BIM-ENABLED RECOMMENDATIONS FOR DIGITAL HANDOVER PROCESS IN THE HIGHWAYS SECTOR

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List of Abbreviations

AIM : Asset Information Requirements

ADMM: Asset Data Management Manual

AM : Asset Management

BIM : Building Information Modelling

CAD : Computer Aided Design

C / I : Civil Infrastructure

COBie : Construction Operation Building Information Exchange

CMMS : Computer Aided Maintenance Management System

CAFM : Computer Aided Facilities Management System

EIR : Employer Information Requirements

FM : Facilities Management

HE : Highways England

NIST : National Institute of Science and Technology

IAM-IS : Integrated Asset Management Information System

IFMA: International Facility Managers Association

SRN : Strategic Road Network

RIS : Road Investment Programme

CDM : Construction Design Management

HE : Highways England

O&M: Operations and Maintenance

IFC: Industry Foundation Classes

CAD: Computer Aided Design

2D: Two Dimensional

3D: Three Dimensional

O&M: Operations and Maintenance

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Dedication

I dedicate this thesis to my lovely older sister Mine Pinar Bayar

Declaration

This thesis is presented as an original contribution based on Doctor of Philosophy Research at the University of Salford, Manchester, United Kingdom and has not been previously submitted to meet requirements for an award at any higher education institution under my name or that of any other individuals. To the best of my knowledge and belief, the thesis contains no materials previously published or written by another person except where due refence is made.

.... (Signature)

Muhsine Sanem Bayar

.... (Date)

Abstract

An efficient maintenance of the UK's highways network is of critical importance to the country's economy and among the top priorities of the government and public agencies (e.g. Highways England). The public highways agencies have huge data sets related to asset management and maintenance. However, those data sets are usually held in disparate platforms and have been historically developed using multiple standards and formats. As a result, full value of such data is often not fully realized. The highways construction sector is having major issues related to information losses, duplication of work and unreliable asset information due to disparate formats and archives. Effective management of asset data and availability of reliable information as and when needed could bring in key benefits for effective management of the highways network.

Hence, timely mandate of UK Government's BIM Level 2 use in all the public construction projects is targeting to ensure smoother transition of information from project design and construction to maintenance and operation phases of highways infrastructure assets. Implementation of Building Information Modelling can streamline asset management by enabling evaluation of overall sustainability (i.e. economic, social and environmental) of projects, and assisting facility managers to make informed decisions about the facility by providing accurate up-to-date life cycle information.

Although the concept of BIM has been around for years, its integration into the Highways sector has been relatively slow when compared to Building sector. This study investigates the current status of Building Information Modelling implementation within the Highways development projects with an intention to identify areas of issues and challenges to inform future projects for improved data management for asset handover. Current literature highlights that there is little research has been done in the highways sector in terms of newly adopted BIM workflows. The role of clients is crucial to lead the projects. They have to understand the adopted process with its dynamics hence they need clear guidance on how to effectively lead the projects. Therefore, this research aimed at developing BIM-enabled recommendations to improve data management in highways civil infrastructure handover practices for highways sector clients in the UK.

To achieve this aim, a critical review of the literature on highways construction industry, data handover practices and BIM was undertaken. The researcher explored the current barriers in the highways industry relating to asset maintenance and data management, as well as data handover challenges, effects and relevance of BIM implementation to manage the asset lifecycle. The research adopts multi-case study approach within the highways construction development projects in the UK. The research acquires qualitative approach to have an in depth understanding of state-of-the-art in practice. The research took

an interpretivist and value-laden approach and conducted 15 semi-structured interviews to collect data from the case studies as well as document analysis and observation. By applying so, the researcher investigated major causes of loss of data, as well as maturity levels of BIM and its benefits, and challenges for its implementation.

The collected data from the qualitative study was analysed, a cross-case study analysis was provided as well as the individual case study analysis. The critical aspects affecting the highways schemes were identified. To achieve the product of the research, the challenges of data handover in the highways construction industry further categorized into four main groups namely process, people, commercial/contractual and data/knowledge transfer. Further, to validate the developed recommendations the researcher conducted a focus group discussion with 12 built environment experts. The recommendations were validated and enriched with the expert views.

The research concluded that there is a meaningful relationship between BIM maturity and the success of the data management process in the highways construction. That means, the success of the data management mainly relies on the effective implementation of BIM.

CHAPTER 1

Introduction to the research

1.0 Introduction to Research

The key focus of this research is to improve asset data handover and lifecycle data management practices within the public-sector construction projects in the Highways Civil Infrastructure sector in the UK. This introductory chapter provides the context and background of the research topic. In addition, it discusses the research problem, the aim and objectives, research questions, and the significance of the research. It presents the expected contributions to knowledge that might emerge from the completion of the research, a brief map of the methodology, and the overall structure and layout of the research. This chapter provides background information to understand the need of this PhD research. The aim of the study is to develop BIM-based recommendations for the public-sector construction clients for enabling data management of the construction assets in Highways Sector, which is currently absent in the literature. The guide acts as a tool for the public clients and their asset managers to enhance the current process of infrastructure asset data handover.

1.1 Introduction

The construction industry is the backbone of the UK government's industrial strategy and has been recognized as a key contributor to the growth of the UK economy (Cabinet Office, 2012). It represents 7% of the UK GDP and £110bn per annum of expenditure (Cabinet Office, 2012). UK Government has concerns about the growth and efficiency of the UK construction market for several reasons such as domestic and international markets, emerging economy pressures (Cabinet Office, 2012). In response to these concerns, the government's construction strategy highlights the need for efficiency and reform. The strategy has two main purposes. The first is realising a cost reduction of 15-20% in government construction projects, and the second is to use the purchasing power of the government. UK construction client is the largest client to influence changes in industry standards. The strategy attempts to challenge current business models and practices, replace adversarial cultures with collaborative ones, and demand cost reduction, innovation and growth across the supply chain (Cabinet Office, 2012).

Key priority in the strategy is the use of data and management of information to determine expected project costs, drive out waste, improve efficiency and allow the government to function as an intelligent client (Cabinet Office, 2012). This priority is being realised with the government's BIM strategy (BIM Task Group, 2013), a commitment to fully collaborative 3D BIM on all centrally procured projects by 2016, and the alignment of design and construction with operation and asset management (Soft Landings) (Cabinet Office, 2012).

Construction industry has been passing through an evolutionary phase. Building Information Modelling (BIM) is creating digital prototypes of built assets and this has improved the flow of data through the construction process, and, therefore, ensuring extreme efficiencies. As part of the construction public industry, UK Highways Agency and its supply chain is required to meet this target. The UK's public Highways Agency has huge data sets related to asset management and maintenance (Aziz, 2015). However, those data sets are usually held in disparate platforms and have been historically developed using multiple standards and formats. Full value of such data is often not fully realised.

Maintenance of highways network is of prior importance forming nations' most valuable assets in addition to their fundamental role in the economy (Transport London Report, 2007). Good quality highways infrastructure brings a wide range of economic and lifestyle benefits. They provide access to business and communities. They have broad contribution to local identity and reflect the quality of life. However, the limitations of road infrastructure, is evident where overcrowding and congestion can cause costly delays, pollution and other negative externalities. As they form an important part of human life, and the condition of roads and highway assets are to be managed in systematic way. In the future, highways will be facing increasing pressures and impacts from a range of issues including changing weather patterns, population growth, capacity constraints, shortages of land and capital, rapidly changing technologies surpassing the pace of new infrastructure development (Marshall, 2014).

New concepts and emerging technologies and emerging solutions shall provide a better understanding in the long-term challenges and maintenance of current construction infrastructure. Current tough economic climate highlights the importance of maintaining the highways and makes the best use of technology in providing the best cost-effective service to people, to maintain the integrity of highways for future generations. To achieve this goal, rather than thinking of short-term maintenance, planned and well designed, technology-laden, long-term solutions should be made. In addition, short term repairs are costlier and in time they undermine the integrity of the crucial structural assets.

The potential of Building Information Modelling (BIM) in handover processes provides a more efficient maintenance of highway assets. Efficient data management as enabled by BIM could make highways and other infrastructure assets cost-efficient and resilient. BIM provides a structured framework for creation, maintenance and exchange of asset data throughout project life cycle. Despite its significant potential for an improved project-life cycle performance, research on the data requirements for BIM-based asset management have remained scarce (Becerik-Gerber et al., 2011; Love et al, 2014; Bayar et al., 2016). Beyond building assets, this scarcity is even more notable for large civil infrastructural assets.

1.2 Problem Statement and Research Justification

The literature review indicates following challenges in existing highways civil construction practice;

1.2.1 Lack of an Integrated Approach for Asset Lifecycle Data Management

Lack of clearly defined guide for built asset data management often results in sub-optimal levels of operation during assets' life cycle (Hartman et al., 2008). Even in cases where contractors transfer a rich data set to owners during asset handover (such as warranties, manuals, equipment details), there may be a gradual degradation of the information over the assets' life cycle, resulting in asset facilities being under-utilised. The high cost of asset operations and maintenance within the Highways construction sector is also attributed a very hot climate and there is lack of a holistic approach to asset design, construction and operations. The UK Government's BIM mandate to integrate design and construction of an asset is leading to better asset performance (UK Government Construction Strategy, 2011). The lack of an integrated approach is also evident through the lack of participants of asset users in early lifecycle decision making. This lack of clear definition of information requirements at the initial stage could cause a barrier to benefit realization at the project's completion (Kasprzak, 2012). Currently, there is lack of clarity on what information is required by clients to effectively maintain the facilities, often leading to wide variation on various public-sector highways projects. There is a need to develop a better understanding of the challenges of developing an integrated approach to asset life-cycle data management within the Highways civil infrastructure sector in the UK.

1.2.2 Lack of Standardization & Specific Public Sector Strategy of Asset Data Management for Highways Civil Infrastructure

A review of various best practice indicates that the need for effective lifecycle data management has crystallized in the form of standards, such as BS PAS 55(2015) (i.e., Asset management -Specifications for the optimized management of physical assets), PAS 1192:2 (2015) (i.e., Specification for information management for the capital/delivery phase of construction projects using BIM), and ISO 55000 (2013) standards. However, these standards are too building-centric that some specifications do not apply to the highways assets. Therefore, the highways assets need specific standards due to their own specific conditions. The effective operation and maintenance of a facility is heavily dependent on the retrieval of documents collected particularly in design and construction stage. According to Teicholz (2013), existing approaches rely mainly on handover of hard copies and 2D CAD drawings to owners upon project completion. Such approaches are constrained (e.g. lack of accessibility, inability to update information on 2D drawings).

As part of the UK Government's Digital Plan of Work (PAS 1192-2: 2013), specification for information management for the capital/delivery phase of construction projects using building information models are being followed (BIM Task Group, 2016). These specifications indicate that the handover process needs to start by documenting Employer's Information Requirements (EIR). The EIR is included in pretender documents (which is currently a missing document that needs to be generated by the highways construction clients). These standards (Figure 1.1) promote a collaborative working environment in which information is produced using standardised processes and agreed standards and methods. Standardization of information allows information to be used and reused without interpretation or change. Thus, a collaborative working environment is produced using defined standards.

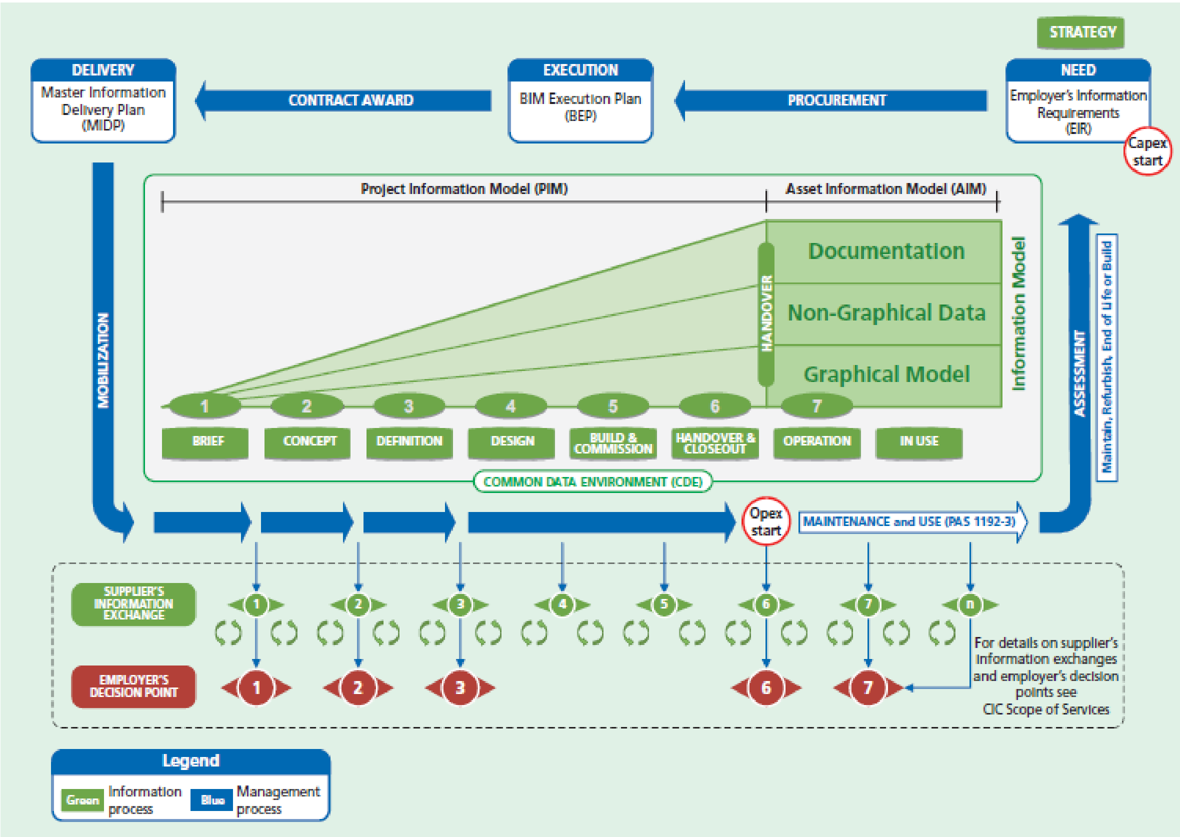


Figure 1.1: Information Delivery Cycle, PAS 1192:2 (BIM Task Group, 2016)

Highways Construction sector is lacking the process development for highways civil infrastructure and lacking a clear strategy from the Government in terms of what data required for the public-sector Highways infrastructure and how data must be collected and retained over a lifecycle. Even though, HM Government's mandate for utilising BIM for all public-sector construction from 2016, there is a need for clear guidance for the highways civil infrastructure public-sector clients and their asset managers.

The highways infrastructure was historically built and there is lack of access to the asset data as and when needed. Relevant asset information, thus, is locked in data silos. (E.g. CAD drawings) or in differing file formats and media (e.g. excel sheets, images), creating problems in accessing information to support the operations and maintenance of a facility. This research therefore, focuses on identifying factors and gaps related to lifecycle data management in the Highways Construction Sector with a view to devise recommendations for narrowing the gap between the design and construction phase, and the maintenance and operation phases. This will facilitate development of recommendations that will help filling this gap, and thus enable lifecycle management of asset data. Lifecycle data management is particularly pertinent considering recent initiatives by the UK Government that focuses on sustainability.

The increasing complexity of construction projects augments the difficulties in the process of information gathering and documentation (Jordani, 2010). Many researchers have highlighted the loss of information from the project design and construction phase to the operations and maintenance phase of the built assets. Furthermore, in the context of buildings, Bew and Underwood (2010) argue that there are information losses associated with handling a project from the project design team to the construction team and the building owner/operator. This information loss has a negative impact on asset lifecycle.

A review of the UK construction industry indicates various efforts (e.g. BIM Task Group, Government Soft Landing Initiatives) to improve standardization and public sector built asset management. Loss of information because of the poor data management has been largely documented in various reports. Fallon and Palmer (2007), highlighted that key stakeholders in the public-sector infrastructure facilities, including designers, contractors, product suppliers, and owners, have huge financial losses by validating and recreating information that should be available in the first place. The industry pays extra to repeat surveys and collect information about already existing assets and information.

1.2.3 Lack of Adequate Exploration of Emerging Technologies in Enhancing Quality of Asset Data Using BIM

Just like all the other construction sector Highways construction is an industry that has traditional thinking and habits. However, BIM based approaches has considerable benefits when compared to traditional approaches. Currently there is lack of adequate exploration of emerging technologies in the highways civil infrastructure sector which causes many information losses and rework. Hardin (2015) defines BIM as use of tools, processes, and behaviours to leverage efficiencies in the construction industry. BIM allows for the presentation of information in an analytical format ensuring consistent data flow. Thus, new opportunities to address traditional communication and coordination challenges are becoming possible because of technologies and process-related improvements, such as Building Information Modelling, Management information systems, and integrated approaches to projects delivery. (E.g. Concurrent Engineering, Integrated Project Delivery). In this context, Love (2013) observes that BIM could provide a catalyst for change, due to its ability to reuse information that has been used during project design and construction stage for lifecycle management of infrastructure.

It provides an effective approach to integrate people, processes, information and business systems (Shen et al., 2010).

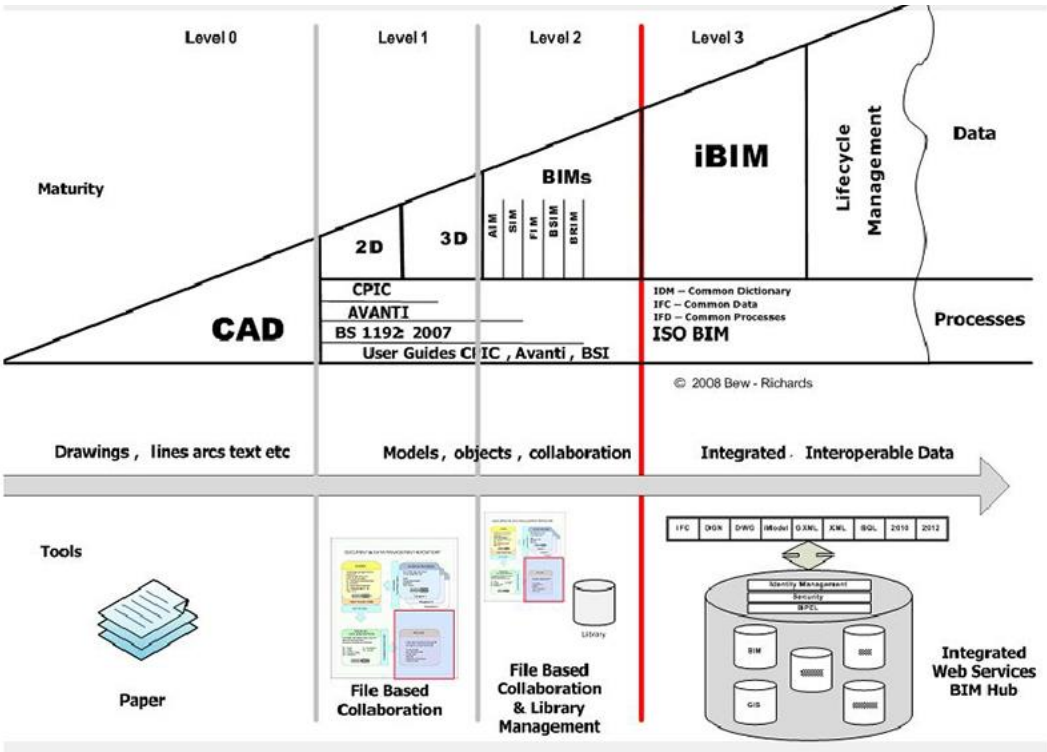


Figure 1.2: BIM Maturity Model (Bew & Richards, 2010)

The use of BIM-based approaches offers considerable benefits when compared with conventional approaches (Eastman et al., 2011). BIM has solutions for both technological and process challenges, to allow for a consistent approach to data management through the asset lifecycle. Figure 1.2 illustrates the various levels of BIM maturity with an eventual goal of having a fully integrated interoperable data (Level 3), thereby enabling clients to gain an advantage through better management of knowledge and organizational learning.

Most of the Highways infrastructure projects are still operating at Level 0 and Level 1 of Maturity, although there are some initial islands of Level 2 compatible projects, 2D CAD still being the most prevalent method of data exchange as well as the traditional habits of the construction supply chain. Literature indicates the reason is mainly complex nature of infrastructure assets depending on their need for multiple data sources. Accordingly, Aziz (2016) includes that the current situation in the highways construction raises issues that are mainly related to information losses, duplication of work and unreliable asset information due to disparate formats and archives. In the current highways sector, historically built asset require an extension of their economic life that can be achieved by efficient data management. Efficient data management as enabled by BIM could make highways infrastructure assets cost-efficient and resilient as BIM provides a structured framework for creation, maintenance and exchange of asset data throughout project life cycle.

In the project lifecycle, the handover process forms the greatest information division bridging the gap between construction and operation phases (Eastman, 2010). The amount of information generated is huge; however, the information is not tailored for upcoming processes and bottlenecks. The existing information should also be merged with newly generated, gathered and structured information. The major advantage of replacing BIM with the traditional disparate methods is BIM's greater ability to control projects with a minimised risk of errors and data loss at the handover for complex and specific built assets (Figure 1.3).

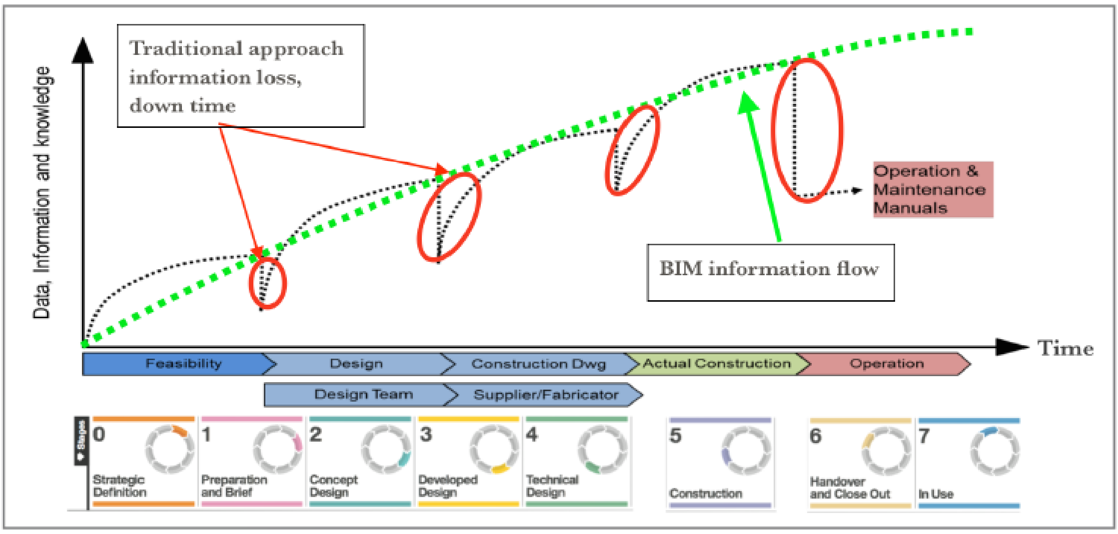


Figure 1.3: Reducing data losses at handover stages using standardized workflows (Eastman, 2010)

1.2.4 Fragmentation in the process

The Highways construction sector requires explicit storage to share and exchange the project information between all stakeholders (Van Nederveen et al., 2010). The sharing of timely and accurate information would help project stakeholders to make more rational decisions and reduce mistakes and rework (Autodesk Research, 2011). Several participants need to cooperate to create one single product that carries the full expectations of the various stakeholders from the owner, to the user, and to the authorities as well.

The construction industry's dynamic, complex and fragmented nature causes problems in sharing information and communication among multiple participants, as shown in Figure 1.4. Participants on both sides of the data handover of the assets have limited knowledge about the project due to traditional data sharing and fragmented data sharing process, as they work in separate spaces.

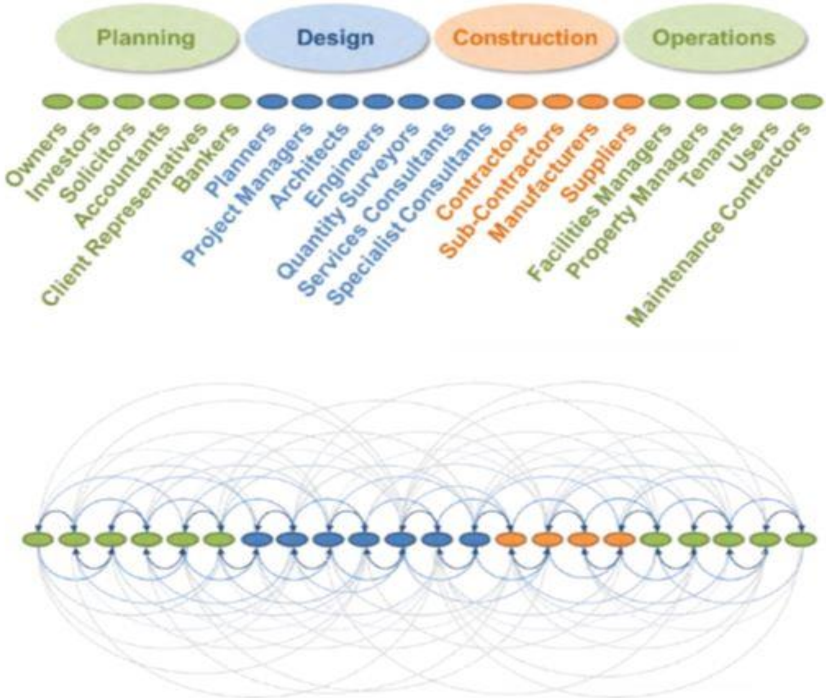


Figure 1.4: Fragmentation of Information sharing pathways in the construction industry (Montague and Slattery, 2013)

There is huge amount of data loss during the information flow among stakeholders of the projects. During the construction of a project, large amount of data is produced and shared among stakeholders. However, when the traditional approaches are being used the information is not tailored for upcoming possible processes and bottlenecks. Existing information should be merged with the newly generated, gathered and structured information as the project grows (Figure 1.5). Current data handover practices require improvement in terms of data protection, accurate data flow and asset data standards. However, BIM could aid to minimize information loss during the information sharing process. As the information artefact grows through the project life cycle stages, more effort required to maintain the data, and more time consuming to access it (Figure 1.5).

