stipulated in the BEP?
32. In the project phases, who is in charge of the quantity take-off? Is it possible to validate the quantity take-offs at the different stages it occurred?
33. Are the quantity take-offs done in accordance to how it was defined in the contract?
34. Who is liable for 4D and 5D BIM
35. Are the model's parameters utilised for planning and costing during the design phase? Does it need to be altered for any reason during production or manufacturing?
36. What software is used to calculate and plan 5D BIM? Does interoperability between the software compatible with the design phase models?
37. What is the software for BIM-to-Field in this project? How is the model visualised on the site?
38. How is the transitioning to the handover process handled in this project? Is all information needed for operating the building contained in the model?
39. Does the facility manager need to know the format of the data he needs to use in his operation and facility software at the commencement of the project?
40. Do you consider exporting to an external database for the O&M manager to use?
41. Do you believe the model should be linked with a database by the contractor? Or the O&M/FM manager should be liable for the as-built models and documentations?

42. How does data from the model's earlier phases interact with O&M model/system?
43. Were there any challenges you encountered while utilising COBie in this project?
44. How does the model progress from one phase to the next? Who is in charge of the progression?
45. How and where is the model saved after the project is completed? How is information/data security maintained?

Thank you for your valuable response!