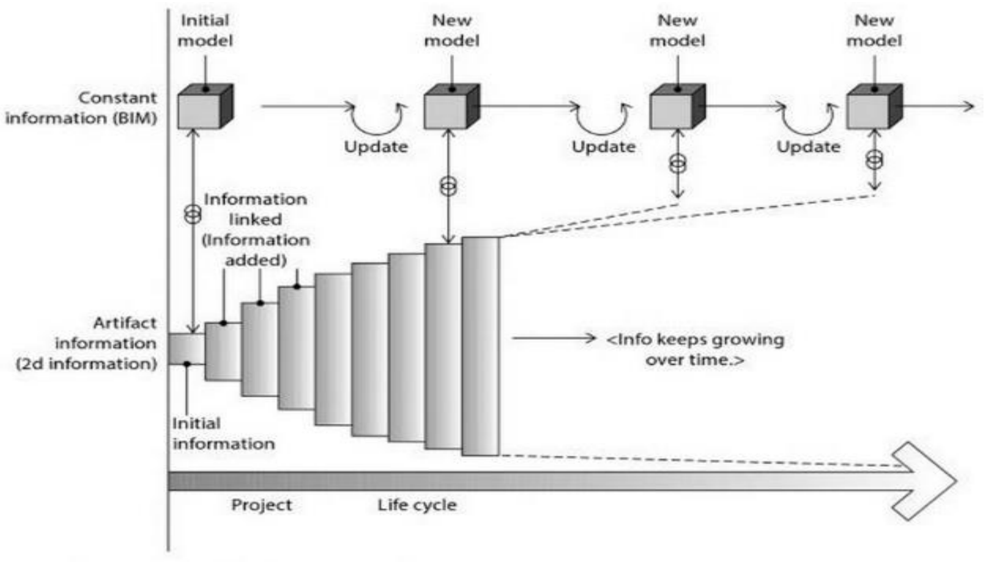


Figure 1.5: Information artefact grows through the project life cycle stages; more effort is required to maintain the data and more time consuming to access it (Hardin et al., 2015)

BIM provides a structured framework for creation, maintenance and exchange of asset data throughout project life cycle. By promoting the use of Building Information Modelling, the UK Government aims to develop standards to enable all members of the supply chain to work from the same data while providing a 'proper basis for asset management after construction' (Cabinet Office, 2011; Arayici, 2015).

1.2.5 Lack of horizontal infrastructure laden approach

Adoption of BIM and the associated open standards, on all public infrastructure projects remains problematic because of the differences between the design requirements of vertical and horizontal (buildings, infrastructure). This highlights the further developments to be done in the context of horizontal infrastructure. The Civil Infrastructure (C/I) projects are different in nature as compared to buildings. (BIM Task Group, 2013). In the C/I context, objects tend to be continuous as in the roads, rather than discrete like windows and doors as in the buildings. Attributes of the continuous objects will often change in value along the object. Location of the objects typically is via linear referencing or geospatial coordinates or feature geometries (BIM Task Group, 2013).

Current standards are too building-centric, and further development is required for infrastructure assets. However, the more advanced nature and experience in the use of digital tools available for vertical infrastructure can be used to inform the development process for smarter information use in the horizontal domain (BIM Task Group, 2016).

UK Government Construction Strategy (2011) mandates to use COBie, an international standard that is used for delivery of managed asset information and it improves the exchange of information, for public construction projects at certain stages of the construction process and is increasingly used for vertical infrastructure. However, the use of COBie fails implementation for horizontal infrastructure because the object-based model does not work with string-based models that form the basis of highways construction. Currently, COBie for civil infrastructure is under development.

1.3 Research Questions

Research questions 'define an investigation, set boundaries, provide direction, and act as a frame of reference for assessing the research work' (Neuman, 2006). This research deals with developing recommendations for highways construction clients/asset managers in order to prevent data losses from construction to operations and maintenance of the highways infrastructure assets. The research is very crucial, because currently in the UK there is no specific civil infrastructure guide for public sector clients for use BIM enabled digital workflow for data management in the assets' lifecycle. This situation makes the construction processes legging behind, affecting the economy.

Therefore, this research is expected to answer the research questions on:

i. How to enable BIM to enhance data handover from construction to maintenance in the Highways supply chain?

ii. How to maintain the accurate information flow for data handover from construction stage to maintenance stage with BIM in the Highways supply chain?

1.4 Aim & Objectives

The aim of this research is to develop BIM-enabled recommendations for the Highways public sector clients that would improve and maintain the data handover process from construction to maintenance stages in the Highways supply chain.

Key research objectives include:

i. To review the current barriers and bottlenecks for data handover in the Highways construction sector

ii. To explore potential of BIM in supporting public sector highways construction sector

iii. To identify the challenges faced by project teams in the management of data within the highways public sector infrastructure in the UK context.

iv. To specify BIM-enabled recommendations that will encapsulate methods and processes for enhanced data handover from construction to maintenance

v. To validate the BIM-enabled recommendations by examining the opinions of construction sector experts and provide recommendations for the Highways construction clients

1.5 Research Methodology

The research methodology is crucial for the researcher to collect data effectively in order to achieve aim and objectives of the research. This research adopts Saunders at al.'s (2016) onion research model. According to Saunders et al. (2016), research strategy is the way the researcher chooses to find the answers of the research questions. This is followed by the research philosophy and research approach, which could be qualitative and quantitative of mixed of two. This research used qualitative method to collect meaningful data. The data was collected in two phases as the first phase document analysis together with observation and the second phases was multi-case study (semi-structured interview) with 15 experts within the case studies. A focus group discussion was conducted with 12 experts in the built environment to validate the recommendations developed from the case study findings.

1.6 Expected Contribution to Knowledge

This research arose from the UK Government's Level 2 BIM mandate for the public-sector construction projects. A critical literature review has been undertaken and showed that there is need for research for highways sector clients to effectively maintain the infrastructure assets. The literature highlights that currently the highways sector is struggling to alter their traditional construction process to the newly adopted BIM processes. The highways sector clients lack BIM-based clear guidance for digital handover for enhancing the assets' operational phase.

This research investigates the current challenges faced by the highways sector construction projects for data management within the UK context. Little research has been done on highways infrastructure assets handover in the UK highways sector and this research will fill in the gap in the literature serving as a reference material for the highways sector clients for public projects. The data collected as part of this research yields new insights into infrastructure assets handover processes in the UK public sector. The research also helps to inform and guide how public-sector highways projects are handed over to the operations or asset/facility management team in the UK. This research also contributes to the BIM implementation for infrastructure.

Therefore, this research develops clear recommendations for the clients in the highways sector and also offers the following academic and practical contributions:

1- This research critically reviews and synthesizes the current knowledge relating to BIM implementation in the UK highways context, asset data handover practices and BIM's relevance to solve the data management issues in the lifecycle for infrastructure assets.
2- This research provides comprehensive academic investigation to identify and analyse current issues within the highways sector as for implementing BIM and data and asset management. The findings of the research contribute to the development of recommendations for the clients.
3- The research will serve as a reference for further research in the area BIM in highways construction sector asset management.

1.7 Structure of Thesis

The dissertation is divided into following chapters.

Chapter 1: Introduction

This chapter introduces the dissertation and provides the related background and context of the research topic. It discusses the research problem, the research aim, objectives, question, and the significance of the research. In addition, it explains the scope of research and provides outline research approach.

Chapter 2: Literature Review

This chapter provides a review of the current literature. The theoretical base of the research is developed in this chapter. Chapter 2 explores the concept of asset handover processes in the construction industry globally. This is followed by a review of the application of the state-of-the-art BIM technologies to improve the data flow and the relationship between the construction phases in the construction industry. It also reviews the key data management practices and affecting factors in the UK construction industry. The chapter provides in-depth understanding of the current UK construction dynamics with a specific focus on the lifecycle of data management in the industry in general.

Chapter 3: Research Methodology

This chapter provides and rationalizes the philosophical stance for the research and the adopted research methodology. It discusses the methods of the research and presents the selected methods with their justifications. The research adopts qualitative techniques and their protocols, which are discussed in depth. The chapter also discusses the developed recommendations with their validation with focus group discussion including the issues of ethics related to the research.

Chapter 4: Qualitative Data Analysis

This chapter presents the analysis and interpretation of the qualitative data collected from the case studies. Qualitative data is collected from semi-structured interviews, observation and analysis of documentation related to civil infrastructure handover process.

Chapter 5: Validation of Recommendations

This chapter presents an overall analysis collected from case studies and semi-structured interviews. The chapter provides the final form of the recommendations with focus group discussions.

Chapter 6: Conclusion and Recommendations

The last chapter presents conclusions from the research and highlights the key contributions to knowledge, and the recommendations for the built environment and for further research.

1.8 Scope of the Research

Recent efforts of initiatives such as BIM Task Group have focused on building asset data management mainly. This research will address existing knowledge gap on how BIM and emerging standards such as PAS 1192:3 could be used to provide a structured approach to highways maintenance. Current standards are too building centric and there is need for specific standards for Highways infrastructure.

The research enables highways authorities to operate, maintain and restore key assets to meet key performance requirements while developing recommendations for highways public client organizations such as Highways England, to achieve a better continuity in the flow of asset information from the design and construction to operations and maintenance phases. This research therefore is targeted at developing recommendations for Highways sector clients using BIM concept and applying it in analysing and evaluating emerging technology for Highways civil infrastructure assets. The research will be limited to case studies of UK public client organization Highways Agency because of the tested tools and technologies. However, the recommendations could be used and serve as a reference material in highways civil infrastructure sector globally.

1.9 Limitation of the Research

It is a well-known fact that every research activity has its own dynamics hence has its own limitations. This research was conducted to investigate issues on how to enhance effective data management in highways civil infrastructure asset handover phases of public sector highways development projects in the UK. The private sector is excluded from this research. The private sector has different dynamics, often driven by short-term return on investment, thus, the need for long term data management is often excluded.

Due to HM Government mandate in BIM Level 2 use, the public construction industry requires to implement BIM, however there is lack of published literature and best practice on the data management related to civil infrastructure asset handover within the public-sector highways development projects. Thus, as another limitation is that the researcher investigated currently available cases of the UK highways sector.

1.10 Research Process

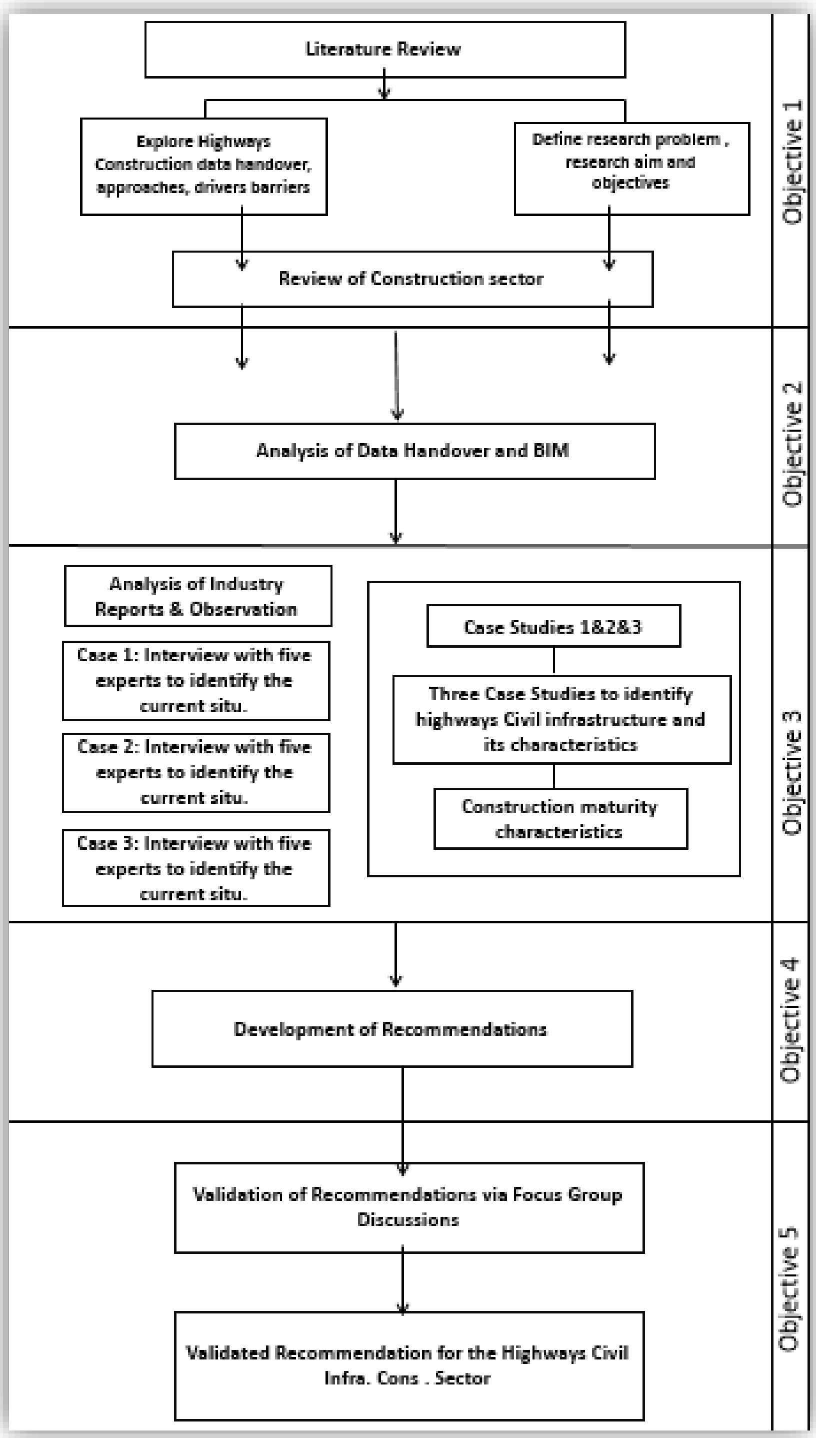


Figure 1.6: Schematic Representation of Research Process

1.11 Summary

This chapter has presented an insight into the research study, emphasized the justification why this study is valuable for highways civil infrastructure (C/I) handover in the UK and, why it should be conducted. It contains the research aim, objectives, and questions to be achieved. The contributions to knowledge have been identified, and an indication of the methodology to be adopted has been provided. Finally, it identified an outline of the structure of the thesis. The next chapter focuses on the background that is related to exploring the aim of the current project and on the literature, review related to the state-of-the-art in building lifecycle data management practices with a specific focus on Highways civil infrastructure.

CHAPTER 2

Literature Review

2.0 Literature Review

This chapter explores the need for effective asset handover practices and reviews key focal literature in this research area. It covers the issues on data management and asset handover principles and procedures. The chapter also presents the importance of the highways infrastructure with a focus on the lifecycle of data management in the construction industry in general. Finally, a summary is presented to integrate different perspectives of the literature, which have been presented in this chapter.

2.1 Background of the Highways Construction Industry

The construction industry in general is notoriously known as being conventional, wasteful, adversarial, fragmented and dominated by single disciplines, reluctant to innovate and poor dissemination knowledge (Designing Buildings, 2018). Highways construction is no exception with disparate stakeholders from diverse backgrounds. Current issues highlight that with the HM Government's mandate the sector should alter their traditional construction habits and workflows. However, this change requires major challenges in the current business process. Just like any process related changes, it is expected that the industry will have some time to get used to the changes mandated. At present, the highways sector requires guidance from the client organisations to successfully realise their projects. Hence, firstly, the client organisations must understand the current situations with the highways sector and the requirements for mandate for successfully lead the project processes.

UK public sector Highways clients have a huge portfolio of aging assets. Historically, their data sets have been usually held in disparate platforms and developed utilising multiple standards and formats (Bayar et al., 2016). Thus, full value of such data is not fully realised. Aging assets require economic life extension through efficient data management. With the increasing portions of smart systems and structures, the current network is becoming even more complex.

Currently, commonly used medium for data exchange is 2D drawings and traditional manual processes. Furthermore, the situation was explained by Aziz (2016) that, newly generated information in new formats such as RVT, PLN, IFC is a great challenge for industry stakeholders that are already struggling to make sense of the CAD file formats (DWG, DGN, DXF etc.). As with the CAD formats, these are often proprietary and undocumented. It also presents a great challenge that the current closed and open formats need specific versions of tools to work with. As per multi-decade lifespans, it is a huge bottleneck. Previously generated data are held disparate media; in the model, in CAD files, PDFs, printed paper, in spreadsheets and in the binders. Industry's traditional habits and resistance to change are forming crucial issues and these issues are continuing (Arayici, 2015).

2.2 Data Handover

Conventionally, handover is a process to provide the asset information to the clients of the facility for operation in their lifecycle. Additionally, Fallon and Palmer (2007) defined "handover" as handing over the information at the close out stage to the team who is responsible to operate and manage the built asset during its lifecycle. Handover process consists of providing the client the information of the design and construction related to the facility, the client/owner through the facilities/asset management staff to use the information to operate and maintain the facility in optimal conditions. Thus, handover process delivers information generated during the different phases of the development of a facility. Understanding key stages of data handover and information requirements in each is very crucial. These phases are:

- Planning
- Design
- Construction
- Project Closeout/Commissioning
- Operations and Maintenance
- Disposal

Figure 2.1 shows these stages regarded as traditional approach and are seen as sequential process in a facility's lifecycle. The smaller arrows show the key information handover stages (NIST, 2007).

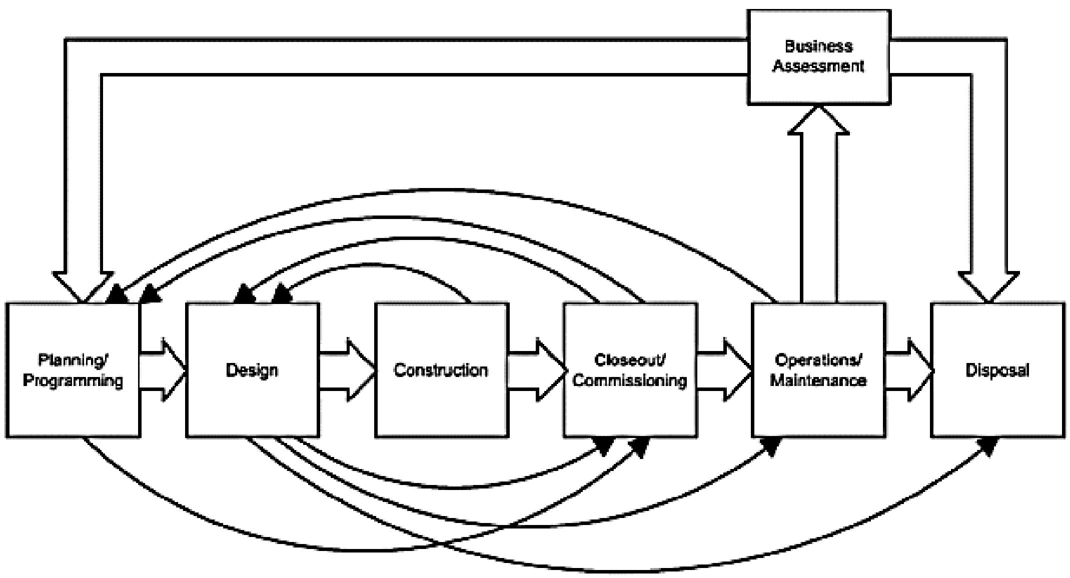


Figure 2.1: Asset lifecyle stages (NIST, 2007)

Nevertheless, often these information stages are fragmented. The operational management of the assets mainly dependent on the retrieval and sharing of information collected through the lifecycle stages (Arayici, 2016). This process presents many difficulties in information accuracy and causes data loss. Jordani (2010) highlights that the problems in asset management occur more when information exchange challenges are experienced during design/construction stages. Currently there is huge data loss in exchanging information between various parties of the construction projects. This is due to the various systems, software being used by the project stakeholders. Consequently, this situation presents huge costs and time losses.

Accordingly, Teicholz (2013) explains the situation by presenting the Figure 2.2 below. In Figure 2.2, the blue lines indicate the handover of information at each stage of the built asset lifecycle must be re-generated to be able to fit the receiving parties' system and therefore, at these handover stages, the information is lost. Furthermore, the information loss affects the clients in decision-making during the operational phase by adding more cost to the assets' operation.

Figure 2.2: Information loss at handover stages (Teicholz, 2013)

2.2.1 Current Challenges in the Handover Process

The issues with conventional project handover has been widely discussed in many industry reports and academic papers (Fallon & Palmer, 2007). Typically, asset information is requested by clients/owners at the end of handover stages such as closeout/commissioning and operations/maintenance in paper documents' form and then is usually stored in a facilities' information storage area as shown in the

Figure 2.3. This approach is very time consuming and difficult. Furthermore, it is very difficult to find the accurate information. Hence, the construction industry is paying extra costs the repeat surveys to get the accurate asset information to use in the operational phases.

Qurnfulah (2015) highlights that construction sector is known as its low productivity, slow pace of change, waste and fragmented processes. Furthermore, highways construction sector is no exception. Fragmentation of construction processes lead to poor flow of data through lifecycle. This is particularly evident when built assets are handed over from contractors to owners. A lack of standardised approach in lifecycle data management often results in project asset managers/clients receiving piles of documentation at the handover stage in a variety of different formats, such as 2D drawings and specifications (Jordani, 2010). Current literature highlights that traditional approaches and thinking is still being a strong case. The use of 2D drawings is still the most common medium of information and resolve conflicting issues interfering with construction.

Figure 2.3: Information storage (Teicholz, 2013)

In the current construction practice, asset managers /clients use either CMMS or CAFM systems and the information is manually deposited these are either paper documents and 2D digital files. Furthermore, if the facility is in use when the information needed, effective use of the system is delayed until it contains the necessary data, which needs to be checked for accuracy and completeness (Teicholz, 2013; Arayici, 2016). This situation causes huge time and money loss.

Present FM/AM systems rely on polygonal 2D information to represent numerical data entered a spreadsheet (Eastman et al., 2011). Verification, input and update of the information in FM/AM systems is costly and time consuming. Due to fragmented nature of the process, the information tends to be incomplete and/or uncertain. Furthermore, manually input of the asset information by the FM/AM manager leads to duplication of work and causes poor data storage systems.

Arayici (2016) largely explained that it is very crucial that information was acquired in the design and construction is effectively transferred to the operations with maximum benefits to the owners/clients as they have integral role in the whole process of the assets' lifecycle. If the asset information is unstructured and unclear, the transition of information and its storage cause one of the most crucial challenges in FM/AM processes, this challenge is interoperability. Inadequate interoperability adds to the costs of sharing information between business systems at various stages of a built asset lifecycle, and two-thirds of an asset's cost is due to inefficiencies during operations and maintenance because of poor information sharing (Jordani, 2010).

These issues indicated highlight the need for effective management of data as acknowledged by BIM Task Group (2013);

- Planning for asset management does not start early enough in the process and this adds to wasted time and resources even before the asset becomes operational.
- The transition from completion to operation wastes time, resources and effort before the predicated performance is achieved.
- The actual performance of an asset does not match the design specified performance
- End user needs are often overlooked, and this leads to additional expenses in ensuring the required business functions are met

As per the current difficulties presented, the UK Government mandated BIM Level 2 use for all construction industry to improve the handover practices. Early adopters in the built environment such as building sector have addressed data management issues related to the technology adoption and new workflows. However, for highways civil infrastructure, there is still challenges in BIM implementation (Becerik-Gerber et al, 2011). The highways civil infrastructure is unique in nature as it forms the largest infrastructure with many project participants and various data.

2.2.2 Asset Data Handover in Highways Civil Infrastructure

In the current conventional practice, the maintenance and operational handover of a major highways project from the project team (construction contractor) to the Network Delivery and Development service delivery team (maintenance and operations teams) should take place on the date of project completion/road opening. However, the project team will retain responsibility for issues arising from the construction during the defect period. According to Highways England's project control framework (Highways England, 2013*)*, these documents are normally required for the handover; (i) as built drawings/documentation, (ii) updated health and safety file from the option selection stage prior to the preliminary design stage, (iii) template for handover schedule, (iv) civil assets maintenance handover certificate – including outstanding matters checklist, (v) technology commissioning plan, (vi) technology assets maintenance documentation and certificate, (vii) operational handover documentation and certificate for traffic management and regional control centre, and (viii) updated permit to connect from the construction preparation stage. The documents have been developed starting from the design phase through the end of the construction phase in a highways project.

Documents required for the handover are generally deposited in Highways England's data management system (IAM-IS). Some documents for certain assets may be stored in other relevant Highways England systems such as Highways Pavement Management System (HAPMS) or Structures Management Information Systems (SMIS). In addition, mandatory road safety audit reports are produced during the development and construction phases of a major project to help identify potential safety issues and mitigate these where possible. The project control framework underlines the importance of coordination between the project team and maintenance/ operational bodies from the very early stages of the project-life cycle. There are efforts to integrate the fragmented data management systems at Highways England however; these are currently in the infancy stages (Aggregate Industries, 2015).

2.2.3 BIM for improved Handover

The development and management of highway infrastructure is facing unprecedented challenges globally (ICE, 2017). Traditional handover practices present major issues and need improvement. The construction industry is notoriously known with its traditional habits and slow pace of change (Arayici, 2015). However, as the technology advances, the industry has to alter its workflows and conventional thinking to catch up with the current advancements. Accordingly, the UK Government's BIM mandate targets managing assets in their lifecycle by reducing the cost of rework. Figure 2.4 shows the physical assets' cycle from concept to design to construction to operations to reuse and eventual demolition. The figure depicts that the data would be available when it is needed during its lifecycle.

According to the Cabinet Office (2011), poor handover practices after the completion of the projects cause negative impact on the assets' operational phase. Currently, this situation presents major costs. Hence, the UK government is proposing implementation of Government Soft Landings (GSL) in order to achieve smooth transition of data from design to construction and asset management teams at the handover stage (Cabinet Office, 2016).

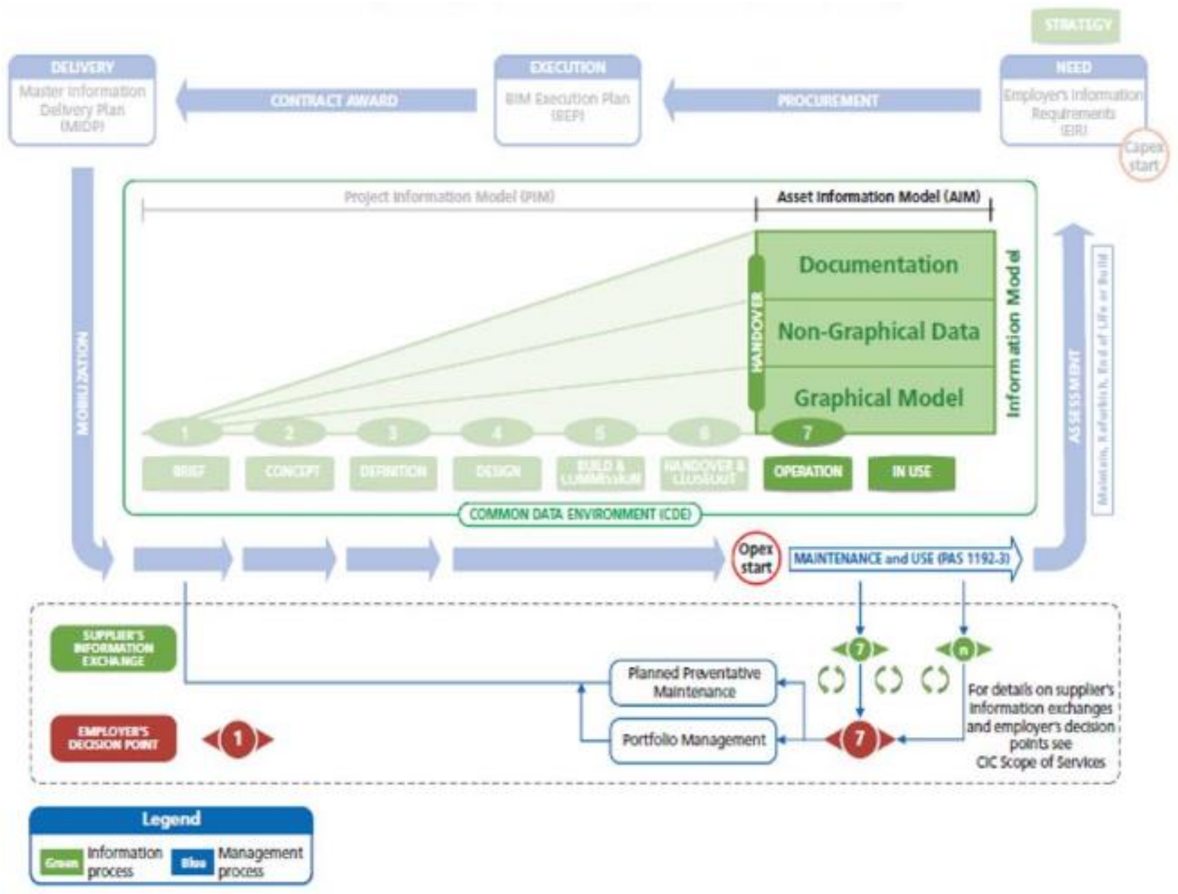


Figure 2.4: Information Delivery Cycle, PAS 1192:3 (BIM Task Group, 2016)

The Figure 2.4 demonstrates that with its integrated approach, BIM is expected to improve the maintenance issues in the highways construction as provides access the data when needed. With its planned preventive maintenance activities, the highways infrastructure could be more efficient.

Recent industry surveys show that the use of BIM is still relatively low for asset management purposes (McGraw Hill Construction, 2014; Malleson, 2016). Given the UK Government's and large transportation clients' (i.e. Highways England, Network Rail) vision to further penetrate BIM into the life-cycle project management of large infrastructure assets, it can be stated that there is a clear need to better understand the data requirements for a BIM based-asset management for large infrastructural assets to guide the current handover practices, to improve the overall asset management performance for a higher end-user satisfaction and to reduce the associated asset management costs. As highlighted by Kemp (2016), "the need for accurate asset information for large infrastructure managers (e.g. Highways England, Network Rail) is an essential enabler for the safe and efficient operation and maintenance of those assets and for decision support".

An optimal asset data management strategy must begin from early construction scheme design stage. However, hardcopy sign off files are still most commonly used method of disseminating drawings across transportation projects (Steel et al., 2012). The Highways sector's complex and fragmented nature causes problems in sharing information and communication among multiple participants, especially in the Operations and Maintenance (O&M) phase. There is an urgent need to investigate data flow for asset management in the highways sector to make the data accurate and readily available for decision makers.

There are huge costs associated with inadequate interoperability and mismatch between design software, and software systems and processes used in capital asset management. NIST (2004) suggests a cost reduction opportunity in capital asset management practices through better synchronizing asset life-cycle data management using BIM. Despite its significant potential for an improved project-life cycle performance, research on the data requirements for BIM-based asset management have remained scarce (Becerik-Gerber et al., 2011; Love et al, 2014). This scarcity is even more notable for large civil infrastructural assets.

Identified benefits of BIM has led countries across the globe to start implementation of BIM (Sanchez et al., 2016) as part of public procurement process. As it has been previously explained that in 2011, the UK Government mandated the use of Collaborative 3D BIM. BIM has been central to the UK Government's objective in achieving 20% saving in asset costs and higher value for money (Cabinet Office, 2011). The document further emphasizes the importance of using BIM in the entire asset lifecycle. Both by the help of mandate and benefits monitored from the pilot construction projects, BIM has gained momentum and its wide range of capabilities are now being used in many construction fields.

Use of BIM for asset management in O&M phase is still in its initial stages, and thus, there is not institutionalized "best practice" for using BIM in the FM phase, and how any software in O&M is used depends on the organization's goal and requirements (IFMA 2013). Moreover, BIM is more commonly used in building sector, and highways sector still needs effective approaches for using BIM, especially in FM phase (BuildingSmart 2016).

2.3 Building Information Modelling

In this section, relevant literature on Building Information Modelling (BIM) and its use and characteristics, current efforts in development, and interoperability standards in the UK will be discussed. Current literature highlights that most of the standards are more building-centric (vertical infrastructure) due to BIM's initiation from the building construction sector. Thus, BIM is still in infancy stages for highways infrastructure assets therefore for this research some attributes will be made from the building sector assets, which is currently mature enough and currently much of the BIM studies are on building sector.

According to UK Government's construction plan (2011), the construction sector is accepted as one whole sector of built assets regardless of being vertical (i.e. Buildings) or horizontal (i.e. Highways, Railways). Hence, the construction industry as a whole is sharing best practices for the improvement of the linear infrastructure as well as the entire infrastructure sector. However, current literature highlights the need for infrastructure specific standards and policies (ICE,2013). The following section review will explain the concept of BIM and its importance in the asset lifecycle.

2.3.1 Introduction to BIM

The National BIM Standard (2010) defined BIM as a digital representation of the physical and practical characteristics of a facility and a mutual knowledge resource for data about a facility, creating a reliable foundation for decision making throughout its lifecycle. BIM is a practice of computer-generated design and construction during the lifecycle to share knowledge and communicate between the projects members developing the Building Information Model. It is one of the most promising technologies for the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industries.

Building information models encapsulate and represent the three-dimensional geometry of building objects and the corresponding attributes of a physical facility. By its very nature, it promotes collaboration from design and construction participants around the digital model of a facility. The core of BIM is geometry, but also is a structured information base of non-graphical data that provides detailed information about the identity of facility components and their properties.

BIM is the management of information through the whole lifecycle of a built asset. It delivers value by underpinning the creation, collation and exchange of shared models and corresponding intelligent structured data. Using BIM brings about improvements in three important ways (ICE, 2013);

1. It provides a "single source of truth" for asset data and information for all parties to share during design, construction, and throughout the operational phase of assets.

2. It brings people, processes, information and technology closer together.
3. It clarifies how we create and share data and information, by stating the requirements for that provides data, when and how they provide it, and what checks need to be undertaken to ensure it is accurate.

It has been extensively discussed in the literature that BIM has tremendous benefits compared to conventional processes. Arayici (2012) largely explained that traditional processes followed within the construction industry are inefficient and cause duplication of work, over processing, lack of effective design management and communication, deadline and reworking. Building Information Modelling is an intelligent 3D model-based process that provides insight and managing projects faster, more economically with less environmental impact (Halpin, 2006; Arayici,2015).

Current civil infrastructure suffers from the conventional construction processes, and classical construction industry problems as explained. In addition, collaboration and communication among the project parties present many difficulties. This major issue needs urgent improvement. There is a need for collaboration between project parties through an intelligent system that integrates product and process information (Anumba et al., 2008). The UK Government's timely decision of BIM Level 2 mandate aims to improve the current challenges faced by the current construction sector.

Mihindu & Arayici (2008) highlighted that so many projects gained momentum and have their maximum benefits with the acquisition of BIM. Many researchers recommended BIM as a solution for low productivity. Kymmel (2008) supports this assertion that through the help of a virtual model it is possible to practice and experiment or adjust the proposed model before its actual construction.

Accordingly, Thomson & Miner (2007) supported that BIM is a concept that connects all project data and storing it in a single source of online system, therefore project can be tested virtually. Several attributes such as time and cost dimensions can be integrated to the virtual model that helps to analyse the project from various aspects. Figure 2.5 illustrates the BIM infrastructure model with its documentations.

2.3.2 Relevance of BIM for Infrastructure

As previously discussed despite its name, many benefits of BIM are no longer restricted to the architecture and building industry as shown in Figure 2.7. Figure 2.6 illustrates that BIM is quickly establishing a foothold with civil engineers, public sector transportation, and infrastructure officials as a tool to deliver design projects faster and smarter. While it has its roots in architecture, the principles of BIM apply to everything that is built (vertical and horizontal infrastructure), including railways and highways civil infrastructure (Strafici, 2008). Thus, BIM has a very broad meaning that describes the process of creating and managing digital information about a built asset such as building, bridge, highway and tunnel. Figure 2.7 illustrates the integrated BIM of highways infrastructure and associated asset information.

The UK Government has recognised the potential for BIM to transform the construction industry as a whole, is pursuing a strategy which requires a collaborative 3D BIM (with all project and asset information, documentation and data being digital) on its projects by 2016. The UK strategy has been considered by many to be the most ambitious and advanced centrally driven BIM strategy in the world (HM Government, 2012). Government's support for BIM is acting as a motivating factor, providing energy to the development of the common standards and protocols that are an essential part of the BIM process (BIM Task Group, 2013).

UK Government's (2011) bold decision of the use of Collaborative 3D BIM (with all project and asset information, documentation and data being electronic) on all public-sector projects by 2016 under the Government Construction Strategy, has led the Government and all the construction industry working together to develop the construction industry's skills and reduce the cost of infrastructure.

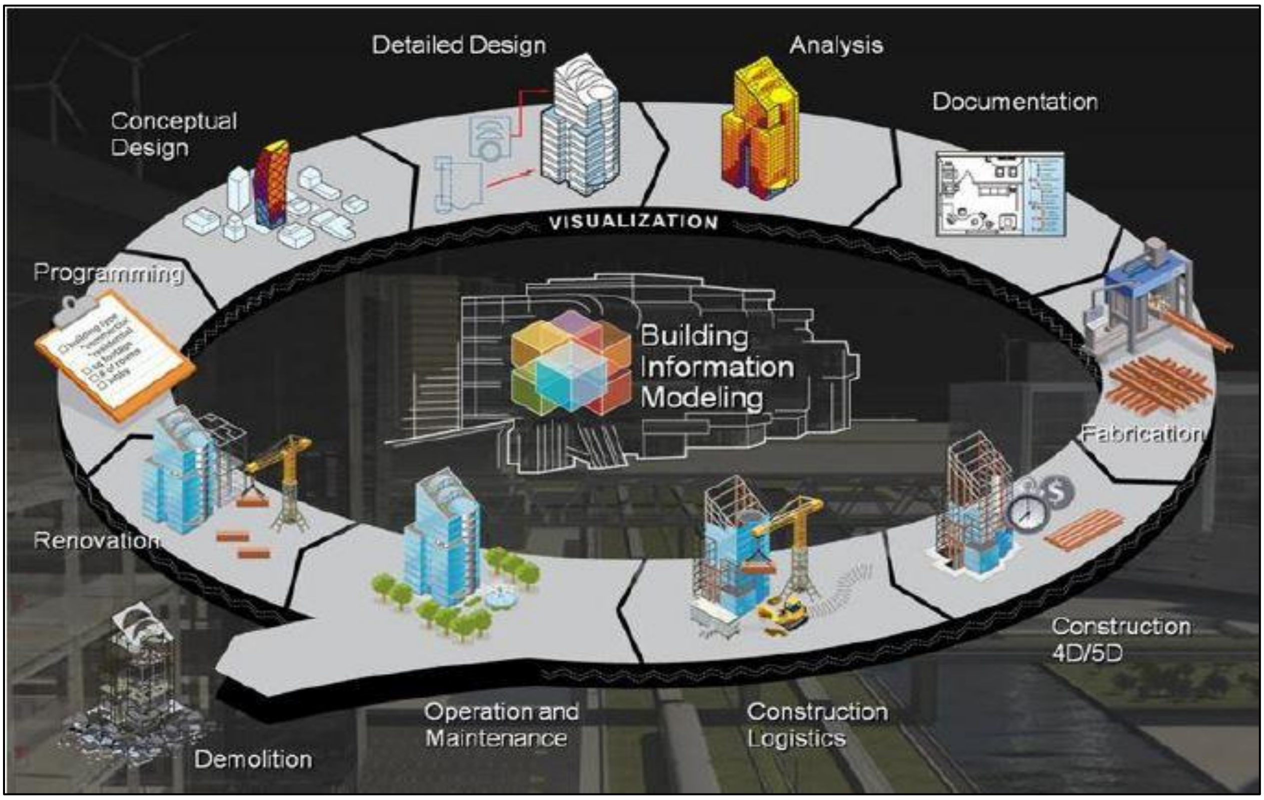


Figure 2.5: Collaborative and Integrated view of BIM through the project lifecycle, (Image courtesy of Autodesk® Research,2014)

Both by the support of mandate and benefits monitored from the pilot construction projects, BIM has gained momentum and its wide range of capabilities is now being used in many construction fields and their stages. At present in the building sector, BIM workflows are more mature than the infrastructure sector. However, civil infrastructure has initiated their BIM use with the UK Government's motivation. The bold decision is considered step forward to amend current inefficiencies in the highways construction sector. Figure 2.6 presents some sample uses of BIM and integrated design in design, construction and maintenance within civil infrastructure.

BIM Task group (2016), to raise awareness of the BIM programme and requirements, recommended the supply chain to form a feedback route by sharing the best practice samples of the industry.
Moreover, Highways Agency published their Interim Advice Note 184 (2016) as a guide document for the highways construction sector to initiate the UK Construction Strategy requirements.

Project stages		
Design	Construction	Maintenance
Drawings creation	Indicating differences	Better data availability
Clash detection	Better management	Asset lifecycle monitoring
Time and Cost plans	Quick overview of changes	Asset condition management
Simulations and analysis	Progress monitoring	Traffic and diversion simulations

Figure 2.6: BIM Relevance for Highways Design, Construction, and Maintenance (Adapted from Aziz, 2016)

Highways England, as executive body to the Department for Transport, has adopted the UK Government Construction Strategy which requires 'fully collaborative 3D Building Information Modelling (with all project and asset information, documentation and data being electronic) as a minimum by 2016, which is currently using traditional construction processes. The Agency shares the vision that significant improvement in cost, value and carbon performance can be achieved using open sharable asset information. BIM will facilitate the delivery of consistently high-quality asset data for use in operational, financial and engineering decision making and planning processes across the Agency. According to IAN 184 (2016), The Highways Agency will; (i) move from a control focus to a decision-based delivery model, (ii) integrate teams to accelerate delivery and reduce waste, (iii) drive improvement, innovation and deliver value.

The Highways England acknowledges the challenges that it and the supply chain will face in the adoption of BIM and as such, it is clear that highways agency will need to adopt a pragmatic but progressive approach to the adoption of BIM (Interim Advice Note, 2016). Interim Advice Note (IAN) 184 (2016) was produced as a first step to define the governance needed for the implementation of BS1192:2007 and PAS1192-2. It will enable the supply chain to configure their systems and Common Data Environments (CDE) to produce and receive information in a consistent manner on behalf of the Highways Agency. The requirements of PAS1192-3 (for the operational phase) and BS1192-4 (UK Implementation of COBie) will be addressed at a later stage (IAN, 2016). As the Agency undertakes improvements to its Asset Management systems, and as technology and process for the design and construction of infrastructure improve.

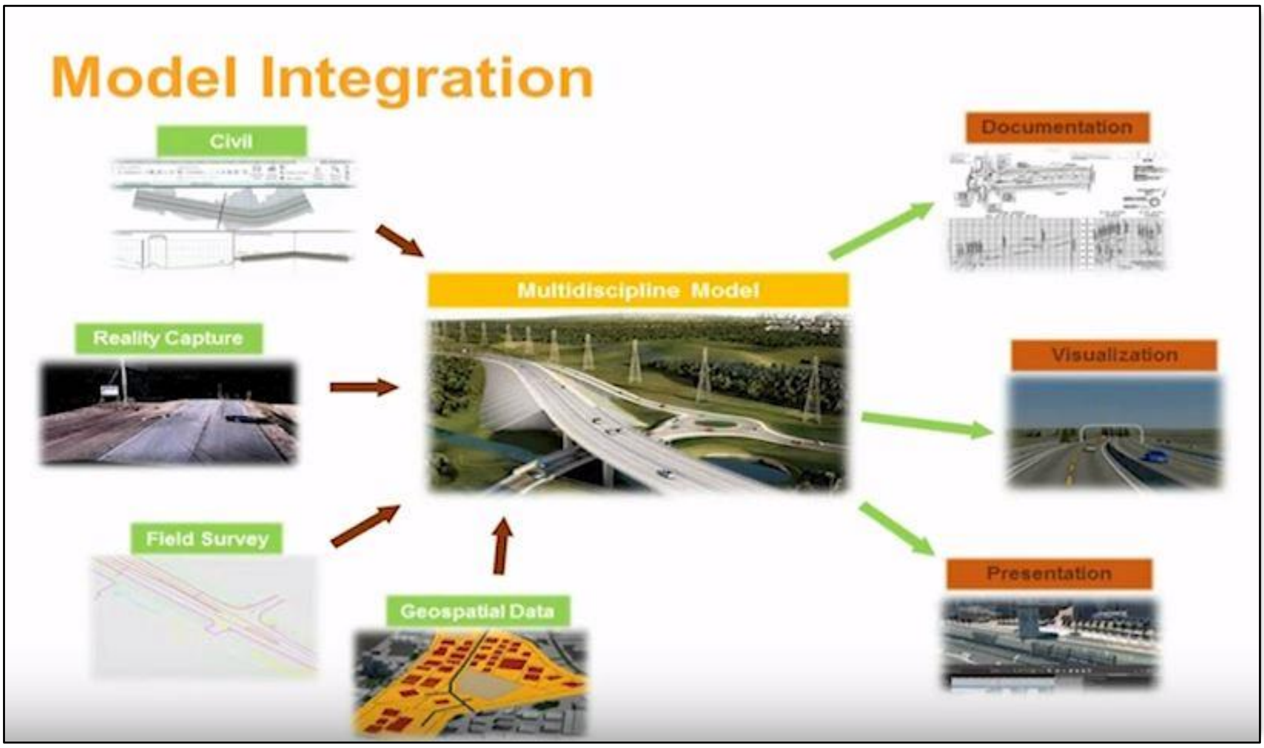


Figure 2.7: Collaborative and Integrated view of BIM through the project lifecycle (Autodesk Research, 2015)

BIM is a holistic approach to the design, construction and management of the facilities used in the built environment. At present, the technology tends to be confined to the construction phase, where design and engineering teams use three-dimensional, real-time, dynamic modelling software to create a BIM model that encompasses geometry, spatial relationships, geographic information, and the quantities and properties of asset components (See Figures 2.6 & 2.7). BIM use in the operational phase of the assets now in the developing stages as BIM workflows are in adoption stages. However, BIMTG (2013) supported that if appropriate operational information could be incorporated into BIM model, end users would have all the information they need to operate the building contained in one central database without having to maintain separate asset management systems.

2.3.3 BIM Implementations for the Integrated Supply Chain

Supply chain is the network created amongst different parties producing, handling and/or distributing a specific product/asset. Specifically, the supply chain encompasses the steps, it takes to get a good or service from the supplier to the customer. Khalfan et al. (2015) have indicated that sustainability and efficiency can be better achieved by the integration of supply chain partners with the adoption and implementation of Building Information (BIM) in a construction model. Furthermore, (Khalfan et al.,

2015) mentioned that the success factors for integrated collaboration using BIM can be classified as information sharing, organizational roles synergy, processes coordination, environment for teamwork and data consolidation (Khalfan, 2015). BIM enables and supports decision making for construction industry in delivering technologically seamless projects.

Data communication and the ability to exchange information with other partners is a very crucial factor for collaborative decision-making process. Considering the entire project lifecycle implementation BIM workflow will lead to an increase in productivity as well as forming a repository and database for all the information that has been produced during the facility's entire lifecycle, therefore gathering information when and where needed is crucial for the Highways construction assets in terms of accuracy and just in time information needs.

2.3.4 The UK Government Construction Strategy and Initiatives to support BIM-based Asset Handover

UK Government Construction Strategy published in 2011 and, interoperability through open data standards was the major component of the strategy. Interoperability is defined as 'the ability to manage and communicate electronic product and project data between collaborating firms' and within individual companies' design, construction, maintenance, and business process systems (Galleher et al., 2004; Jawadekar, 2012).

Inadequate interoperability adds to the cost of sharing information between business systems at various stages of a built asset lifecycle. In the buildings context, according to the NIST Interoperability Study (Jordani, 2010; Arayici et al., 2012) showed that in building sector, two-thirds of an asset's cost is due to inefficiencies during operations and maintenance because of poor information and insufficient information exchange. Figure 2.8 below shows the costs of inadequate interoperability by stakeholder group involved in the building lifecycle and it clearly indicates that 57.5% of inadequate interoperability is from the operations and maintenance phase of a building asset in comparison to the design (16,8%) and construction (25,7%) phases (Teicholz, 2013; Arayici, 2015).

Stakeholder Group	Planning, Design, & Eng. Phase	Construction Phase	Operations and Maint. Phase	Total (Millions)	Pct. Of Total
Architects and Engineers	1,007.2	147.0	15.7	1,169.8	7.4%
Per square foot (SF)	0.89	0.13		1.02	
General Contractors	485.9	1,265.3	50.4	1,801.6	11.4%
Per square foot (SF)	0.43	1.11			
Special Fabricators and Suppliers	442.4	1,762.2		2,204.6	13.9%
Per square foot (SF)	0.39	1.55			
Owners and Operators	722.8	898.0	9,072.2	10,648.0	67.3%
Per square foot (SF)	0.64	0.79	0.23	1.66	
Total	2,658.3	4,072.4	9,093.3	15,824.0	100.0%
Per square foot (SF)	2.34	3.58	0.24	60.16	
Pct. Of Total	16.8%	25.7%	57.5%	100.0%	

Figure 2.8: Cost of Inadequate interoperability in building context (Teicholz, 2013; Arayici, 2015)

The research results shown in Figure 2.8, enabling interoperability and streamlining the process through the AEC stages of an asset into operations phase can contribute positively in lowering the maintenance costs (Arayici, 2015). That is to say, BIM is widely considered as the way forward for better streamlining and structuring of information through the lifecycle stages of the assets and can provide better dealing with the challenges met by the owners and asset managers attempting to implement sustainable lifecycle management.

In the Highways civil infrastructure context, interoperability is one of the main concerns as the sector has recently initiated BIM use in their business processes. Highways infrastructure is complex matter due to its linear nature, forming largest infrastructure with various information from multiple stakeholders working on the same project tasks. NAO (2014) report supports that highways infrastructure as compared to building sector requires more information than building, as it forms the largest infrastructure with its visible and invisible assets.

2.3.5 Initiatives to Support BIM-based Asset Handover

In improving towards Level 2 BIM, many standard and processes, with the support of technology, are being developed. Figure 2.9 shows the process within the information cycle (defined in PAS1192-2 by BSI (2013)) of how the assets in the Capital Expenditure (Capex) phase will help link accurate information into the Operation Expenditure (Opex) stage towards providing a whole lifecycle analysis. It shows the key documents and workflows that support a fully integrated approach to BIM. These initiatives are too building centric however; the construction industry will be considered as a whole and will be informing each other (BIM Task Group, 2013). As the best practices emerge the infrastructure specific standards could be used to enrich the current standards.

- **PAS 1192: 3 Specifications**

PAS1192:3 Specification is for information management for the operational phase of construction projects using BIM. It describes data management procedures for operational phase of built assets, where those assets may be buildings or infrastructure and may be pre-existing or new assets (Design Buildings, 2016). PAS 1192:3 is a specification that is complementary to PAS 1192:2. Its purpose is to provide a structure for data management through the whole life cycle of asset management. PAS 1192:3 looks at the assets at an operational level by creating an asset information model. To use the model, the 'asset owning organization' must identify their assets and numerous pieces of information about those assets to enable creation of the asset information model. The key elements of standard information is being available, transferable and having integrity. It includes how a Project Information Model (PIM) is transferred to become an Asset Management Model (AIM) (NBS, 2015). This is a crucial step in the project lifecycle, as the user of the information changes meaning, information should be mature enough for the purpose (See Figure 2.9).

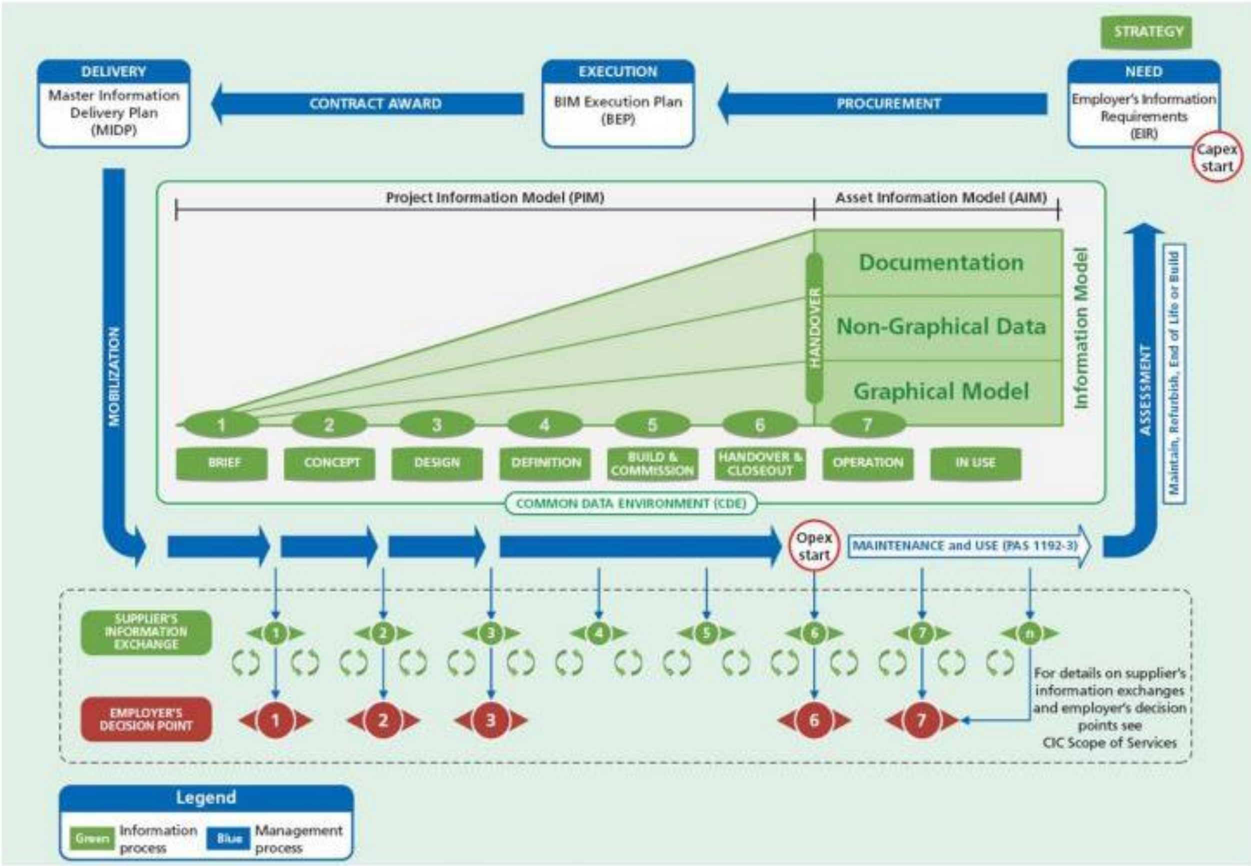


Figure 2.9: Information Delivery Cycle Framework (BSI, 2013)

- **UK Government Soft Landing (GSL) policy**

GSL policy aims to bridge the gap between expectation and reality through engaging users and operators to review and comment on design, construction, commissioning and handover proposals (BIM Task Group, 2013). The policy is intended to enable a smooth transition from the design and construction phase to the operational phase of a built asset (Cabinet Office, 2013). Another way to enable whole life cycle data management and prevent information losses at the project handover stage is to use the GSL policy (Cabinet Office, 2012). It was created in 2012, it sought to align design and construction better with operation and asset management. The client is involved at an early stage, engaging with design and construction teams to identify their requirements and expectations at the end of the process (NBS, 2015). Highways England needs to ensure capturing all the information it requires, and that it engages with its stakeholders, to be able to meet their expectations as the network operates. As Highways England currently seeks to update its asset management policies, it may not be able to initially implement a PAS 1192:3 model but it can certainly begin to adopt some aspects of GSL practices, such as stakeholder engagement to inform information requirements and to ensure smooth delivery. GSL makes information available to the client prior to the handover so that they understand the asset before they are tasked with operating it and work together with client team for optimising asset performance.

The GSL framework and PAS 1192:3 standards provide structures, which can inevitably help Highways England and its supply chain deliver more efficient information as they are supported by a formal process (Aziz, 2016). To make these processes to be effective, early and active client engagement and support is essential. Teams involved need to have a clear understanding of Asset Information Model required effectively operating and managing assets. Information in the final models will naturally mature through the design and construction process, provided the teams maintain it throughout, so it is effective and ready to use at the point of handover. These processes should enable a project team to compile and transfer project information for handover in a flowing manner.

- **Common Data Environment (CDE)**

Common Data Environment (CDE) is defined as a "single source of information for the project, used to collect, manage and distribute documentation, the graphical model and non-graphical data to the whole project team" (Boxall, 2015). This collaboration of data helps minimise risks and avoids mistakes/duplication. Creation of a CDE is also recognized in the PAS 1192:2 framework where cloud-based sharing uses an accessible project server or piece of software to store and share the data, creating a shared knowledge resource. Implementing a CDE across all Highways England schemes will ensure that there is a consistency in which assets are constructed and information is shared. Consistent data from multiple projects could enable easier access to information and cross comparisons between different projects/asset classes (Aziz, 2016).

This environment of a single source for data storage ensures confidence between all parties. It confirms that the information is being shared and up-to-date, accurate and fit for the intended purpose. The advantages of deploying a CDE for all stakeholders (PAS1192-2, 2013) (Arayici, 2015) will ensure the following:

- Ownership of information remains with the originator. Although the information is shared and reused, only the originator shall share it.
- Shared information will reduce the time and cost in producing co-ordinated information.
- Any number of documents can be generated from different combinations of model files.

As the client/facility manager has access to this environment, this will enable them to comment on the information captured by teams for their FM/AM purposes and they can make sure that their requirements are met as prescribed in Employer Information Requirements (EIR) (Arayici, 2015).

2.4 Asset / Facilities Management

Asset management in the building context defined as the process of monitoring and maintaining facilities systems, with the aim of providing the qualified service to users. Similarly, facilities management is a branch that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology (IFMA, 2006). In this case, the researcher uses both notions in the BIM context for the data management of the built assets in the highways sector. Therefore, International Facility Managers Association (IFMA) (2006) indicates the core competences for facilities are:

- Long-range and annual planning
- Facility financial forecasting
- Real Estate acquisition and/or disposal
- Work specifications, installation and space management
- Architectural and engineering planning and design
- New construction and/or renovation
- Maintenance and operations' management
- Telecommunications' integration, security and general administrative services

There are two main types of FM systems for the support of FM functions as Computer Maintenance Management Systems (CMMS) and Computer Aided FM (CAFM) systems. Figure 2.10 shows the data transfer processes in the FM database.

CMMS facilitates the management of operations and maintenance of properties in terms of the physical and financial aspects and makes that information accessible to support facility-related decisions (NIST, 2007; Arayici, 2015). This system is to record, manage and communicate day-to-day operations and helps to evaluate the effectiveness of facilities' operations (Sapp and Eckstein, 2013).

On the other hand, CAFM is an information rich database system (Exitech, 2011; Arayici, 2015). The system is described as the combination of Computer-Aided Design (CAD) and/or relational database software with specific abilities for facilities/asset management to ensure an asset is fully in use at lowest possible cost at each stage of its lifecycle. The CAFM system is being used in support of operational and strategic facility management of all the activities that are associated with administrative, technical, and infrastructural FM tasks when a facility is operational and supporting strategic planning.

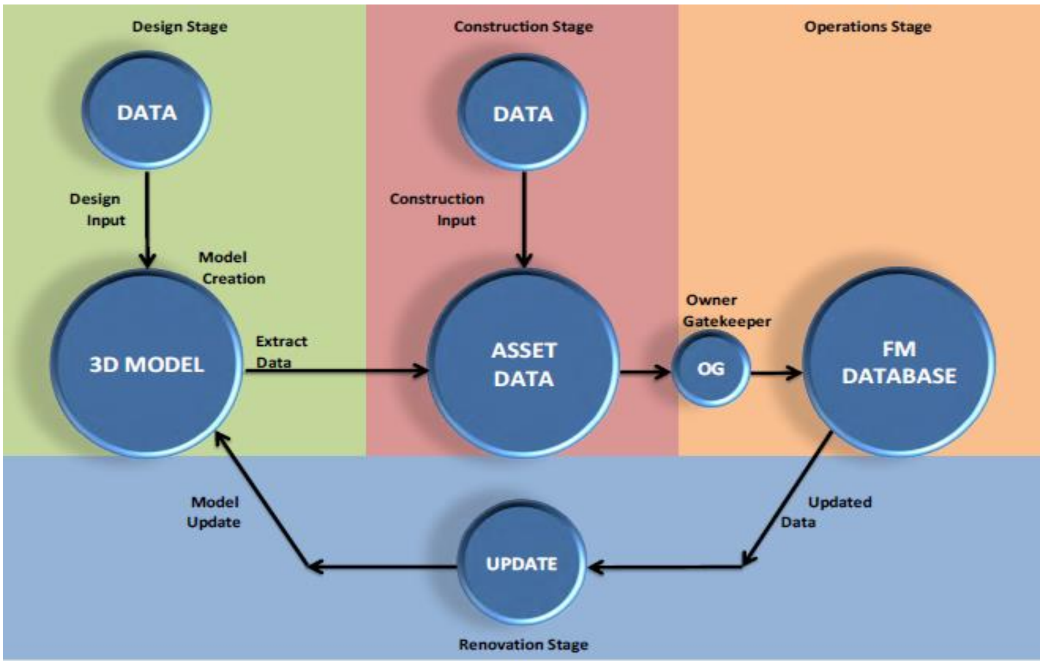


Figure 2.10: Data Transfer Process FM Database (BIM Forum, 2012)

2.4.1 Involving FM/AM in Common Data Environment

PAS1192-2 (2013) defined CDE as a single source of information for any given project, used to collect, manage and disseminate all relevant approved project documents for use by multi-disciplinary teams in a managed process. The data environment is a single source of data storage that ensures confidence between all parties in the information being shared and ensures that it is up-to-date and accurate for the purpose of the project.

The client or facility/asset manager has access to this environment, through the client shared area, this will enable them to comment on the information captured by teams for their FM purposes and ensure that their requirements are met as prescribed in EIR (Employers Information Requirements). In the context of highways agency although there is a preliminary CDE, the agency lacks the EIR document thus the information requirements are not adequately sufficient.

2.4.2 Asset Information Modelling (AIM) for Integrated FM/AM Practices

According to BIM Dictionary an AIM is defined as "A sub-type of Information Models supporting the maintenance, management and operation of an asset throughout its lifecycle. An Asset Information Model (AIM) is used (a) as a repository for all information about the asset; (b) as a means to access/link to enterprise systems (e.g. CMMS and BMS); and (c) as a means to receive and centralize information from other parties throughout project stages.

NBS (2014) defines Asset Information Model as "Asset information model is the name given to the same model post-construction, i.e. supplemented with the data needed to assist in the running of the completed asset".

An Asset Information Model (AIM) is a data set that compiles the data necessary to support asset management, provides all the data and information related to, or required for the operation of an asset, can provide graphical and non-graphical data and information as well as documents and metadata, can relate to as single asset or to a portfolio of assets, can be created from existing asset information systems, from new information, or from information in a Project Information Model that was created for the construction of a new asset.

An Asset Information Model might include (NBS, 2014):

-Information describing the original design intent

-3d models

-Information or links to information about ownership, rights and restrictions, surveys, work that has been carried out, operational performance information, condition information.

However, for existing assets, some of this information may be incomplete.

The Asset Information Model is managed within a Common Data Environment (CDE) and information within the CDE can have a wide variety of status levels, however there will generally be four main areas of information:

-Work in progress

-Shared

-Published

-Archive

An Information Management Process (IMP) should be established to maintain the integrity of the AIM. The AIM is managed by a data manager (sometimes referred as a data administrator and data technician) with responsibility of accepting information into the shared area of the CDE and authorising it for the published area. Changes to the AIM may be triggered by events such as: maintenance work, repairs, refurbishment or upgrades, replacement, decommissioning, risk assessments, performance evaluations, changes in regulations, changes in the party responsible for maintaining or operating the asset, changes in ownership and so on (NBS, 2014).

2.4.3 Asset Information Requirements (AIR) and Data Handover

A clear asset management strategy should be developed as per the complicated nature of the built assets. Asset Information Requirements (AIR) should define the required information for the Asset Information Model (AIM) (NBS, 2014).

PAS 1192-3 Specification for information management for the operational phase of construction projects using building information modelling states that "...specific AIR shall be specified as part of a contract or as an instruction to in-house teams and may use data and information from the AIM relating to the asset management activities being carried out. The AIR shall also specify data and information to be captured and fed into the AIM. Where the activities relate to major works covered by PAS 1192-2, then the AIR will inform the EIR (Design Buildings, 2016).

2.4.4 Employer Information Requirements

An EIR is a pre-tender document that set about identifying the information to be delivered and the standards and processes that are to be adopted by the project stakeholders (BSI, 2013). Furthermore, Pennsylvania State University, PSU (2013) highlights that, if the owners are aware of the information they need for operations and maintenance, they can now start to specify the exact information they wish to receive in a modifiable electronic format so that they can then incorporate this into their FM systems.

Additionally, Hardin (2009) mentioned that it is an owner's decision as to whether to demand having a BIM model with a clear specification of what components are needed in the model. EIR is a mechanism to put this demand in at the pre-tender stage. Employers, by defining the information they require and in what format they require it, will start to decrease the time and cost of populating the facility management system and increase the ability for model maintenance (PSU, 2013). Figure 2.11 below shows the core contents of an EIR.

The EIR document is very crucial for the project teams to accomplish the projects they were assigned to. The project team should be provided clearly explained EIR document for the projects' success.

Technical	Management	Commercial
○ Software Platforms ○ Data Exchange Format ○ Co-ordinates ○ Level of Detail ○ Training	○ Standards ○ Roles and Responsibilities ○ Planning the Work and Data Segregation ○ Security ○ Coordination and Clash Detection Process ○ Collaboration Process ○ Health and Safety and Construction Design Management ○ Systems Performance ○ Compliance Plan ○ Delivery Strategy for Asset Information	○ Data drops and project deliverables ○ Clients Strategic Purpose ○ Defined BIM/Project Deliverables ○ BIM-specific competence assessment

Figure 2.11: Core contents of EIR (BIM Task Group, 2013)

Currently Highways Agency lacks EIR document, they need to clearly identify the requirements for the highways construction processes. Thus, the development projects initiated their Level 2 BIM submissions without clear guidance from the client (Bayar et al., 2016).

2.4.5 BIM Execution Plan (BEP)

The BEP is a response to EIR from the project teams. Developing a BIM Project Execution Plan is beneficial to owners to assist in model maintenance for use in Facilities management (FM). The BEP should enable the project team to ensure that the requirements within the EIR are achievable. Therefore, it should contain fundamental owner specified information and requirements (PSU, 2013; Arayici, 2015). BEP should specify a workflow for transferring FM data from the BIM to the CMMS whether directly, or using middleware, for interchange of information between the CMMS and the BIM model (Teicholz, 2013).

Since BEP paves the way for how the BIM use should be present in a project, the BIM execution plan requires input from all stakeholders.

2.4.6 Data Drops for BIM

To ensure that projects are properly validated and controlled as they develop, data is extracted from the evolving building information model and submitted to the client at key milestones (Design Buildings, 2016). This submission of data is called ‘data drop’ or ‘information exchange’.

In terms of the Level 2 BIM requirements, the HM Government, as client, is mandating data drops at key stages throughout a construction project. The open data format they have demanded is buildingSMART Construction Operation Building Information Exchange (COBie). This is a simplified, non-geometric sub-set of IFC. This is a relational database that, in its most simple form, can be a spreadsheet (NBS, 2012).

Employer's Information Requirements (EIR) should set out the nature of data drops. Project brief defines the nature of the built asset that the employer wishes to procure, the Employer's Information Requirements defines information about the built asset that the employer wishes to procure to ensure that the design is developed in accordance with their needs and that they are able to operate the completed development effectively and efficiently (Design Buildings, 2016).

Data drops are likely to include (Design Buildings, 2016):

- Models (Industry Foundation Classes (IFC) models and native project information models).
- Data structures (such as COBie files and schedules).
- Reports (typically PDF's, although native files can be more useable).

The client will check the data in terms of compliance with the Employer's Information Requirements, compliance with the brief, cost / price, and so on before deciding whether the project should proceed to the next stage.

The timing and exact requirements for data drops will vary with the nature of the project and the needs of the client, however, the RIBA Plan of Work proposes 6 data drops aligned with the following stages (RIBA, BIM Overlay to the RIBA Outline Plan of Work, 2013):

1. Design brief
2. Concept
3. Design development / technical design
4. Production information / tender documentation
5. Practical completion
6. Post-practical completion

2.4.7 Construction Operations' Building Information Exchange COBie

COBie is an international standard that is used for delivery of managed asset information and it improves the exchange of maintenance information. The COBie specification defines the information needed for handover requirements which includes physical materials, products and equipment, equipment locations, serial numbers, warranties and spare parts' lists (NIST, 2007). It delivers consistent and structured asset information useful for an owner/operator for post-occupancy decision making. It can be considered as a vehicle for sharing predominantly non-graphic data about a facility and, through being a non-proprietary format based on a multiple-page spreadsheet, it can easily be managed by organizations of any size and any level of IT capability. In short, the purpose of COBie is to eliminate waste associated with paper-based document exchanges and increase profitability.

As highlighted previous chapters, the UK Government construction strategy (GCS) requires BIM mandate with all project and asset information, documentation and data being electronic as a minimum by 2016. This mandate refers to all centrally procured Government projects as largely explained in the Government Construction Strategy, including new build and retained estate, vertical and linear (BIM Task Group, 2013). Furthermore, the BIM mandate covers all capital improvement projects including Civil Infrastructure (BIM Task Group, 2013). However, the Construction-Operations Building information exchange (COBie) was designed specifically for buildings (BIM Task Group, 2013). It uses buildings-oriented structure of a facility as floor /space to establish placement of components as can be seen Figure 2.12. The figure presents building-specific components such as floor, space and zone.

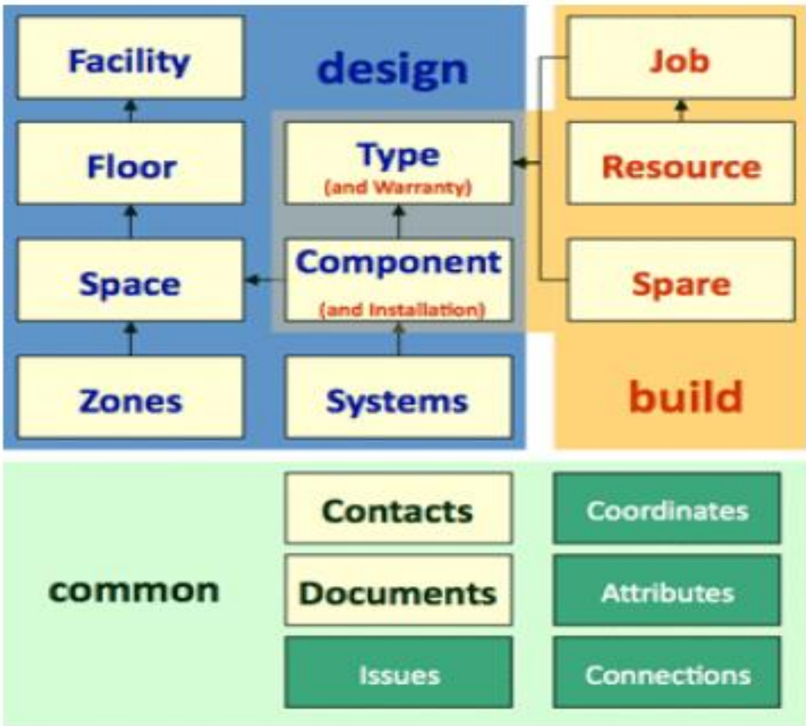


Figure 2.12: The COBie Structure

The Civil/Infrastructure (C/I) projects are different in nature as compared to buildings (BIM Task Group, 2013). In the C/I contexts, objects tend to be continuous as in the roads, rather than discrete like windows and doors. Attributes of the continuous objects will often change in value along the object. Location of the objects typically is via linear referencing or geospatial coordinates or feature geometries (BIM Task Group, 2013).

The COBie approach consists of all project stakeholders capturing facility data gradually during key project stages, known as data drops (Figure 2.13) and then exporting and importing this data into a central database to encourage an open format approach, not just at handover, throughout the project lifecycle. It aims to streamline the handover process between the construction and operations phases and also to support the model maintenance through the facilities' lifecycle (NIST, 2007).

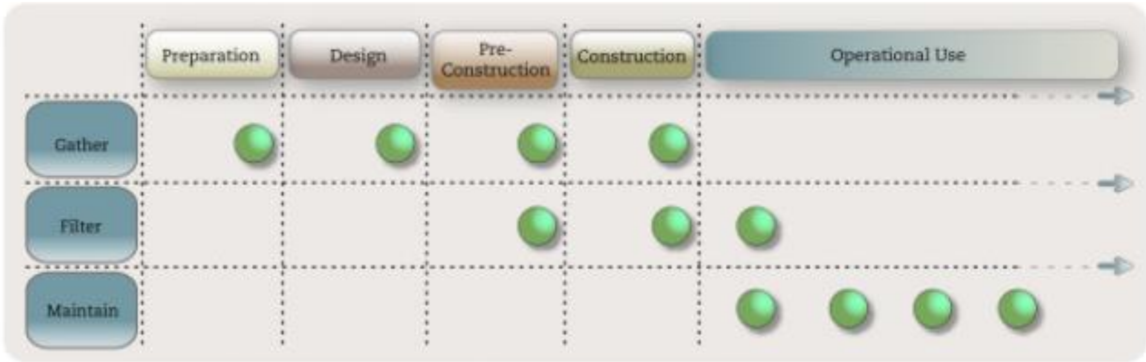


Figure 2.13: COBie data drops throughout a project's lifecycle

COBie can be created and updated by four ways (Arayici, 2015);

- Manually putting the data in COBie spreadsheet
- Extracting BIM attribute data and importing into a COBie compliant file
- Direct us of COBie compliant software
- Exporting an Industry Foundation Classes (IFC) file with correctly structured property sets

However, Kasprzak & Dubler (2012) highlighted that information exchange is not still flawless process from construction to operations, as COBie is not yet capable of integrating effortlessly into an existing and extensive FM database as only certain selected software applications can support this desired integration.

Currently interoperability is a major problem between certain applications and end users still need to spend considerable time on manual adjusting, exporting and importing COBie data into their FM systems, which is what occurs in current FM/AM processes. Thus, this situation highlights that although the information can be exchanged, this is mostly undertaken by manual process. To develop the industry in this exchange process, owners and project teams should share and standardize this process (Kasprzak & Dubler, 2012).

2.4.8 Industry Foundation Classes (IFC)

IFC is an open and standardised specification for BIM which is developed and maintained by BuildingSMART. It uses common data schema that makes the exchanging of information between software applications possible and helps enhance interoperability.

2.5 BIM Maturity

Collins dictionary defines maturity as being fully developed. In the BIM context, Succar (2009) defined BIM maturity as quality, repeatability and degree of excellence within a BIM Capability. Hence, to be fully developed in something, it is required to pass a set of evolutionary stages to reach the desired level of sophistication. Researchers have been trying to offer recommendations to the construction industry in order to reach a level of sophistication.

- **BIM Implementation Maturity Stages**

As the UK Government has recognized the potential of BIM to transform the construction industry as a whole. The Government's support for BIM is acting as a main motivation for the industry to change their conventional workflows. In order to improve the development common standards and protocols and classifications published (BIMTalk, 2010). The BIM Task Group (2013) classified BIM maturity levels as shown in Figure 2.14.

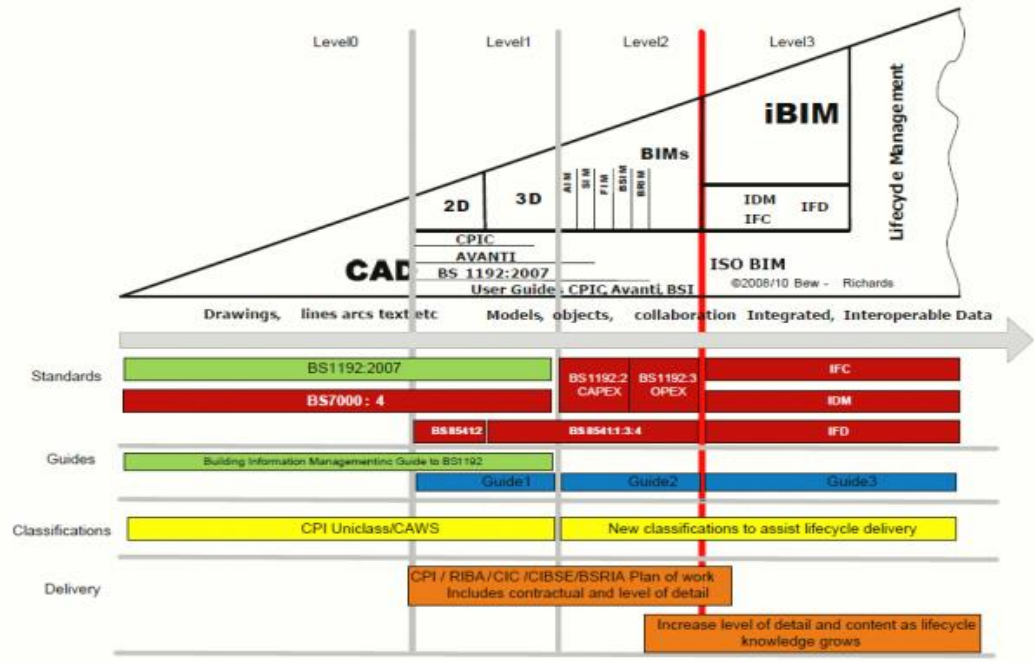


Figure 2.14: BIM maturity Levels (Bew & Richards, 2013)

Level 0: Unmanaged CAD, 2D drawings with paper (or electronic paper) data exchange

Level 1: Managed CAD in 2D or 3D format with a collaborative tool providing a common data environment with a standardised approach to data structure and format. Commercial data will be managed by standalone finance and cost management packages with no integration.

Level 2: A managed 3D environment held in separate discipline 'BIM' tools with data attached. Commercial data will be managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may use 4D construction sequencing and/or 5Dcost information.

Level 3: A fully integrated and collaborative process enabled by 'web services' and compliant with emerging Industry Foundation Class (IFC) standards. This level of BIM will utilise 4D construction sequencing, 5D cost information and 6D project lifecycle management information.

Similarly, Khosrowshahi and Arayici, (2012) depicted BIM implementation maturity in Figure 2.15 there are three stages in BIM implementation: object-based modelling, model-based collaboration, and network-based integration.

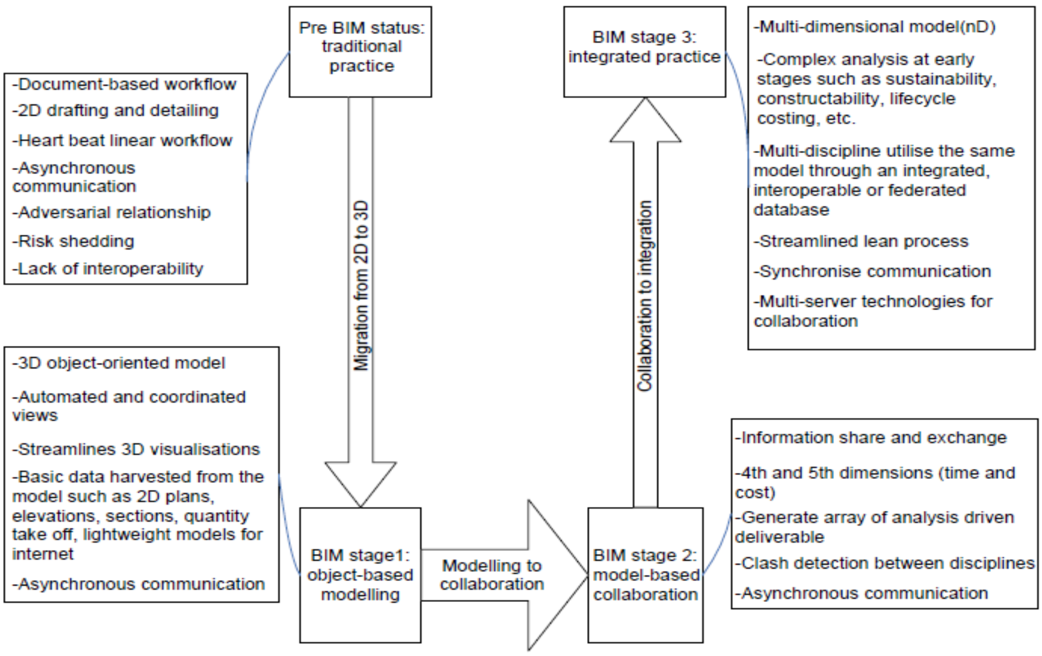


Figure 2.15: BIM maturity stages in BIM implementation (Khosrowshahi and Arayici, 2012)

As per the inefficiencies caused by the traditional approaches, the UK Government’s mandate the public-sector construction required to have BIM Level 2 (Figure 2.15).

2.6 BIM for client organizations

To achieve expected potential of BIM, it must be led by the client. Without the motivation and support provided by the client the implementation would not be successful. The main reason behind this crucial factor answered by Eastman (2011) that is to gain higher quality and performance for the whole asset lifecycle. Accordingly Love et al. (2013) support that the losses caused by the traditional construction could be reduced by the BIM implementation as it changes the conventional methods. This was concluded by Arayici et al. (2011) that the collaboration of the stakeholders will expand the clients' boundaries and leads to increased organizational performance of the project in various phases of the asset lifecycle. BIM could help in creating a new culture of collaboration among all the stakeholders and exchange information in the beginning of the project lifecycle. However, the organizations' readiness and capability to adapt this change could impact on the benefits expected. This new process of collaboration provides valuable benefits for the clients to fully understand the projects (Eastman, 2011; Succar, 2009).

2.7 Summary

This chapter explained background of the UK construction industry and presented the literature available on the asset handover practices, as well as identifying the concept, origin, and growth of BIM and its uses in the construction. The chapter detailed current data management practices, and the related issues; these include facilities/asset management and data handover and the reason for effective data handover for highways construction.

As the main objective of this research is to develop BIM-enabled recommendations for maintenance of the assets and validate it for highways civil infrastructure clients in the UK. The chapter contributes to the research objectives by achieving the following objectives by (i) reviewing the current barriers and bottlenecks for data handover in the Highways construction sector (ii) exploring potential of BIM in supporting public sector highways construction sector

This chapter identified that there is limited research has been done in BIM for highways construction and it suggests that Building Information Modelling as a solution to enhance the current problems of the highways construction as per the HM Government's Level 2 BIM mandate. The next chapter will introduce and discuss the research methodology used in this research.

CHAPTER 3

Research Methodology

3.0 Research Methodology

This chapter presents an extensive explanation of the methodological issues for this research. Saunders, et al. (2012) highlighted that the research aim, and objectives are the key elements that determine a suitable research methodology and research method. This chapter describes the methodology and processes applied to do this research. It presents the philosophies, approaches, strategies and data collection techniques used in research indicating the rationale behind using these various patterns in this study. As highlighted by Crotty (2004), the basis of applied science lies in preparing theoretically-grounded solutions for practical problems. From this argument, this research adopts an interpretivist qualitative philosophy for the most part of the research. Mono inductive method, and multi-case study methodology were used, including semi-structured interviews, observation and document analysis were used as data collection tools. Based on the case study findings recommendations were developed. Focus group discussions were used for the recommendations to be validated.

This research initiated by an extensive literature review on the subject area to identify the gaps in the knowledge concerning BIM and its potential for data management, asset maintenance and currently available handover processes in the highways construction sector as explained in previous chapters. In addition, literature review extended to develop an understanding of the information related to handover of built assets in the highways sector (civil infrastructure) and investigating all BIM processes. Then, the research created an understanding reflecting the need of the highways public sector clients. To validate and improve the generated recommendations, the researcher conducted focus group discussion with the built environment experts to guide the highways construction clients in the UK.

3.1 Definition of Research Methodology

According to Fellows and Liu (2009) research methodology is ‘definition of the problem, defining the problem in such a way that lends itself to careful investigation’. Similarly, Crotty (2004) explains that research is a plan of action, procedure, or design setting behind the choice and use of specific methods and linking the choice and use of approaches to the desired results. Likewise, Collis and Hussey (2014) further support that the research process, which starts with the theoretical basis to gathering data and ending with the analysis of the data. In short, research methodology is the systematic approach that suitable procedures to collect and analyse data and to find issues to be discussed.

3.2 Research Design (Model)

To implement the research aims and objectives, it is crucial to identify the methods of the research that are available in literature and analyse them to address the most suitable approaches to be applied by the author. In social science, there are three types of research;

1) **Descriptive research**, which aims to explain problems that are under investigation. This type of research helps researchers to understand and analyse subjects in depth.
2) **Exploratory research** aims to provide better understanding and improved explanation for a case that has not been defined or understood properly.
3) **Explanatory research** aims to discover the reasons/cause of the case under investigation. It is conducted to answer the research questions based on specific techniques (Cargan, 2007).

This research falls into exploratory study and aims to develop recommendations to enhance data management in infrastructure data handover practices in the UK Highways construction sector, for public-sector clients. To formulate the research methodology for the study in an appropriate context, the researcher adopted the Saunders et al. (2012) research "onion" to present a holistic and systematic method to the research. According to Saunders et al. (2012), the research process is described as an 'onion' with five layers. The outer layer is the philosophy of the research, the second layer is the research approach, and the third layer is research strategy, then time horizons, and data collection. The following section presents the philosophy of the research, the research approach, the research strategy, and the data collection techniques, as shown in Figure 3.1.

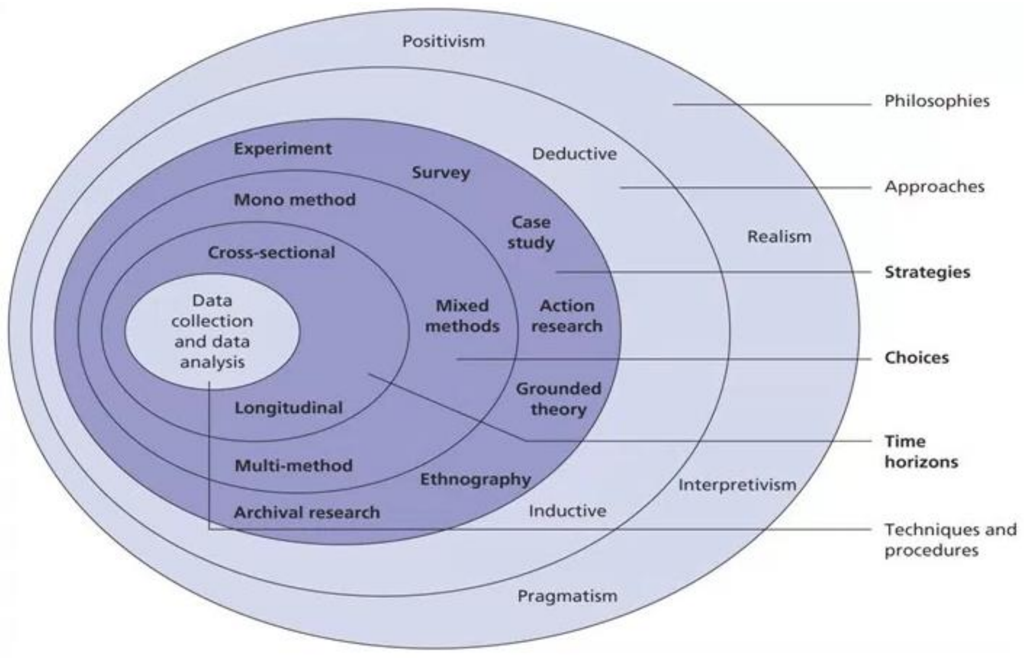


Figure 3.1: The research Onion, Saunders et al., 2012

3.3 Research Philosophy

According to Saunders et al. (2011), the research philosophy has essential assumptions about the way in which a researcher sees the world. These assumptions will support the selection of the research strategy and methods used in implementing the objectives. The main impact is the views of the relationship between knowledge and the process used to create it. There are three main philosophical positions that underlie the designs of management research: Epistemology, Ontology and Axiology (Saunders et al., 2011).

Ontology is a philosophical attitude concerned with what is known or what constitutes social reality. Creswell and Clark (2007) state that ontological assumptions hold a diverse range of viewpoints of social realities, but they need to be placed within political, cultural, historical and economic value systems to understand the differences. Ontology consists of two main aspects: 'Objectivism' and 'Subjectivism'. Objectivism represents the position where social entities exist externally to social actors concerned with their existence (Crotty, 1998).
Subjectivism embraces social phenomena from the perceptions and consequent actions of social actors concerned with their existence (Saunders et al., 2011). Essentially, it explains what knowledge is and assumptions about reality (Creswell, 2013).

Epistemology is concerned with what creates acceptable knowledge in a particular field of study (Saunders et al., 2011). On the continuum of epistemology, the extreme positions are called 'Positivism' and 'Interpretivism'. Positivism suggests the use of quantitative experimental methods to test hypothetical-deductive generalisation; and Interpretivism suggests the use of qualitative and naturalistic approaches to inductively and holistically understand and explain a phenomenon. According to Creswell and Clark (2007), the Interpretivism aim is to increase the general understanding of the research subject in which the research progresses through gathering rich data from which ideas are persuaded.

Axiology is dealing with role of values;

● In positivist research, the researcher identifies that research is value-free and unbiased, as positivists think through that they are independent from what they are studying (Collis and Hussey, 2014).

● In contrast, interpretivists consider that the process of research is value laden, which means that the researcher is interacting with what is being investigated (Collis and Hussey, 2014). In other words, they are influenced by personal beliefs.

Depending on the characteristics of these philosophies and the nature of this specific research (the researcher aims to develop recommendations to enhance data management in highways infrastructure practices of the construction projects in the UK).Thus ,qualitative attitude was selected this research. This research philosophy is subjectivism in ontology part because there are few assumptions that have been used to explain the relationship between BIM implementation and data handover. While, the epistemology part is mainly interpretivist, which allows the researcher to get richer and deeper understanding of the justification and rationale to the relationship between BIM-enabled implementation and data handover.

3.4 Research Approach

Saunders et al. (2011) described the research approach as how theory is developed, which can be classified as either the deductive approach or the inductive approach. The aim and objectives along with the research questions play a significant role in the selection of the research approach (Saunders et al., 2012).

In the deductive approach, researchers develop a theory and hypothesis (or hypotheses) and design a research strategy to test the hypothesis. While in the inductive approach, the researcher collects data and develops a theory because of data analysis (Saunders et al., 2011). Although it is potentially misleading, Saunders et al., state that the deduction approach is close to positivism and induction to the interpretivist philosophy. Saunders et al. (2014) summarised the main research approaches as in Table 3.1.

Table 3.1: Deductive and Inductive Research Approaches (Saunders et al., 2012)

Deduction	Induction
Moving from theory to data	Moving from data to theory
Used more in natural sciences	Used more in social sciences
A highly structured approach	Flexible structure to permit changes
Explain causal relationships between variables	Understanding of meanings humans attach to events
Select samples of sufficient size to generalise conclusions	Less concern with the need to generalise

Hussey and Hussey (2003) argue that the researcher can move between an inductive and deductive approach. Likewise, Sekaran (2003) and Saunders et al. (2012) suggest that adopting deduction and induction is possible in the same research, but also a beneficial approach.

Synthesis of the research philosophies

Thus, in this research, the researcher has selected to use inductive approach; using case studies in order to develop recommendations. The factors, necessary to investigate the issues affecting asset handover practices in the highways construction sector in the UK, were derived from the literature. Afterwards, the findings from the study integrated to the existing body of literature (inductive).

3.5 Research Strategy

Saunders et al. (2012) defined research strategy as the plan of the way in which the researcher will go for answering the research questions with the aim of achieving the research aim and objectives.
Saunders et al. (2011) suggest the following research strategies; experiment, survey, case study, action research, grounded theory, ethnography and archival research. They also argue that no research strategy is inherently superior or inferior to any other and the research strategies are also not mutually exclusive. For example, it is quite possible to use the survey strategy as part of a case study (Saunders et al., 2011). Case studies present the information in the context of a particular organisation, inclusive of the characteristics of the organisation and give actual data (Haron, 2013). While this research focuses on to improve data management using BIM for the operation and maintenance of the civil infrastructure assets in the UK highways sector, it seems that the case study represents the most suitable strategy for this research. The next section will go into detail for selecting the case study research strategy.

3.5.1 Case Study Research Strategy

Case study research strategy is extremely powerful in social science research. A case study is a perfect methodology when a holistic, in depth analysis is required (Yin, 2009). It is also relevant if the researcher has little control over the events, focuses on contemporary events, and wants to gain rich information and deep understanding of the situation in the real life. It takes out the details from the perspective of the participants by using several sources of data. It enables a researcher to closely study the data within a specific situation (Yin, 2009). The evidence is collected systematically by interview and/or observation

Yin (2009) indicates that case study is the best strategy when 'why' or 'how' questions are being posed. This lets the researcher explain not only what happened but also how it happened. For this research case study strategy has been adopted, as it is the most suitable research strategy to identify and investigate data management in infrastructure asset handover practices for highways public sector clients in the UK, to answer the research questions. The occasion is contemporary, and the researcher has no control over this phenomenon.

- **Justification for selecting case study strategy**

To justify the selection of case studies as the research method, Fellows & Liu (2007) suggest that specifically for construction, there are five methods that can be considered, and they are action research, ethnographic research, surveys, case studies, and experiments. The critical consideration is the logic that links the data collection and analysis to yield results and hence conclusions to the main research question being investigated. Therefore, it was suggested that the research design must consider the research questions, determine what data is required and how the data is to be analysed (Creswell, 2009). As the research is positioned within a qualitative approach based on the research questions posed, the options that were available are action research, ethnographic research, and case studies. This research however, opted to choose case study as a research method.

Table 3.2: Various research strategies (Yin, 2009)

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

By referring to the guide given by Yin (2009) which can be seen to in Table 3.2., the selection of case study as the research strategy was reinforced by the following justification.

a) The research questions

As discussed previously in the research approach, this research poses the question of what and, how in an exploratory way. The questions posed deal with operational links needing to be traced over time rather than mere frequencies or incidence (Yin, 2009).

b) The extent of control an investigator has over actual behavioural events

Describes the degree to which the researcher can manipulate the behaviour of the subject, for example by giving or withholding motivators (Yin, 2009). In this context, the options available were reduced to histories and case studies since the researcher had no control over the implementation of BIM by the organisation, condition of respondents during data collection, or any policy engaged within the organisations that were investigated.

c) Contemporary events

In this justification, the only difference between history and case study is that histories are dealing with data of dead past where no relevant persons are alive to report, even retrospectively, what occurred (Yin, 2009). Therefore, it requires an investigator to rely on primary documents, secondary documents, and cultural and physical artefacts as the main source of evidence. Case studies, on the other hand, besides using the same evidence, add two more sources of evidence: direct observation of the events and interviews of the persons involved in the events. Therefore, it justified the need of selecting case studies as the research method for data collection as the researcher managed to use the two sources of evidences.

Case studies present the information in the context of a particular organisation, inclusive of the characteristics of the organisation and give actual data. Experimentation and surveys are ineffectual because the implementation of a new system has variables and factors that cannot be extracted out of the original context. Furthermore, in determining recommendations for data handover implementing BIM in the highways context (in the UK), it involves the understanding of the organisations' business process, perception of people and unique work environment subjective to the organisation.

- **Case study design and Justification of selecting multiple case study over single case study**

Crowe et al. (2011) explained case study design in different ways depending on the researchers' epistemological standing. This is supported by the fact that a case study can be designed to meet certain research requirements; hence it can be single case or multiple cases. When the case study design process is carefully undertaken and details within a case are given adequate consideration, it provides tools for researchers to study complex phenomena within their context (Baxter and Jack, 2008). Yin (2003), discusses four types of case study design based on a 2x2 matrix that comprise single and multiple case study reflecting distinctive design situations (see Figure 3.2). The following are the types of case study designs (1) single-case holistic (2) single-case embedded, (3) multiple-case holistic (4) multiple-case embedded. According to Yin (2009), these classifications provide the liberty to select a case according to the nature of a specific research and can be adopted in advance before the start of data collection of research.

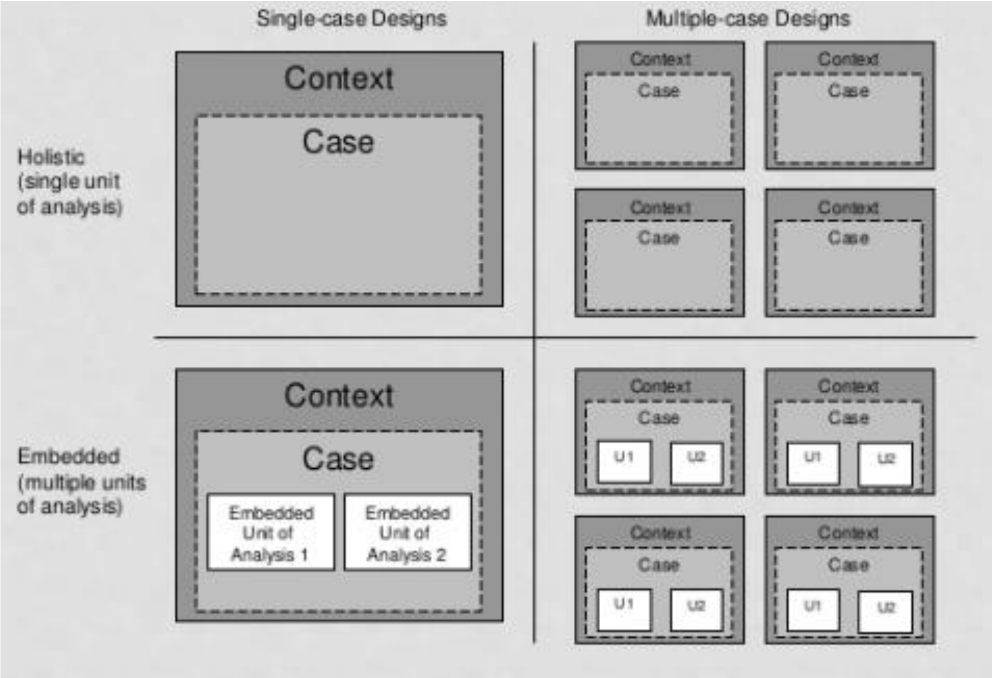


Figure 3.2: Types of case study designs (Yin, 2009)

To improve robustness and generalisation of case study results, multiple case study design was preferred to single case study design. Multiple case studies provide credibility to research results and reduce substantially criticism and scepticism that usually are associated with case study, thereby producing an even stronger effect on the outcome of the research (Yin, 2009).

As a matter of fact, conducting two cases begins to 'blunt' these criticisms and scepticism; therefore, having more than two case studies, research produces a stronger effect on the research process (Yin, 2009). In the light of this, Yin (2009), advised that having at least two cases should be the researcher's goal. According to Amaratunga and Baldry (2001), multiple cases strengthen the results by replicating the pattern matching, thus increasing confidence in the robustness of the research process. Therefore, the selection of two or more cases falls within direct replication logic (Yin, 2009). One of the strengths of multiple case studies approach is that it allows the researcher to use a variety of sources, a variety of types of data and a variety of research methods as part of the investigation (Denscombe, 2007). More significantly, the analytic benefits from multiple case studies may be substantial if there is the possibility to have direct replication (Yin, 2009). From the discussions, multiple cases provide clear and compelling credibility to the research process, as it has been provided, research involving multiple case study are regarded as more robust as compared to single case study. Therefore, in this perspective, multiple case studies provide an opportunity to the researcher to gain access to a variety of data from a wider spectrum. This enables the researcher to adequately explain the understanding of the phenomenon being studied. Considering the various rationales that have been espoused in respect of case study design for the purposes of qualitative data collection, this research adopted a multiple case study approach. In the context of this research multiple case study design is the most appropriate approach since the phenomenon being studied does not present a critical, extreme or the unique case situation.

Furthermore, there are two distinctions when implementing case study research strategy as multiple case or single case study designs. According to Yin (2009), multiple case studies are used to replicate results and maintain theoretical generalizations and also increase the external validity of the research. On the other hand, Yin (2009) gives five justifications for implementing a single case study: critical case, unique case, representative or typical case, a revelatory case, and longitudinal case. However, a single case study has a shortage on the generalizability of conclusions that are to be drawn (Voss et al., 2002). Thus, the researchers must have a strong justification if they choose a single case study as a research strategy.

Referring to the above discussion, the researcher implemented multiple case study design (holistic) where the context is in the UK Highways construction sector. Three of the UK Highways public sector cases used as effective cases and has sufficient scale this research. As representative cases, these schemes have initiated BIM use for their construction processes and considered to be the trailblazers of the UK in the highways construction sector. The schemes provided answers to the research questions and will give a rich understanding about the influence of obstacles that affect lifecycle data management in highways construction sector. As the schemes are the first BIM implementation projects in the UK for the highways development projects, there is lack of published literature and BIM-based guide in data management in highways assets handover practices for public sector construction projects in the UK. The choice of multi case study design will allow cross case study analysis. Thus, lessons learned, and knowledge retrieved from these schemes can be extrapolated to other schemes.

- **Case Study Selection Criteria**

As for the number of cases for selecting case studies, Alsehaimi et al., (2012) highlights that there is no consensus in the appropriate number of cases that need to be developed when applying a multiple case study approach. However, according to Yin (2013), a selection of cases should be directed by the replication of logic. Each case should be considered as an experiment itself, and subsequent cases will be used either to confirm or refute previous findings. Careful selection of cases is crucial to maintain enough information is obtained by the researcher to generate the conclusion at the end of the study. The number of case studies investigated by the researcher will depend on the similarity between the results but mainly the researcher need at least two construction organizations that work for public client organisations to produce solid conclusions via using multiple case study design. Table 3.3 gives the case study project details for this particular research.

The selection of cases is based on the aim and objectives of the research and the research context. It is simplified as the following:

a) The type of organization should be one of the UK public highway construction projects and working for the client organizations.

b) The organization must have initiated implementing BIM within their construction process due to government level 2 mandate of BIM delivery.

c) Various levels of organizational experience in BIM implementation, which allow the researcher to compare BIM implementation in various levels of BIM experience.

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

Table 3.3: Case Study project details

Name	Location	Project Description
Case A	Manchester, UK	Highways Development/upgrade Project
Case B	Sheffield, UK	Highways Development/upgrade Project
Case C	Manchester, UK	Highways Development/upgrade Project

- **Case study design protocol**

The aim of this research is to develop BIM-enabled recommendations for highways construction clients in the UK in to successfully manage the public infrastructure assets in their lifecycle. With respect to this research, the case study design protocol in Figure 3.3 was created based on Yin's research (2009). The Figure 3.3 depicts the step by step approach in conducting this research.

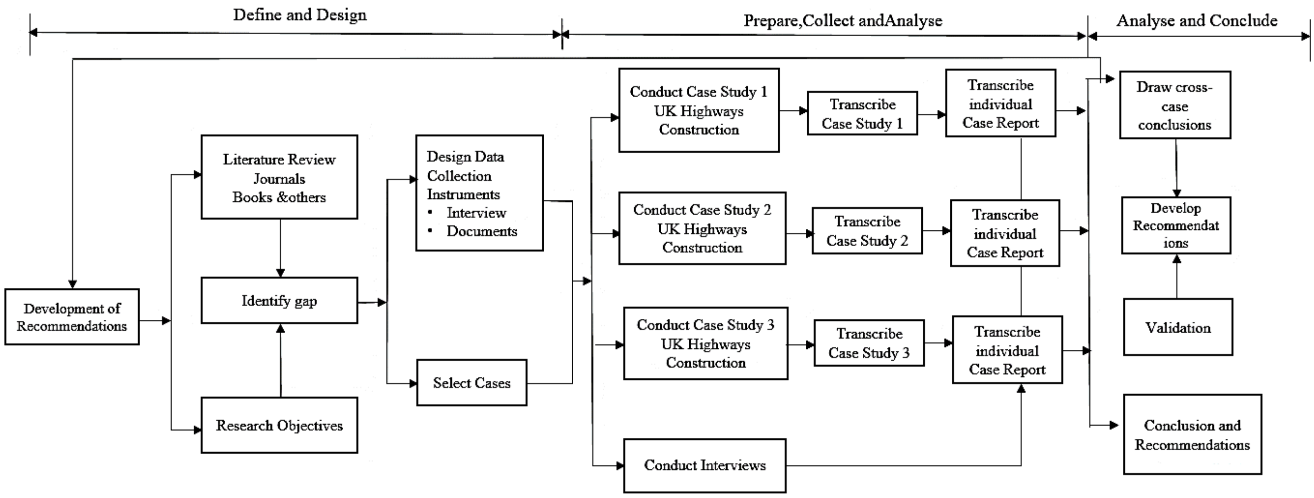


Figure 3.3: Case study design map adapted from Yin (2009)

3.6 Research choices

The aim of this research is to develop recommendations for highways construction clients implementing BIM. Therefore, the appropriate research choice is a significant aspect of achieving the research aim. The term research choice refers to the combination of quantitative and qualitative techniques and procedures for analysis (Saunders et al., 2009). The terms, quantitative and qualitative are frequently used in business and management research to differentiate both data collection techniques and data analysis procedures (Saunders et al., 2009). Researchers further argued that they can select from either single data collection technique and corresponding analysis procedure, this is referred as **mono method** or use more than one data collection techniques and analysis procedures to answer research questions, this is known as **multiple methods** (Saunders et al., 2009).

Saunders et al. (2009) explained that mono-method represents single data collection technique and it corresponding analysis procedure. The mono-method combines either a single quantitative data technique, such as questionnaires, with quantitative data analysis procedures or a single qualitative data collection technique, such as in-depth interviews, with qualitative data analysis, with qualitative data analysis procedures. It is applicable for quantitative and qualitative techniques. Similarly, the multiple-method refers to combination where more than one data techniques are used to answer research questions. This method further broken down into two forms; namely multi-method and mixed methods. Multi-method research refers to the combination of more than one data collection technique with its associated analysis techniques but restricted within either quantitative or qualitative research environment. This means that the researcher can choose to use quantitative techniques by using questionnaires and use quantitative analysis techniques, this approach is known as ***multi-method quantitative*** study. Alternatively, researchers can choose to collect qualitative data using in-depth interviews and analyze these data using qualitative procedures; this is known as ***multi-method qualitative*** study. Further, if multi-method is adopted, the researcher cannot mix quantitative and qualitative techniques and procedures. On the other hand, the mixed-methods approach uses quantitative and qualitative techniques and analysis procedures and analysis procedures are used either at the same time or one after the other but cannot combine them. This method tends to base knowledge claims on pragmatic grounds (Creswell, 2003). With respect to this research, and to understand and better grasp the perceptions of the industry practitioners initiated BIM implementation in the Highways civil infrastructure sector in the UK, this research falls into multi-method qualitative research study as per data collection and analysis techniques, this has provided the clearest possible grasp of the issues being researched.

The following section of the research methodology explains the techniques for data collection and analysis adopted for this research.

3.7 Research (Data Collection) Techniques

There are four main research data collection techniques that have been used to complete the research with the focus of justifying the use of each technique. The research techniques were linked to each other and they are: the literature review, in-depth semi-structured interview, documents review, and direct observations (Denscombe, 2007). Table 3.4 illustrates these techniques and their relevant strengths and weaknesses.

Table 3.4: Strengths and weaknesses of data collection technique (Yin, 2009)

Techniques	Strengths	Weaknesses
Literature review	A great amount of data can be collected in short time and minimal cost; It offers a conceptual framework for the study.	Need high skills in recognizing and analysing the relevant information, and writing a meaningful summary.
Documentation	Provide exact details (Useful for exploration) that can support verbal interpretations	May be incomplete and representative only of one perspective; Access may be limited.
Archival Records	Available on a wide variety of topics; Ease of data analysis	May not be available for the research questions of interest to you; accessibility may limit due to privacy reasons.
Interviews	Insightful; Useful for exploration and confirmation; provide in-depth information	Response bias; expensive and time consuming; Reactive effects
Focus group	Can examine how participants react to each other; exploring ideas and concepts.	Discussion may be dominated by one or two participants; Measurement validity may be low.
Observation	Reality: discover what is occurring in actual time; Contextual: covers situation of case	Data analysis can be time consuming.
Questionnaire	Inexpensive; Data is easily analysed and interpreted.	Low Response rate; Lack of clarify questions if the respondent misunderstand

Yin (2009) states that there is not only one technique that fits all studies, the nature of the research, as well as philosophy, approach and strategy of the research, along with the aim of the study will determine the relevant techniques to use. Collins and Hussey (2014) states there are two main kinds of data collection as primary and secondary.

Primary data was the main concern of data collection for this research. However, the secondary data was collected to link the topic of the research, and the current body of literature was used to identify to gap in the Highways construction for the study. This data was primarily collected from industry reports, reference books, articles, scientific papers, theses, and internet research.

In the context of this research, Yin (2009) states that there are five data collection tools in the case study; document review, direct and participant observation, interviews, archival records, and physical artifacts. These tools may be used in balance or in cycles. Accordingly, a case study strategy must use several resources of data collection according to their condition relevant to the research (Yin, 2009).

This research uses both secondary and primary data. Due to the nature of the research questions and time constraints of the PhD research, interviews, document review, and direct observation were adopted to collect in-depth knowledge and understanding of the state-of the art practice from the case study. To validate the results from the in-depth case studies, triangulation has been formed using focus group discussions to enhance the reliability and validate the collected data, in addition to enhance the generalizability of the results.

3.7.1 Literature Review

According to Saunders et al. (2011), the literature review provides a description and critical analysis of the current state of knowledge in the subject area. In addition, the literature review justifies any new research through coherent critics of what has gone before and demonstrates why the research is important (Khoshgoftar & Osman, 2009). This research involves two stages of literature review. The first stage of the review carries two purposes as following:

a) At an early point of the research, the first stage literature review was conducted to understand knowledge of the current issues in the UK highways construction industry and subsequently to identify the research problems and form the research aim and objectives.

b) After the aim and objectives were recognized, a more detailed literature review was conducted on the subject matter to form knowledge regarding BIM, data handover in highways sector and BIM-based handover for client organizations concentrating on the theoretical and fundamental concepts. This was directed to develop an understanding how crucial it is to develop BIM-based approach for data handover recommendations for public client organizations for the highways construction sector in the UK, which the industry lacks now.

3.7.2 Interview

Yin (2009) states that, the selection of the technique depends on the level of valuation the researcher could have in catching information since some of the evidence such as acquisition records can be confidential, and the willingness to share some documents and thoughts is beyond the control of the researcher. Therefore, the interviews and direct observations obtained during the case studies visit are considered as the main data collection techniques for the case study.

There are three types of interviews, which are varied in their style and are based on the choice of the researcher and the nature of the problem of the research (Saunders et al., 2012).

1- Unstructured interview
2- Structured interview

3- Semi-structured interview

Unstructured Interview: For this kind of interview, the questions are not prepared beforehand or planned; therefore, the interviewer uses their previous experience to drive the interview. The main advantage of the unstructured interview is that it can be carried out in a short-time notice and there is flexibility because questions can be asked in different areas. On the other hand, since the questions are unstructured, the collected information could be irrelevant to the subject of the research and/or useless.

Structured Interview: Planned questions are considered in advance and generally cover all the problem's aspects. The main advantage of this approach is when the same questions are asked to each selected individual, the researcher achieves a well-trusted collected data that participate on robust results. The main disadvantage of this approach is the inflexibility to explore areas of interest/concern that may arise during the interview.

Semi-structured interview: This includes a mix between the interviewer's experience and planned interview questions. Key advantages of semi-structured interview are:

- Flexibility in asking questions and explore more areas of the research;
- Much freedom is given to the interviewer;
- Allows the researcher to explain ambiguity;

Key disadvantages of semi-structured interviews include being expensive and time consuming, especially when large numbers of participants are present. Also, mood of the interview could affect the interaction with the interviewee and, hence, may affect the validity and reliability of the research. A semi-structured interview technique was selected in this research because it is a data collection process that allows the researcher to use previous information of the topic to be examined while producing rich qualitative data about the phenomenon under study.

According to Easterby-Smith, Thorpe, & Jackson (2012), the in-depth semi-structured interview is the most essential of qualitative methods. The interviews allow interviewee's experiences, knowledge, ideas and impressions to be documented (Alvesson, 2003) and provide an opportunity for the researcher to uncover new signs and open up new dimensions of a problem (Yin, 2009). According to (Robson, 2002), semi-structured interviews have programmed questions but the order of the questions can be changed depending on the interviewer's perceptions of what seems to be most suitable.

3.7.2.1 The Interviewees (Research Sample)

In qualitative research, the number of interviews is flexible and there is no need to be exact with the number of respondents before starting the research, it all depends on the replication of reasoning. In this context, many experts in the research area, such as Yin (2009), Saunders et al. (2012), and Collis and Hussey (2014), mention that the qualitative researcher must carry on interviewing respondents until the researcher reaches the saturation point or replication. In addition, Mason highlighted (2010) that in qualitative research, the guiding principle for choosing the sample size should be the concept of saturation. Therefore, the researcher followed this fashion in order to get data from the interviews without exactly knowing the number of respondents would be interviewed until the study reaches saturation point.

For this research, the researcher conducted 15 semi structured interviews in total with the industry practitioners with various engineering and management backgrounds from the selected organizations. The selection of the highways organizations was made based on the implementation of 3D parametric tools as the main technology of BIM for UK Government's Level 2 Mandate. The construction companies were identified and through the companies' webpage, internal contact and industry research projects database of the University of Salford, contact numbers and email addresses were obtained. The selection was from the designers and the contractor organizations.

Firstly, the applicants were informed about the interviews via phone callings, then via emails, and formal application letters were sent. As the participants were responded positively to the interview request. The researcher started conducting the interviews in November 2017, this process lasted approximately 3 months. Table 3.5 presents the details of those 15 participants interviewed for the case studies.

Table 3.5: Profiles of the Interviewees for Schemes

Code	Background	Area of Expertise	Current role	Experience(years)
C-A1	Civil Engineer	Design/BIM Manager	BIM champion	20
C-A2	Project Management	Facility manager	Technical Standards	16
C-A3	Architectural Technology	Construction Technology	BIM Support Officer	13
C-A4	Civil Engineer	BIM Implementation Engineer	Technical Office	7
C-A5	Architect	BIM Implementation Engineer	Technical Office / Handover section	8
C-B1	Civil Engineer	Design Manager	BIM Manager	18
C-B2	Civil Engineer	Maintenance manager	Technical Standards	16
C-B3	Architect	Construction Technology	BIM Implementation Officer	10
C-B4	Project Management	Property Management	Asset Manager	25
C-B5	Civil Engineer	BIM Implementation Engineer	Technical Office / Handover Section	12
C-C1	Architectural Technologist	BIM Implementation	Technical Office	8
C-C2	Architect	Construction Information Technology	Technical Office/Site	15
C-C3	Civil Engineer	Maintenance	Technical office	10
C-C4	Civil Engineer	Construction Technology	Technical Office	12
C-C5	Management	Design Management	Design Manager	30

3.7.3 Document Review

Documentation is a method of research that several qualitative researchers considered useful and meaningful in the context of their research strategy. It helps to validate evidence from other sources and obtaining some basic realistic information about the case at hand. Furthermore, it was used as a supplementary method to semi-structured interviews. Additionally, it will provide a means of triangulating data collection methods. The documentation review is expected to be related to every case study subject (Yin, 2009).

Yin (2013) states that "for case studies, the most important use of documents is to corroborate and augment evidence from other sources". BIMTalk, (2010) identified several advantages of the documents over other research methods. (a) It is a non-reactive technique where the information given in a document is not subject to a possible distortion as a result of the interaction between the researcher and the respondent, e.g. as in interviews; (b) it helps the researcher to study the past; (c) it is a cost-effective method as the information has already been produced (BIMToolkit, 2012). However, documents may have some limitations in terms of the accuracy and completeness of the data.

To overcome possible low reliability of the data produced from the interviews for this research, the researcher could refer some of the organization's documents for example policy documents such as clauses in construction contracts in addition to annual reports, government legislation, and financial reports.

3.7.4 Focus Group Discussions

According to Krueger & Casey (2000), a discussion technique is considered to be a useful and effective data collection as it provided a conductive platform for making sense of various concepts. The focus group discussion is considered to be a highly efficient technique for qualitative data collection since the amount and range of data is increased by collecting from several people at the same time (Robson, 2004). In addition, the focus group discussion is the most appropriate and effective in obtaining information, insight, experience, and knowledge of a large group of industry players in the shortest period of time. Gu & London (2010) recognized that the discussion also provides a forum for the different disciplines within the AEC industry to share and clarify their views on various BIM implementation issues such as common understanding of benefits, hurdles, requirements, and expectations of BIM. This research adopted a focus group discussion as an approach for validation of the developed recommendations for Highways construction.

The discussion produces data from a real-life situation and provides better details on the behavior of the subject. It also became a platform for generalization and method triangulation. The main purpose of conducting a focus group discussion was to evaluate and validate the proposed recommendations for

BIM handover for highways construction clients. This method of data collection is believed to assist in revising and modifying the proposed recommendations for successful data handover (optimizing data handover) using BIM.

3.8 Data Analysis Technique

Data analysis of research is a crucial stage as it assists to examine the gathered data and to reach appropriate conclusions according to them. The aim of data analysis is to use the evidence collected in depth to produce substantial logical conclusions and eliminating any alternative interpretations (Yin, 2009). Saunders et al. (2012) argue that there is no typical process to analyse data in qualitative research. Yin (2013) states that data analysis includes examination, categorisation, tabulation, or otherwise gathering the evidence to address the initial suggestions of a study. While this research study covers qualitative data, thus, this type of analysis will be investigated in detail. According to Collis and Hussy (2014) qualitative data is categorized into quantifying methods, such as content analysis, and the non-quantifying methods, such as general analytical procedure.

Yin (2014) indicated that to reduce potential analytical difficulties, a general strategy for data analysis should be developed. Easterby-Smith, Thorpe, and Jackson (2008) noted that it is important that the researcher follows analysis procedures that are consistent with the philosophical choices of the study. Therefore, this research adopted qualitative analysis procedures. These procedures included thematic analysis, and content analysis. Thematic analysis has been used to analyse the data collected from the open questions' findings extracted from the semi-structured interviews. Furthermore, a content analysis method was used for analysing the notes taken in the recommendations validation phase of the focus group discussions.

The following sub-section presents the data analysis procedures used in this research in detail.

3.8.1 Qualitative data analysis

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

There are different techniques that are shared by most approaches to qualitative data analysis (Lacey & Luff, 2001) as ;

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

The researcher used the thematic analysis technique. According to Braun and Clarke (2006), the thematic analysis is a method that allows researchers to identify, analyze and report themes within data. It minimally organizes and describes the data sets in rich detail.

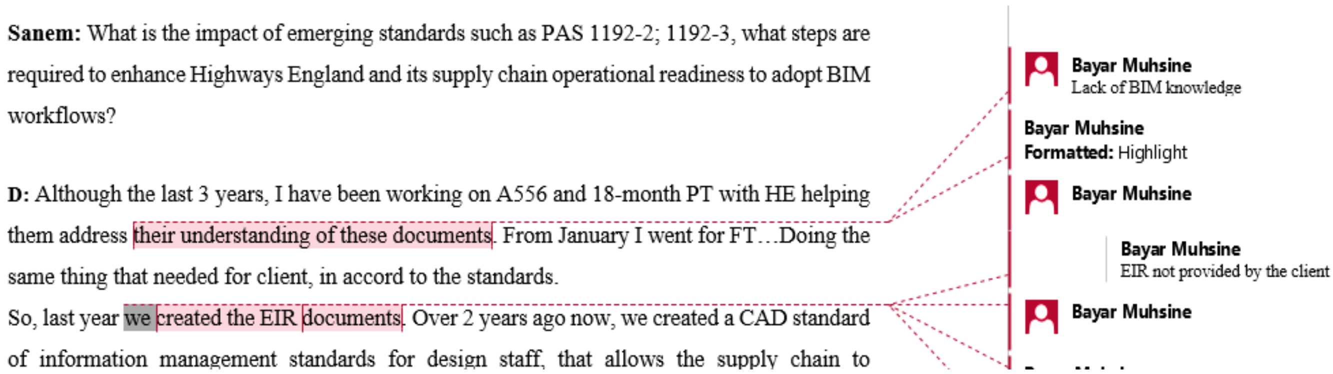
The analysis of interviews began with the intra-case analysis of each case and was followed by cross-case analysis for all organizations involved. The qualitative data management and analysis the researcher used the approach of reading and re-reading of the interviews to find similarities and differences to create themes and to develop categories for analysis of the qualitative data.

This study implemented the multiple case study design where the data is analysed case by case through the objective analysis and later by cross-case analysis (Stake, 2013). Thus, interviews and documents analysed for each case. Following the case-by-case analysis, all themes were used to conduct the cross-case analysis. The similar themes across all cases were kept as well as those that were extremely different (Creswell, Hanson, Plano, & Morales, 2007). For the analysis, the researcher followed Braun and Clarke (2006) step-by-step guidelines. The author used the word guidelines to highlight the flexibility of this qualitative analytical method. These guidelines are (1) familiarizing yourself with your data, (2) generating initial codes, (3) The researcher reads through each transcript to immerse themselves in the data, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report (Creswell et al., 2007). Stake (2013) defines three different cross case procedures for a multiple case study. For this qualitative study, the researcher follows merging findings procedure. According to Stake (2013), the researcher whose priority is to combine the findings across cases should use this particular method. This method also allows the researcher to generalise about the cases.
According to Braun and Clarke (2006), the researcher followed the steps below;

First Step, before the data was analysed, the researcher transcribed all the audio that she recorded during the interviews to Microsoft Word documents. This process allowed the researcher to become familiar with the data collected (Riessman, 1993). The researcher created Microsoft Word files for the interviews and secured the data by setting a password. For further protection, all these files saved in the researcher's computer which could be accessed by a security code.

Then all the data were collected into one folder for creating a poll of data where all opinions, perspectives and conceptions on the studied phenomenon were put together in one place. Each interview was given a specific code to use that code when the quotations were selected to assist the themes. The researcher started to read the transcript carefully to familiarize her with it.

Second step, as the researcher had become familiar with the textual scripts, she started to use initial coding (see Figure 3.4) to identify important keywords mentioned by the participants. Being new to the thematic analysis required the researcher to pay more attention. The codes were generated from the data and sometimes she used the same words used by the participators to represent the code.



Sanem: What is the impact of emerging standards such as PAS 1192-2; 1192-3, what steps are required to enhance Highways England and its supply chain operational readiness to adopt BIM workflows?

D: Although the last 3 years, I have been working on A556 and 18-month PT with HE helping them address their understanding of these documents. From January I went for FT…Doing the same thing that needed for client, in accord to the standards.

So, last year we created the EIR documents. Over 2 years ago now, we created a CAD standard of information management standards for design staff, that allows the supply chain to

Bayar Muhsine
Lack of BIM knowledge

Bayar Muhsine
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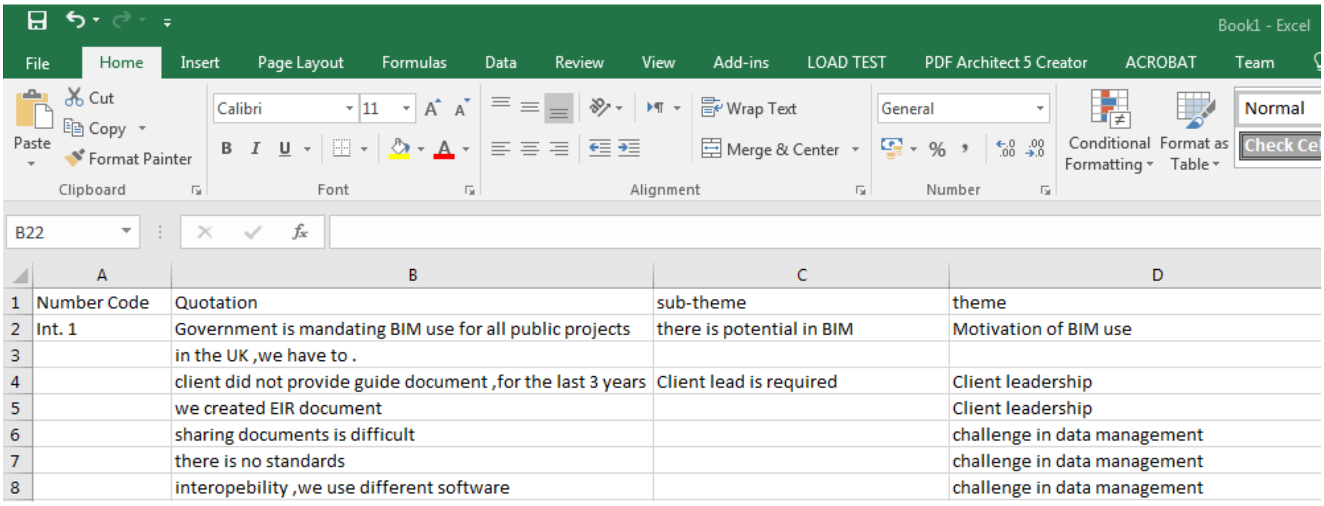
EIR not provided by the client

Bayar Muhsine

Figure 3.4: An excerpt from the Coding Process

Third Step, once all textual data were coded, the researcher started to find the links between similar codes to create sub-themes. The link between the codes was formed by the codes themselves spontaneously by word matching and the researcher was to highlight these notions in sub-themes. In order to complete this step, the researcher used an Excel sheet (see Figure 3.5) so that she could collect all the codes under sub-themes. The same Excel sheet was used in steps 4 and 5 to create the main themes and to finalize the themes.



	A	B	C	D
1	Number Code	Quotation	sub-theme	theme
2	Int. 1	Government is mandating BIM use for all public projects	there is potential in BIM	Motivation of BIM use
3		in the UK ,we have to .		
4		client did not provide guide document ,for the last 3 years	Client lead is required	Client leadership
5		we created EIR document		Client leadership
6		sharing documents is difficult		challenge in data management
7		there is no standards		challenge in data management
8		interopebility ,we use different software		challenge in data management

Figure 3.5: Themes and sub-themes in Excel table

Fourth Step: once all the codes were collected beneath the sub-themes, the construction of the major themes started. The researcher created the themes as they were suggested by the sub-themes. The researcher represented the subthemes.

Fifth Step: once the initial themes were classified, the researcher had to revisit them to elucidate their meaning or to adjust the naming of the themes to make them clearer. The researcher did not make any changes to the themes; but made them more clarified in the light of themes and subthemes.

Sixth Step: the final step in the thematic analysis was the transcribing the report. At this stage, the researcher brought all the quotations, the sub-themes and the themes together to understand the textual data.

3.9 Validity and Reliability

For any given problem, validity is one of the concepts used to determine how good an answer is provided by the research (Miller & Kirk, 1986). Yin (2013) identified two aspects of validity: internal validity and external validity. Internal validity represents what has been identified as the cause actually produces what has been interpreted as the "effect" or "responses" and checks whether the right cause and effect relationships have been established. External validity refers to the extent to which any research findings can be generalised beyond the immediate research sample. It is worth noting that there is a different perspective on validity when viewed within the context of qualitative and quantitative research (Miller & Kirk, 1986). Qualitative research identifies the presence or absence of a given feature for a given problem or situation, as opposed to quantitative research which measures the degree of presence of the feature itself. On the other hand, reliability according to Carmines and Zeller (1979) indicates that the researcher's approach is consistent across different cases and projects and concentrates on the errors and bias of the study. The goal of reliability is to minimise the errors and biases in a study. The objective is to ensure that, if a later investigator followed exactly the same procedures, the same findings and conclusions would be found (Amaratunga et al., 2002). From the above discussion, it can be concluded that the main difference between reliability and internal validity is that reliability deals with the data collection process to ensure consistency of results, while internal validity focuses more on the way such results support conclusions (M. L. Miller & Kirk, 1986).The choice of research framework, the variables, and the data collection tool were to ensure the internal validity of the process. For this research, to accomplish reliability and validity, the researcher implemented clear research plan. The researcher used Yin's (2009) validity and reliability guidance for the cases as seen Figure 3.6.

TEST	Case study tactics	Proposed measures
Construct Validity	Use multiple source of evidence Establish chain of evidence Have key informants review draft case study report	Triangulation - integrating theories - multiple sources of evidence (documents review, survey & interview). - Integrating data analysis methods: content analysis & cognitive mapping.
Reliability	Use case study protocol Develop case study database	Documenting procedures and steps used in the case study Verification of transcripts Consistent interview

Figure 3.6: Validity and reliability procedures for case study (Yin, 2009)

3.10 Summary

This chapter discussed and presented the research model adopted for the research. The researcher used Saunders Research Onion model for this research. This chapter explained procedures implemented in this research to achieve the research aim and objectives. It provided presentation of the methods adopted to ensure the validity and reliability of the research. Both the methodology and the research strategy were outlined, linked to literature, and appropriately justified in line with the literature. The next chapter presents findings of the case studies.

CHAPTER 4

Case Studies

4.0 Case Studies

This chapter presents the description and analysis of the three case studies that form the basis of this research. The section will discuss each case in turn, providing a detailed description of the company backgrounds. Furthermore, it will also provide analysis of the interview transcript for each case, discussing the data handover and BIM implementation with highways construction sector and its processes.

The chapter presents the findings collected from UK Highways construction development schemes using two different data collection methods. These were semi-structured interviews and document analysis. The researcher starts this chapter by presenting the data collected from the official documents including websites to present a summary of the background each case. Next, interview findings were presented followed by cross-case study analysis. The document analysis findings will be used to support some issues mentioned by the participants. Thus, the structure of the chapter as follows;

- Summary of the background of each case study with document analysis.
- The themes and sub-themes which were collected by semi-structured interviews' responses will be presented. The data collected from the official documents assisted in providing support, alongside the suitable quotations extracted from the extracted from the interviews, for the themes and sub-themes.
- A cross-case study analysis will be presented.

The section starts by providing the background of the organization which is then followed by document analysis and discussion. The discussion will illustrate the status of BIM implementation and data management in asset handover of the highways civil infrastructure assets in the UK.

The importance of this chapter, with respect to recommendations development as it provides the primary data for each individual case. Since the data is qualitative in nature, it provides a better understanding of the justification that was made by the interviewees for the BIM and effective implementation of data management in asset handover. This understanding is highly useful to guide the researcher to cross-analyse, discuss and theoretically validate the findings of the project.

4.1 Case A Background

Case A is a public highways development/upgrade motorway project for public sector which is following the UK government strategy to implement BIM Level 2. The scheme is to improve 4.5 miles road and transfer it into a modern dual carriageway which is a major connection. The estimated cost of this scheme is in the range of £165 million to £221 million. Figure 4.1 shows the aerial view of the scheme A.

Figure 4.1: Aerial view of Case A

For this scheme, the researcher interviewed five experts. The list of the interviewees and their backgrounds has been represented in Table 4.1.

Table 4.1: Background of the interviewees for Case A

Code	Background	Area of Expertise	Current role	Experience(years)
C-A1	Civil Engineer	Design/BIM	Design/BIM Manager	20
C-A2	Project Management	Asset manager	Technical Standards	16
C-A3	Architectural Technology	Construction Technology	BIM Support Officer	13
C-A4	Civil Engineer	BIM Implementation Engineer	Technical Office	7
C-A5	Architect	BIM Implementation Engineer	Technical Office / Handover section	8

4.2 Document Analysis Case A

The scheme is one of the first in the UK which initiated implementing BIM in their construction processes. In this scheme, a consistent and structured approach towards technology has been adopted. The scheme implemented BIM processes supported by the related UK policies and protocols to enable achieving efficiency, coordinated, and standardised information throughout the lifecycle of the asset. However, due to lack of best practices, the digital handover was a demanding process to achieve. For instance, Case A started the project without guidance from the client. In order to implement a smooth BIM implementation and data handover process the project, BIM team had to produce Employers Information Requirements (EIR) document. However, as the EIR was developed by project team, the document was developed from their understanding of requirements; hence the document is from their perspective.

EIR is as defined by the BIM Task Group (2013) a crucial document that reflects the client's BIM perception and informs the full project requirements. Currently EIR document for Highways construction client is a missing documentation. The evidence was captured from the participant C-A1.

"[…] simply we had to develop EIR document for the project, at first nobody knew what EIR is, there was no document [...]" C-A1

Designers and contractors compiled all the data according to their understanding of EIR. As previously explained in the second chapter; current standards are too building-centric. Therefore, it is challenging for the highways infrastructure to make sense of some of the standards such as explained for the COBie. In addition, the client is lacking the understanding of EIR documentation for the civil infrastructure assets; therefore, it is not well- described what documents to be submitted to fulfil BIM Level 2 requirements for the highways civil infrastructure. However, Case A is considered to be one of the first Level 2 compliant cases in the highways civil infrastructure sector, although full documentation for digital handover of data is unknown and not clarified by the client at the moment. At present, this situation presents challenges for the highways sector.

The Case A is crucial as it provides a best practice example in the UK for BIM implementation in highways civil infrastructure. Although it is said to be first compliant BIM Level 2 project for highways infrastructure, it was reported that maturity of BIM use in is in developing stages (i.e.: lacks Cobie, component library and their attributes). The information was captured by C-A4's statement;

"[…] however, we are still in infancy stages, there are missing documents, infrastructure specific workflows and standards must be developed [...]" C-A4

Figure 4.2: Case A BIM Model

A full 3D collaborative model has been developed for the project (see Fig.4.1, 4.2 & 4.3). The BIM model was created to develop fully coordinated drawings. The BIM model made it possible for project team to reduce any potential clashes during the construction phase and simulate the construction phase to indicate any errors or problems prior working on site. Improving road safety was also one of the benefits of producing a 3D BIM model as the design team could better understand the design, highlight any hazard, and modify any error during the design stage (see Fig.4.4). In addition, cost information has been integrated into the 3D model and a 4D model was generated. The cost integration facilitated the adoption of different target cost techniques during the stages of the project.

Figure 4.3: Screenshot of Case A BIM Model

For the Case A, mobile technology was effectively used. Mobile technology reinforced the benefits of producing a BIM model and leveraged the information flow from office to site by allowing a secure, accurate, efficient, and up-to-date information flow. A Common Data environment (CDE) platform was essential to maintain this high quality interactive connection between office and site field activities were all recorded using a specific application called MobiCloud, this application provided the scheme real time recording to site activities using any IOS or Android device. Any activity from a predefined list could be recorded and real-time photos could be attached using a site diary. The application would automatically link local weather data and attach it to the record. A back-end connecting system was also available and made it possible to search and view any recorded event.

The project team actively collaborated from the design phases of the project, and the members highlighted the critical areas for the project. The Figure 4.4 shows the collaborative sessions of the project teams.

Figure 4.4: Screenshot of collaborative session output

The innovative mobile technology was supported by the CDE; hence, BIM models have added tremendous value to the quality of captured or produced information. It also made the loss of information at its lowest level. Live connection with site made it possible to update the BIM model with any change and reflect that immediately on cost and project schedules. The quality of information produced in this project would assist to achieve better operational phase during the asset lifecycle.

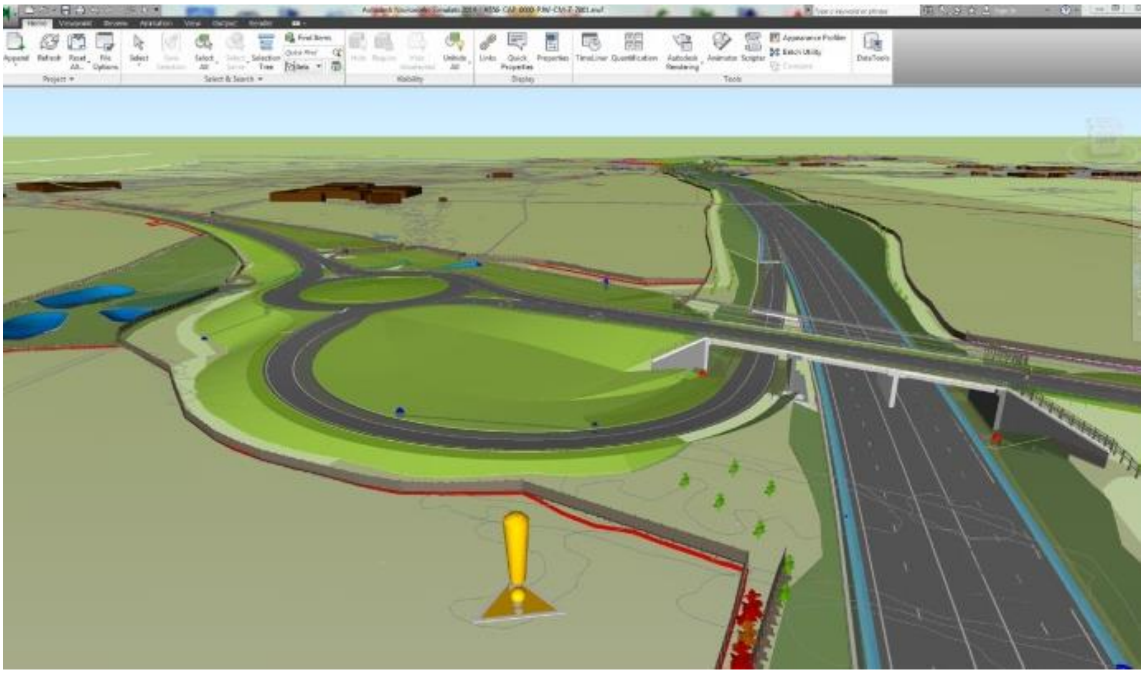


Figure 4.5: Screenshot of Case A BIM Model

The BIM model has simplified and informed the decision-making process and has provided a single central resource of essential data for use throughout the asset lifecycle. The data generated during the project and 3D model outcomes will be used to produce an optimal asset performance which will enable the organisation to explore and closely monitor their asset usage. For example, how the systems are operating, and when and why they need maintaining. Modelling for better user outcomes, with the ability to feed this data back to inform future projects, summarising the real value of Case A.

Even though the project digitally handed over to client complying Level 2 requirements, Case A encountered many problems, due to lack of clear guidance from the client, lack of best practice cases from the highways civil infrastructure for UK and lack of infrastructure specific BIM authoring tools. The project team also had some issues developing 3D model for linear infrastructure. Because current BIM modelling software are more specific to building projects with their asset library. By collaborating with software developers C-A1 expects this to change in later versions. Further, Project Design Manager C-A1 supports this statement by saying:

"[...] The technology for producing a 3D design for buildings are very different to the tools that we have at our disposal for roads, rail, utilities or anything linear [...]" C-A1

As per the requirements the development project, teams started to form a library of standard components to use for the infrastructure assets for future projects, this library is still in developing stages. Fig.4.5 & 4.6 show the components of the highways.

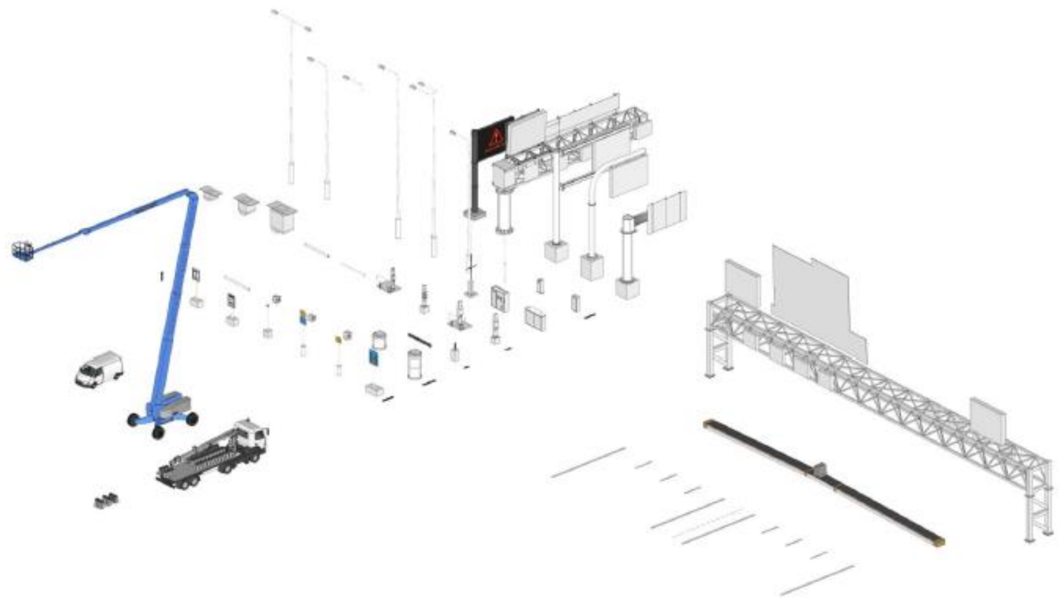


Figure 4.6: Screenshot of Component library, initially for smart motorways and expressways

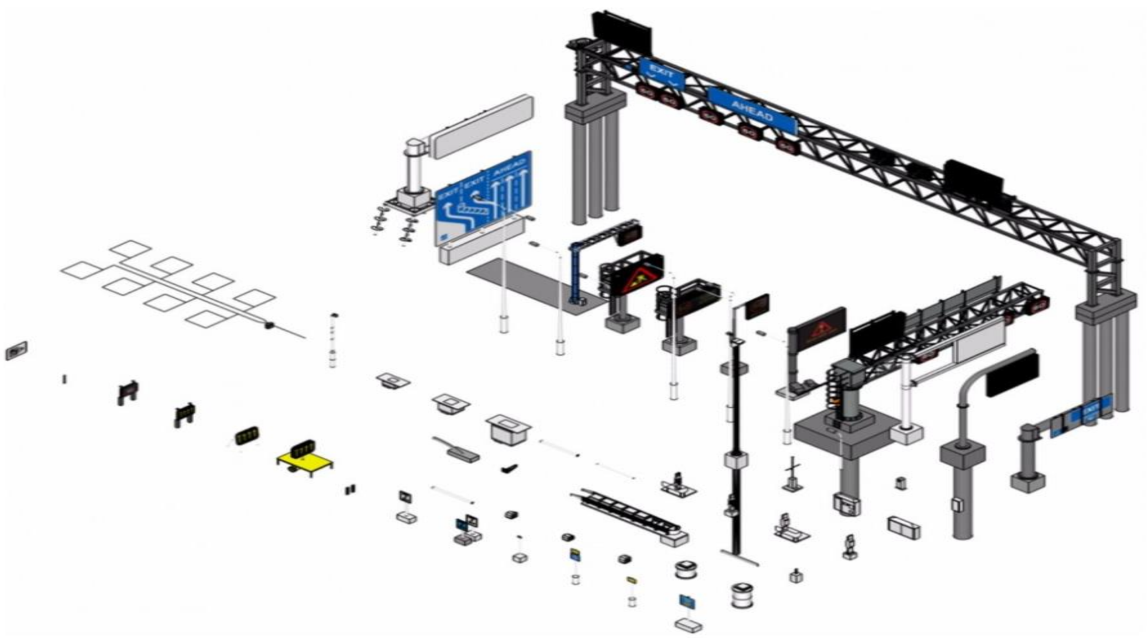


Figure 4.7: Screenshot of Component library, initially for smart motorways and expressways

"[…] In building projects, the Level 2 BIM deliverable information can be obtained from the workflow of REVIT or AECOSIM but we don't have this for our tools. This means we have informed change and overcome a significant hurdle at the same time […]" C-A1

The project team used various software packages to deliver the project. Proprietary systems were used where needed for various disciplines of the project. For example, highways design was modelled using AutoCAD Civil 3D, while other structures such as the six bridges on the scheme were modelled in Revit

2014 and some other software packages were used for the other assets such as signs, lighting and drainage as mentioned by C-A1.

Furthermore, C-A4, the technical engineer of the scheme, explains that they used various innovative processes to deliver the project. Because of the complexity of the linear infrastructure, they needed to use multiple platforms that should speak the same language.

"[…] discrete objects like signs or lighting columns are designed in tools which embed asset data. For other assets such as pavement and road safety barrier we expanded the information we needed to know about them through a link to a database, a technique usually only seen in GIS community [...]" C-A4

The design manager C-A1 further explains that his team then developed a "middleware" to allow each of the BIM elements to talk to each other. This meant linking the information from the various packages making connections to the database which could then be used to derive the data required for handover to the client as part of the Construction Operations Building Information Exchange process (COBie) for future use.

The other issues related were COBie data and interoperability issues with the current data base. COBie for linear infrastructure currently under development and will be used in future highways construction processes. The asset database and produced COBie files are compatible with each other.

"[…] currently it is difficult to go from my design model to COBie but we have a theory and mechanism for doing it in a slow production sense. Over the next two years it might just be design and hit the button to get what we need [...]" C-A2

C-A2 further added that this required the project some investment and dedication however, it made a valuable best practice case informing further highways construction projects.

"[…] It might seem like a straightforward road project, but we have done some really innovative things here, which will inform BIM on future projects [...]" C-A2

One of the major problems that project team encountered was the data provided by the client. The data base is quite old, and the team could not use it for decision-making. The data was historically built and cannot be relied upon decision making. For example, the exact locations of the manholes, the data in the file was generated almost 20 years ago and the asset was not there as it was mentioned in the files. Most of the asset such as manholes were scanned again, because of the team could not understand the exact location and condition of the assets.

The developed BIM model helped the project a great deal, as the team could use it for clash detection for the linear infrastructure. In addition, with the help of the BIM model the team could solve the structural problems without making huge investments with constraints.

"[…] Lane overpass construction activities were not allowed to disturb a large diameter underground service, with vibrations or loadings not permitted. Using the model, the team created the structure with piled foundations and longitudinal and transverse drainage runs and worked with the service owner to develop a solution which in the end saved [...]" C-A1

4.3 Handover Process Case A

The information handover process in this scheme is based on the required standards series of documents set by the client. These standards describe what documents needed for handover in the end of any project and define what information to be included in these documents. However, these documents were previously produced for the traditional handover process. In the Case A the team was tried to enable digital handover method without the guidance of the client.

The client uses an asset management system named Integrated Asset Management System (IAMS). The IAMS (Integrated Asset Management System) is operating with 17 agencies and suppliers' systems within one single integrated system for facility/asset management. Systems like drainage data management system, structure management information system, and geotechnical data management system will be all integrated within one geographical information system. The integrated system will hold information as asset attributes which define the characteristics of an individual asset. However, currently there are data losses due the interoperability. Current repertoire of documents was produced in the past and they do not match the recently generated digital information. The team manipulated the documents manually to overcome the interoperability issues of the asset management system. However, this process is demanding and requires some skilled work.

To enable IAMS as a digital repository for all the highways schemes in the UK, problems with the data interoperability must be solved. The process mainly utilises COBie to allow various sources of information to be interoperable. However, Cobie for linear infrastructure presents many problems as currently it is under development.

Asset Information Model (AIM) models were created using multiple software, for example GIS data was added from Civil 3D software to Revit etc. AIM which will be used as a single source to store all information related to the project. AIM allows a smooth and effortless way to search for any needed information during the operational phase of the asset. Furthermore, EIR is still under development and not mature yet. Highways agency has recognized the requirement of client-led philosophy and is in the process of developing documents, and standards which could be recognised in future highways projects.

4.4 Discussion

The project A shows a case where a systematic implementation of BIM technology in line with the related UK BIM level 2 policies. The implemented technology has raised the level of gained efficiency and delivered value in this project. The project sets up a model for a successful implementation of level 2 BIM for an infrastructure project, and it forms a good best practice example for any future infrastructure case. The Case A achieved full BIM enabled process by:

First, implementing a full 3D collaborative workflow enabled the team to achieve fully coordinated drawings. High quality drawings with no site conflicts have been accomplished. In addition, 4D and 5D BIM were in place giving a good opportunity for the project team to implement different cost control technique, target cost design methods. All the achieved collaborative workflow and information exchange in this project was according to UK BIM level 2 policies which reflect an elevated level of implementation methods and techniques. Although current policies are very building centric, the project team tried to comply with the workflows of the UK Government construction policies.

Second, enabling a digital handover model is one of the recognised achievements in this project. Some IFC and Cobie based files were used to achieve the digital model to be interoperable with the asset management system of the client. Moreover, the adopted method in managing the information based on level 2 BIM requirements enhanced the information flow to enable the digital handover. By accomplishing digital handover model, the project team could enable the Integrated Asset Management System (IAMS). The accomplished BIM model will be beneficial during the lifecycle of the asset and will enable a low cost high quality asset management phase.

Third, some supplementary mobile technology was used to leverage the flow of information from site to office. Implementing advanced applications and hardware were essential in this project to transfer data in a structured and secured method. Benefits in reducing cost and time and enabling digital collection of data were well achieved in this case.

To conclude, the case study shows a case that achieved a digitalised handover model that complies BIM level 2 requirements however the process was not guided by the client's digital handover protocol. The project gives a unique model that could be followed as a best practice model as team had to face multiple problems for BIM implementation. The achievement of a full digital information flow which is integrated in one source of information for the management of the assets was an innovative and relatively new experience.

4.5 Case B Background

The Case B is a public highways development project following the UK Government's BIM Level 2 implementation strategy. The case is one of the pioneer BIM implementation project in the UK which is successfully handed over to the UK Government. The Improvement Project formed part of the Smart Motorway Improvement Projects. The scheme received national recognition as it was one of the first major highway projects to be Level 2 BIM compliant in the UK. The project team worked with the management team and supply chain through collaborative monthly workshops, to develop the model which contains detailed design and contractual information, existing management asset data, pavement data, as-built information and the contents of the Health and Safety File. Good collaborative relationships were maintained throughout the development and construction phases of the project between all parties. This led on to a smooth handover of the scheme into maintenance, due in part to the development of the BIM model. The model is now being used as an asset maintenance tool (Figure 4.12).

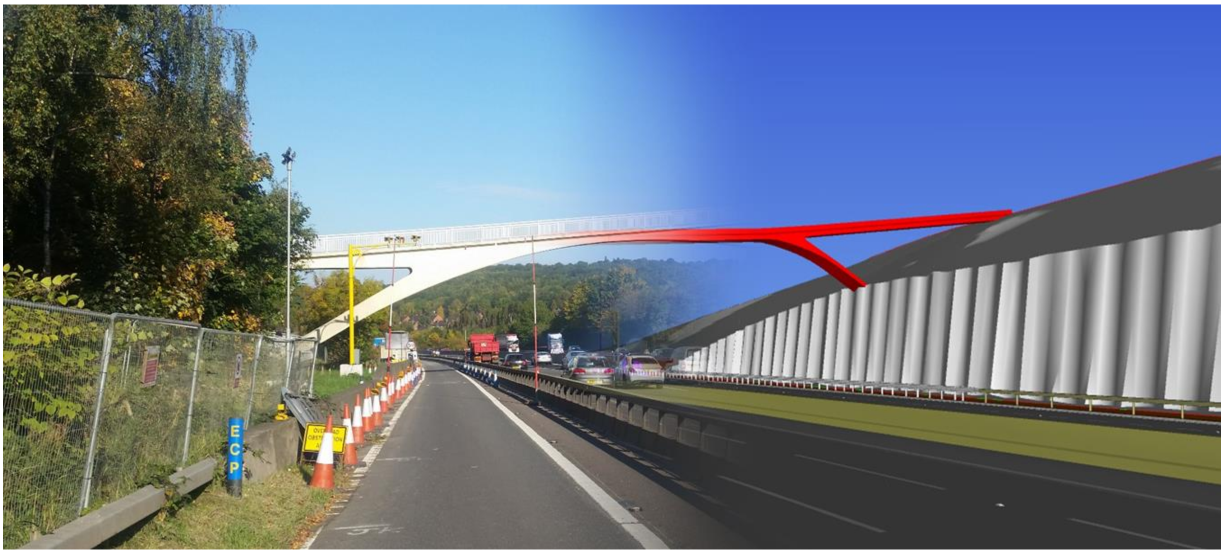


Figure 4.8: Screenshot showing Case B BIM Model

For the Case B, the researcher conducted five interviews with the project team, the profile of the participants shown below Table 4.2.

Table 4.2: Background of the interviewees for Case B

Code	Background	Area of Expertise	Current role	Experience(years)
C-B1	Civil Engineering	Design Management	BIM manager	18
C-B2	Project Management	Maintenance Manager	Technical Standards	16
C-B3	Architecture	Construction Technology	BIM Implementation Officer	10
C-B4	Project Management	Property Management	Asset Manager	25
C-B5	Civil Engineering	BIM Implementation Engineer	Technical Office / Handover section	12

4.6 Document Analysis Case B

The scheme implemented BIM processes supported by the related generic UK policies and protocols to enable achieving efficiency, coordinated, and standardised information throughout the lifecycle of the assets. The Case B had similar challenges as the Case A, as the both schemes are led by the same public-sector client. The Case B started the project without a highways specific guidance from the client. Hence, the team developed EIR document for smooth BIM implementation and data handover.

EIR is a crucial document that reflects the client's BIM perception and informs the full project requirements. Similar issues encountered by the Case B as per the guidance documents from the client. Currently EIR document for Highways construction client is a missing documentation. Furthermore, the client is lacking the understanding of EIR documentation for the civil infrastructure assets; therefore, it is not known what to be submitted to comply BIM Level 2 requirements for the highways civil infrastructure. The scheme provides a valuable best practice example for the highways civil infrastructure for BIM implementation and digital data handover. The asset manager C-B4 is very much aware of the importance of BIM for maintenance of the facilities and its value in the whole in the lifecycle data management. This statement was supported by C-B4;

"[...] I have nothing but praise for the collaborative way everyone worked together to deliver this scheme and associated asset data using BIM, which will be valuable for future maintenance of this scheme and delivery of other [...]" C-B4

The original design of this project was produced in 2D using traditional methods. Then, the 2D model was converted to 3D interactive construction model at a length of 17 km. The section presented a number of significant challenges such as high traffic volumes, limited access, narrow verges and as-built data provided by the client was limited.

Therefore, the project team recognized that development of a BIM model would significantly help during the construction phase and achieve significant construction savings, improve safety and provide a mechanism to capture the as-built records to maximize the maintenance benefits for the future. This way the client would have the reliable as-built data for maintainers and the other stakeholders.

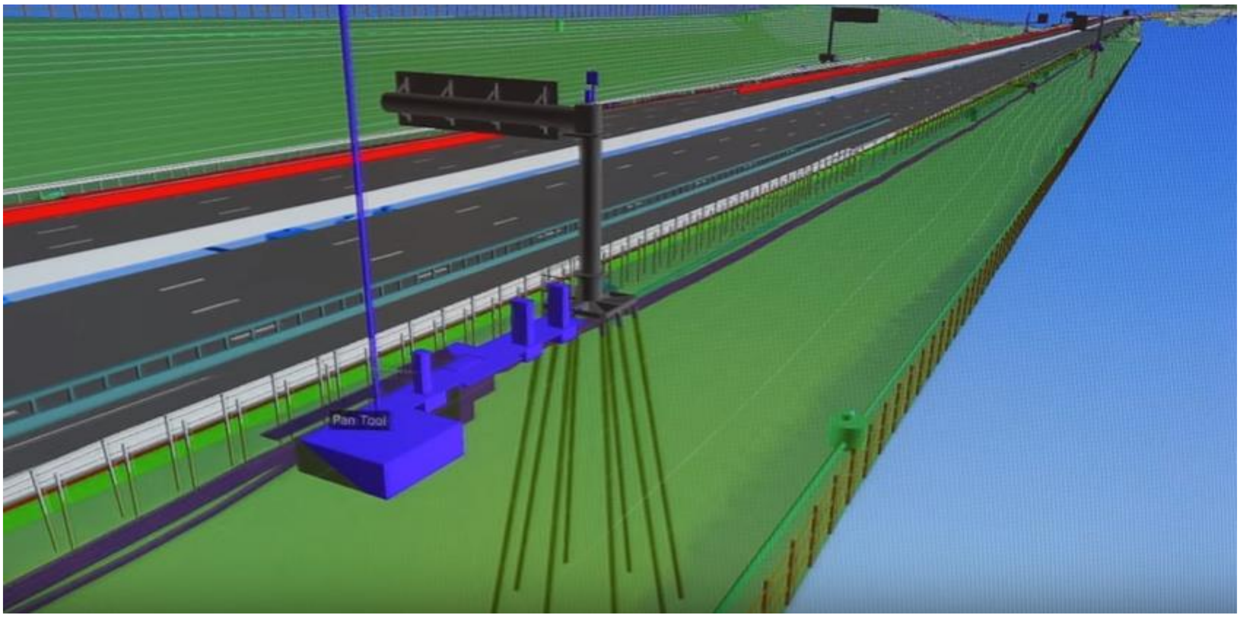


Figure 4.9: Screen shot showing Case B BIM Model showing buried asset

For the Case B the team had to rework the buried assets survey due to unreliable current database. Figure 4.9 shows the buried asset being implemented in the BIM Model. The scheme achieved a good level of BIM use however many issues have not been solved yet such as COBie and component library. As previously mentioned, current standards are too building-centric and cannot capture specific requirements of the highways civil infrastructure.

One of the major issues the scheme encountered was the highways agency's database. The current database was previously developed and do not capture the granularity of data as required by the project team and the maintainers. Further work is needed to capture all stakeholder requirements, so that a comprehensive recording system can be developed, which will enable maintainers and stakeholders to better interrogate and use captured data.

BIM Model made it possible to collaborate effectively with the site. Good interactive feedback was given the site from the designers. Figure 4.10 is showing the interactive sessions with the site engineers.

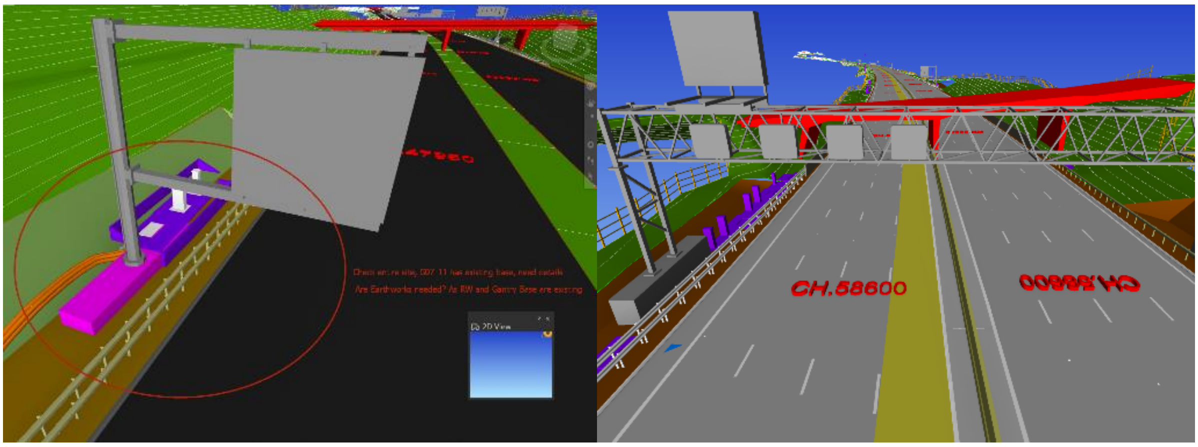


Figure 4.10: Screenshots showing Case B interactive feedback from site and object visualization sight view

The BIM model made it possible to embed various information to the model with the warning signs. Accordingly, Figure 4.11 shows material data sheets and digital surfacing data metrics to be used in the assets lifecycle. Also, Figure 4.11 is showing the as-built records including residual hazards within the BIM model to aid future maintenance operations.

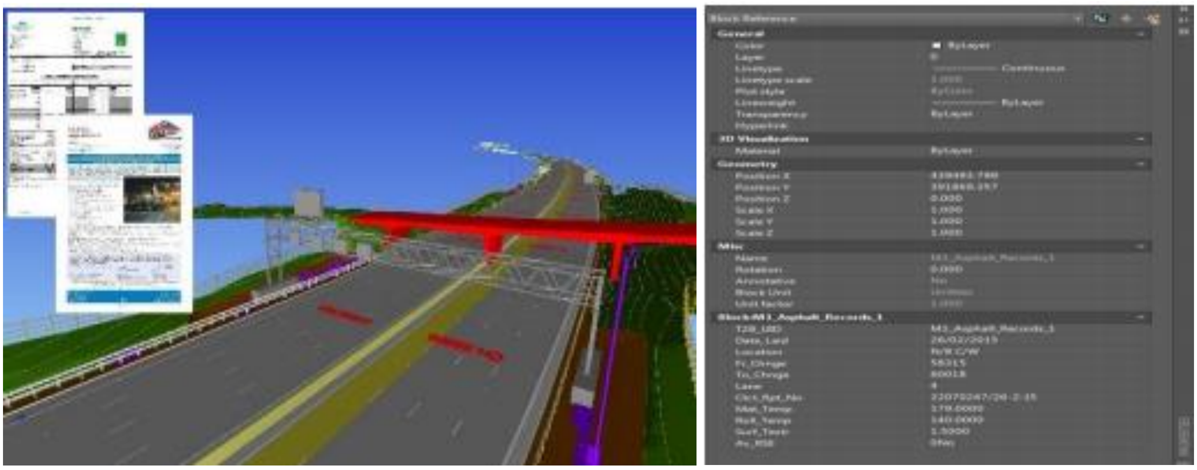


Figure 4.11: Screenshots of capturing material data sheets and digital surfacing data metrics

One of the other achievements of the project presented that collaborative use of BIM in the surface water drainage. The C-B3 reported that;

"[...] reviewing surface water drainage attenuation proposals saved in excess of £400k in direct construction costs and further savings in the program delivery [...]" C-B3

Figure 4.12: Screenshot of capturing as-built records including residual hazards within the BIM model to aid future maintenance operations

4.7 Handover process Case B

The scheme had good collaborative relationships throughout the development and construction phases of the case with the related highways supply chain. This led on to a smooth digital handover of the scheme into maintenance, due in part to the development of the BIM model. This is supported by C-B1 saying;

"[…] This model is now being used as an asset maintenance tool – a first for the Highways Agency – and is an early indicator of what BIM Level 2 could mean for the roads sector [...]" C-B1

In respect to handover the scheme achieved to generate (i) current database compliant spreadsheets, (ii) provision of feedback to software developers to deliver improved base software which will be highways sector friendly for use in the future projects (iii) sharing the development with the client's asset management team and Government's BIM Task Group.

4.8 Discussion

The project team captured the lessons learnt from the project and this was shared with the highways agency supply chain. The team suffered from the client's database as it does not capture the granularity required by maintainers. Current database needs improvement in order to deliver full benefits of BIM in the asset management environment. The scheme highlights that further work should be done for the maintainers and stakeholders to better interrogate and use captured data.

The Case B also recommends that careful considerations should be taken for the accuracy of survey data. Survey data is often of relatively low accuracy which creates problems in the development of BIM design models with much work having to be done during construction and handover to capture as built data. A comprehensive survey of the highways network is required at the correct resolution to allow designers and contractors to have confidence in the survey data provided by the client.

4.9 Case C background

The Case C is a major highways infrastructure development project as part of the Smart Motorway Improvement Projects. The project will provide live traffic information to the road users, by implementing the latest technology of detection loops to monitor the level of traffic. The case is an example of integration of BIM process without guidance from the Highways agency as the client organization. The scheme started with the traditional construction approaches however attempted to integrate BIM processes to their construction plans although this was not in the tender documents. The reason behind this approach was that to develop their BIM adoption for upcoming highways development projects. As initial steps for the further comply with the UK Government's BIM mandate.

For this scheme, the researcher interviewed five participants of the project. Table 4.3 shows the profiles of the interview participants.

Table 4.3: Background of the interviewees for Case C

Code	Background	Area of Expertise	Current role	Experience(years)
C-C1	Architecture Technology	BIM Implementation	Technical Office	8
C-C2	Architect	Construction Information Technology	Technical Office/Site	15
C-C3	Civil Engineer	Maintenance	Technical Office	10
C-C4	Civil Engineer	Construction Technology	Technical Office	12
C-C5	Management	Design Management	Design Manager	30

4.10 Document analysis Case C

This scheme has produced all the related drawings based on 2D CAD systems. No integrated BIM model was produced for this project. The project did not initially start with the BIM process as the project began in 2013. BIM implementation for the construction industry was very immature at that time.

This statement further supported by the design manager of the project C-C1;

"[…] the level of interest and skills related to BIM Implementation was not at the same level as today. 2D CAD system was the adopted methods to produce drawing in all the similar projects. So, BIM was not a part of the design brief in this project […]" C-C1

Even though BIM use was not a requirement, the scheme has initiated preliminary BIM processes for the project. Some innovative mobile technology has been implemented to add more efficiency to the process. The scheme adopted an effective strategy supported by mobile devices used on site. This technology made the construction information available for teams electronically on site, which had a tremendous impact minimising the travelling time between the site and the office as the team on-site could access the needed information and send it back using mobile devices. However, the advanced mobile system would not be available without the good 4G network on the construction site. The adopted strategy aimed at producing the right information from the beginning to the end users. Hence, decreasing the need to rework reduced waste in time and added more quality to the process.

To effectively enable an accurate data management, the scheme has adopted a web based online document management system called, Business Collaborator. The system provides an accessible CDE platform to store data in the cloud. Interactive discussion workflow is one of the recognised advantages of this system. It allowed different users from separate locations to participate in producing or editing information. Innovative software had also been adopted in this scheme. Snapfile Ontrack, a software application that transforms any mobile device into an enterprise level data management system. On site users can create a Snapfile using live photos and data entered on field. The system was linked to GIS to locate any notification or schedule work. Tracking and tracing activities to monitor performance and project time line was also available through the system as it keeps a summary of information captured using Snapfile. Live workflow information could be provided via Ontrack to update and manage the work.

The researcher interviewed five participants of the project (See Table 4.3). Document analysis and interviews suggest that the Case C has followed traditional construction process with some initial attempts to implement BIM model. It has been found that the maturity of BIM implementation is Level 0-1. However, the project forms an initial step to implement BIM and exploration of innovative construction technologies.

It has been found that also the project team has heard of BIM and they have some knowledge at the managerial level; however, the team in general need serious training to understand what BIM actually is. The scheme started some training sessions in BIM tools and applications to use for clash detection and for further project realizations of the highways agency (see Figure 4.14).

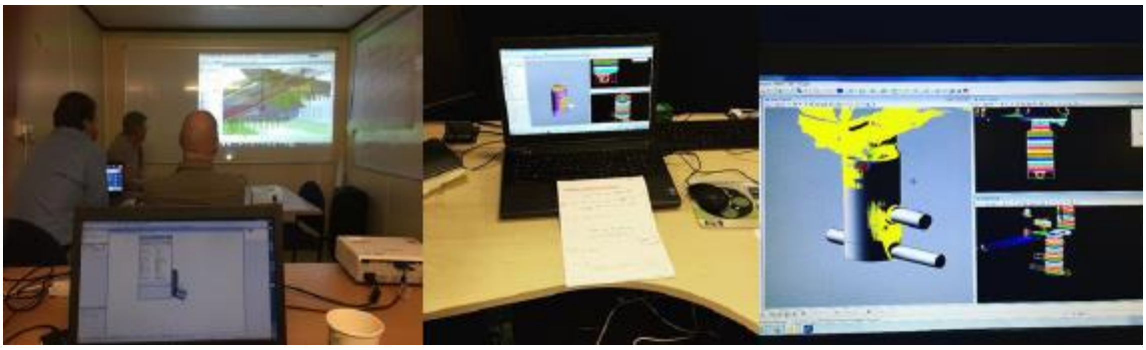


Figure 4.14: Images showing training session and creation of 3D model from point cloud survey

4.11 Handover process Case C

The data handover process in this scheme is based on the required standards series of documents set by client. These standards describe what documents are needed to handover by the end of any project and what information to be included in these documents. The client requires more than 350 documents to be handed over by the end of the construction process. In this scheme all these required documents were delivered electronically by the end of the construction phase. Documents with different format like, PDF, Excel sheets, web-based information, AutoCAD files are to be stored in an electronic filing cabinet. The documents would be stored in a structured, searchable server. Maintenance data is also to be available in this electronic storage. As built drawings will also to be handed and added to the same information storage. This method is believed to be efficient as it aims to eliminate duplication and repetition in information by providing one source of information.

The scheme followed a traditional handover process using some innovative technologies. Although the design manager (C-C5) of the project mentioned there was no data losses within the project, the team had experienced some missing information such as quality assurance check sheets. C-C5 further explained a crucial problem with this process by saying;

"[…] issue is related to the adopted paper-based process as engineers use a paper checklist to capture information on site and then after they are required to transfer it into a digital format. This transformation is usually done about a week later and people might miss or not remember all the details at that time [...]" C-C5

Researcher has found that just like any traditional construction process the Case C encountered the similar problems with the handover and data management during the construction. This finding reinforced that government's BIM mandate would solve problems of the classical constructions sector specific issues as per data management in the lifecycle and handover. This finding further supported by C-C4's statement;

"[…] the best solution is to automate the process by capturing it digitally from the beginning [...]" C-C4

The Case demonstrates that the project design team is not fully aware of BIM and its benefits to the project lifecycle. This is supported by the statement of C-C3;

"[…] generating as built drawings for the handover process, the delivery of the handover information will be all digitally based. Instead of delivering thousands of PDF papers issued for construction, the CAD model will be handed to the ICT group at the end of the scheme [...]" C-C3

4.12 Discussion Case C

As an example of one of Highways Agency smart motorway schemes, the project showed a case where some innovative technology has been implemented to deliver better value for the client and to improve efficiency of workflow. The project provided innovative solutions to improve both delivery and quality of information using mobile technology. The case is expected to bring many potential benefits during the operational phase of the asset. However, other potential benefits could be achieved if more strategies and BIM implementation were introduced earlier.

Using the electronic filing cabinet to gather the information in a structured and searchable way provides an accessible data for client to operate the asset. This will enable the operational team to easily access any needed information while managing and operating the asset and will overcome one of the major problems related to paper based methods. However, not having a BIM model will not enable the team to integrate all asset information like equipment's information, and maintenance information into central source of information.

The team also established a central storage of information that can act instead of a BIM model to keep all information saved and structured. However, more value for client could be achieved by producing a BIM model.

The case study has achieved some points of solutions to solve some issues related to hand over data in construction projects. One of the issues to overcome is related to paper-based handover. The case shows an example of complete digitalised information delivery. The case also shows a method to produce a high quality accurate information through the adoption of a collaborative information platform where designers and site team could stay connected and produced right information from the beginning. Nonetheless, a well-recognised issue related to CAD system is still not solved yet. Non-geometric information is still not linked to the model and problems related to this point are still not solved yet.

The lack of standardisation of the adopted process was a major problem for the Case C. The lack of standardization negatively affects the production of work and may also lead to lose some information during the construction phase. Standardising the process will bring more value and quality to the client and will help to improve the operation of the asset during its lifecycle.

This section reported current situation of the analysed the case studies. The following section will be analysing the interviews in depth.

4.13 Analysis of Participant Interviews

This section will be analysing the interviews undertaken by the researcher. The findings collected from the interviews from the case studies are presented in relation to the research aim and objectives. The researcher interviewed 15 experts in total for the highways cases, the interviewee profiles presented for each case previously in the Chapter 3, in the Case study section. This section will be analysing the interviews in detail.

4.14 Interview responses and discussion

The qualitative data collected was analysed using general analytical procedure. The interview data was analysed using manual categorisation as previously discussed in the methodology chapter. Four themes emerged on the BIM implementation and current data handover processes. There is notable similarity between the responses from the Case A&B. The Case C has partial BIM implementation in their construction processes. All the cases are public highways development projects with diverse levels of BIM maturity.

Table 4.4: Main themes emerged by the interviews

No	Main Themes	Sub themes
1	Motivation of BIM use	1- Potential of BIM in asset lifecycle
2	Client leadership (Contractual/policy)	1- Client lead for BIM implementation process
3	Challenges of Data Management and Handover (Standards & People)	1- Traditional habits 2- Lack of standards 3- Miscommunication 4- Interoperability - (FM/AM) Databases 5- Data sharing – collaboration between design, construction and FM teams 6- Lack of transparency and accessibility 7- Loss of tacit knowledge
4	BIM Maturity, education and best practice	1- Maturity Level (BIM) 2- Lack of Training

Questions asked to the interviewees were open-ended and the researcher used laddering techniques to avoid short, standard answers. This is supported by Grunert and Grunert (1995) as laddering techniques are tools for uncovering subjective casual chains in qualitative interviews, the laddering technique involved a series of consecutive probes to develop casual chains.

Theme 1: Motivation of BIM Use

The main motivation of BIM use for the cases is the government's BIM mandate by 2016 for all public construction projects. Since 2011, the participants of Case A have been using BIM for small scale projects, according to interviewees C-A1, C-A2 and C-A3. However, they barely knew the true potential of BIM and its impact on their projects and did not fully know the application of it in throughout the organization. When they started to implement the Case A project, they realised actual the technology and process behind it, and its crucial impact for all project life cycle. The evidence was captured as:

"[…] ultimately, it comes from government mandate, we were pushed by the government to be BIM level 2 by 2016 [...]. So, following this strategy we started to implement BIM without knowing the potential of it. But, when we started to define and understand BIM for us, we found huge benefits can help us […]. C-A1"

The interviewees from the scheme B mainly shared the similar answers. As they are implementing publicly acquired project, they were required to implement BIM Level 2 with the asset information. The organization very much aware of BIM and its implementation process and benefits throughout the asset life cycle. However, they are aware of the new workflows will take some time to get used to.

"[…] Government is mandating us to integrate BIM use in our construction process [...]" C-B 2

Although BIM has been a buzz word in the construction industry for years it became a true challenge when it was mandated by the HM Government. Because of the industry's lack of understanding and knowledge of the BIM processes. This has taken some time to really understand the potential of BIM process and how it could be helpful for the asset lifecycle. For example, for the Case C, it took some to understand what BIM is, some of the engineers thought BIM is a representation only without attributions embedded in the assets. When they use advanced technology, this was perceived as BIM. This statement was supported by C-C3 by saying;

"[…] we use high technology and 3D model; this is BIM [...]" C-C3

By this statement the researcher understood that there has been a misunderstanding in BIM and its workflows in the lifecycle of the built assets. This also reveals that the project team need training in BIM workflows and its use with attributes. However, there is proficient level of understanding in the managerial level.

In addition, the highways sector has not explored technology explored adequately and majority of interview participants do not know the potential contributions of technology and BIM integration.

Hence, the engineers are lacking the BIM knowledge and benefits in the asset lifecycle and in the operations and maintenance of the assets as well. In addition, they still do not have the thinking of having the end in mind. The researcher suggests this situation due to lack of enough best practices for highways context and lack of robust best practices for BIM's relevance to maintenance and assets' lifecycle.

1- Potential of BIM in asset lifecycle

Construction industry is known as its traditional habits and thinking. The industry has many stakeholders sharing information and collaborating for the same project. The entire construction process is so fragmented and valuable data is lost when it comes to the project handover. The handover is perceived as a date rather than a process. This conventional thinking of handover reinforces the fragmentation in the construction process. However, the researcher suggests that with the well-understood BIM workflows and BIM's potential in the asset lifecycle, this will be improved.

Interview responses suggest that the BIM for asset/facility management is not widespread, and that people do not really know the potential of BIM for data handover and management. There is certainly a lack of solid evidence and best practice case examples to prove BIM's benefits and its importance in operations and maintenance. People do not start the projects the end in mind. However, the respondents are so much aware of the difficulty in the traditional construction processes and paper-based thinking. Especially in the long-term asset maintenance, this makes it very demanding for the maintenance team to gather information from paper-based archives. Evidence for this statement captured as:

"[…] many issues should be solved. For instance, designers and contractors have minimal involvement after the handover. Current archive was historically built, and O&M team is struggling to find the information of the specific assets and it is almost impossible to find all the data about it, that means rework and time and money loss [...]" C-C3

Most of the interviewees are aware of the BIM's potential in data management; this is supported by the C-C5's statement:

"[…] It is simply connecting people in one single platform makes the project more reliable and BIM ensures that all participants are producing information at the right time and in the right way [...]" C-C5

Theme 2: Client's Leadership

Several issues highlighted however most commonly mentioned was that the client's knowledge of BIM implementation and processes in a structured manner for operational level. Furthermore, the client needs to understand BIM-enabled workflows and the required standards throughout the project. Current BIM process lacks client requirements that should be provided by the client. EIR documentation is missing in the process. Clients are responsible for defining the deliverables of required stage of the construction projects as a digital plan of work (DPoW). This plan will cover the entire project timeline from developing a strategy to maintaining the built asset. However, majority of interviewees mentioned that they had to explain the core principals of BIM to the client. The interviewee is further supporting the discussion by saying:

"[…] firstly, client needs to understand what BIM is. Also, they need to have a clear structure of how BIM can work in the project. It is crucial that once the BIM is understood clear guide documents should be provided […]. C-B5

1- Client lead for BIM implementation process

Client's initiative is a must to lead the BIM implementation from developing strategy to managing the infrastructure built assets. All the interviewees believe that client needs to spell out clearly their need for clear handover. Current situation highlights lack of Employers Information Requirements (EIR). Therefore, a client led recommendations should be provided for the supply chain. Currently they do not know the exact requirements for the handover. In addition, client lacks the understanding of BIM. Although BIM implementation is required for the entire public construction projects, currently client-led information is missing. Hence, the team had issues adequately managing the project. There was great confusion how to initiate the project. This situation further supported by CA5's statement;

"[…] At the moment, we actually do not know the actual requirements, because client has no EIR and there is lack of adequate information for BIM implementation. This causes so much confusion for the project. There is lack of standards and process follow-up […]. C-A5

Interviewees believe that implementing BIM will normalize their construction processes for business processes with their supply chain which lead to reduced efforts and saving time and cost. Furthermore, they believe the project should be client led to deliver the desired outcomes within the supply chain. The evidence was highlighted by;

"[…] the client needs to lead all the BIM process implementation […]. C-B1

Interviewees mentioned several issues however the most common one among them is that clients must know what kind of information in which format and when. Interviewees believe that the client needs to understand why they are using BIM and by using BIM what benefits they will gain in line with the government's mandate. This is a solid evidence of the lack of best practices and guidance.

"[…] We do not have sufficient information from the client. They must clarify what information they need and at what stage of the scheme, data formats to be exchanged […]. C-A1

Theme 3: Challenges of Data Management

Government's BIM mandate requires the highways construction make changes in their traditional construction workflows. Data management is crucial in the assets' lifecycle. Current issues in the highways construction sector are mainly related to information losses, duplication of work and unreliable asset information due to disparate formats and archives. Getting the right information from the database is a great challenge as the asset data was created historically. Hence, the team had to double check the asset conditions and rework for the existing assets. This situation created financial and time losses. The case study organizations highlight major challenges managing the historically stored data as they are not relied up on decision making. This is supported by C-C1's statement:

"[…] HE database is quite old, and the data has been stored as paper documents, supplied to FM staff after the operation, sometimes months after handover […]. C-C1

Interview responses suggest that it needs some time to have the standard maturity to streamline the data management process in the asset lifecycle, and it is actually a matter of time.

Challenges of data management have seven sub-themes that need to be streamlined to adequately maintain the asset in their lifecycle.

1- Traditional habits

The respondents understand that current BIM use is still in infancy stages as BIM implementation is newly adopted and supply chain integration is still in early stages. It will take some time to get efficient results from technology and new process. Also, highways supply chain is not mature enough to make sense of the information they receive. This argument was captured by:

"[…] we are still chasing our supply chain for adequate data even if we have the CDE […]. C-A3

Furthermore, some of the project team tend to have the traditional habits even younger generation engineers have traditional mind sets in terms of using the old way of drawing in 2D. The researcher observed that the reason behind this approach is the BIM tools are not meant to be used for infrastructure and it is demanding to control the building industry-specific software.

"[…] I plan the project in 2D AutoCAD, although REVIT has 2D authoring platform […]. C-B3

Hence, it will take some time for project teams to get used to newly adopted workflows and technology. Current situation demonstrates that software vendors also develop highways infrastructure specific software for accurate delivery of the projects. At present, the projects are fragmented, and the process requires manual work.

2- Lack of standards

The client is managing multiple highways development projects however, the is no standard workflow of BIM and asset management. The client should provide standards for the projects. The development cases use their own methods and views to produce documents for adequate BIM implementation for the maintenance.

Furthermore, the respondents are aware that current standards are too building centric and this causes some inadequacies in the construction process. This argument is supported by:

"[…] we understand the current standards however some of them do not work for infrastructure, also there is no standard workflow provided from the client, we are in charge of this […]. C-A2

Although there are BIM models, the process still needs maturity to implement the specific data to the asset with attributes. One of the major challenges is GIS data, which was attached the files manually as well as the health and safety files.

In the cases, majority of interviewees mentioned the various participants facing problems reading the information that were created by different organizations without any standard language.

"[…] even engineers can't make sense of the current drawings given to the maintenance teams […]. C-A2

The researcher suggests this situation require maturity and time.

3- Miscommunication between design, construction and FM/AM teams

The respondents realised that there is still miscommunication among supply chain while sharing data and misunderstanding of BIM implementation. Maintenance teams are having problems understand the data that were given. As well as they are struggling understanding the technical BIM files.

"[…] at the moment, there is miscommunication among people …, supply chain requires some time to understand the new technology environment […]. C-A2

Majority of responses were positive for Case B in terms of data sharing using the recent technologies and process. This argument is supported by;

"[…] our staff is trained to understand BIM processes well…, successfully handed over the project in time […] C-B3

Wang et al. (2013) stated that one of the crucial benefits of BIM is that it is a tool bringing the maintenance teams to the design phase. However current situation highlight the BIM workflows are not that much mature that, there is lack of AM/FM involvement in the design phase. There is huge gap in the perceived value that AM/FM can bring to the lifecycle of the infrastructure assets. This problem highlights the lack of best practice and experience on BIM for maintenance and assets' lifecycle in the highways sector.

4. Interoperability – (FM/AM) Databases

McAndrew et al. (2015) stated that the construction industry notoriously known as late adopters of technology and new workflows This situation has no exception with the highways construction. Current FM/AM database was historically built and the data available is not compatible with the newly generated files and models as they are mostly pdfs and 2D CAD files, in addition the data is not suitable for decision-making. The evidence was captured by;

"[…] All the data stored in the paper-based lockers and cannot be relied up on for decision-making, there is lack of understanding what data already exists and in which format we do not know [...]" C-C2

The project teams faced major errors associated with traditional 2D drawings, and previously created project files from the client's repository. There is no interoperability between project files and this causes rework.

Case B could produce files for the client's database readable however this was done manually and took much time. The COBie files were produced by the project team with its broken process and procedures.

"[…] The COBie files were produced manually and they are broken […]. C-A2

5. Data Sharing-collaboration between design, construction and AM/FM teams

The interviewees agreed that currently there is miscommunication between design, construction and AM/FM teams. AM/FM teams lacks adequate BIM knowledge as they cannot read the data provided as there is interoperability problems with the client's current data base. In addition, the AM/FM teams cannot effectively read the provided BIM Model. This situation is explained by C-B1;

"[…] there are many problems with the database, people are not used to it, they don't know that to do with the BIM model, CoBie is fragmented […]. C-B1

6. Lack of transparency and accessibility

One of the significant challenges in the availability of information at the requested time because current asset information is stored in the lockers and manually categorised. They were historically built and cannot be relied upon decision making. The situation was described by C-C2 and C-B5;

"[…] All the data stored in the paper-based lockers and cannot be relied up on for decision-making, there is lack of understanding what data already exists and in which format we do not know [...]" C-C2

"[…] existing information is too old to make decisions and to rely on, and mostly 2D and paper based, so that the construction team had to rework on the tasks. IAMS current asset management data base's archive is too old [...]" C-B5

The researcher observed that the traditional way of documenting infrastructure assets is by means of 2D plans, elevations and sections makes it very demanding for the project team to gather data. Data is gathered manually and eventually they must be transformed to comply with the newly generated drawings in the same asset management database. This crucial issue explained by respondent C-C3;

"[…] this means information could be fragmented. Features and dimensions shown in different drawings may not be consistent, and inaccurate data could lead to design errors and abortive work. […]. C-C3

7. Loss of tacit knowledge

Each construction project is unique and creates a significant amount of knowledge during execution, however, most of the knowledge remains in the minds of the designers, key personnel leave before the project ends, this causes issues in the project as the data cannot be retrieved or available for current/future projects and for the maintenance of the assets. This situation provides one of the serious issues faced by the highways construction. Also, the researcher observes that the situation demonstrates the necessity of BIM-enabled technology laden workflows. The participants agreed that it is very crucial for the projects to be controlled with the advanced technology, as they have been suffering for a long time. This situation presents significant loss related to economy and time.

"[…] some of the design architects had to leave the project earlier, we need to search the documents […]. C-C4

Theme 4: BIM Maturity, knowledge, education and best practices

Training presents one of the key issues in the current highway sector projects. The client organizations should ensure that the constructions firms provided appropriate training. This will allow project teams to be confident in using recent technology laden workflows. However, firstly the clients should be trained to understand the BIM benefits and its use in the lifecycle of the assets. The investigated case studies provided good examples to the highways sector and demonstrated how important it is to be trained to understand the advanced BIM workflows. Thus, this would provide the actual benefits for the civil infrastructure assets' lifecycle. The researcher suggests the client to provide training programmes for the highways supply chain in order all the participants understand BIM and its benefits. This way, as standard and effective workflow could be followed. At present, since the highways sector newly acquired to workflow, it would take some time and effort to have standardized and effective workflows.

"[…] we are still training our staff and supply chain should be trained, maybe they should be incentivized to use BIM or should be trained somehow […]. C-C4

The researcher provided three sub-themes under this main theme.

1-Maturity Level and improvement

BIM is a new workflow for the highways construction industry and the responders know that they are at the developing stages of the BIM implementation in their project practices. They still tend to use paper-based approaches and tend to think in traditional ways. This argument is supported by saying;

"[…] we still have traditional mind set. It will take some time to get used to […]. C-B3

The responders are aware that they need to improve their BIM understanding and maturity to adequately implement BIM. They understood the benefits of BIM and improving maturity of their processes will help them a great deal, and improved maturity will reduce the gap between client and supply chain so that they can speak the same language. Responder C-A4 further supports this argument by saying:

"[…] Good maturity will help fully understand and benefit from the expectations from using BIM, so that we can speak the same language and send the right documents to supply chain […]. C-A5

The interviewees understood that it is very crucial that client should be aware of what is being done and how BIM requirements must be collated across the organization when they implement BIM and its requirements. The evidence was captured is as;

"[…] the client has to understand their own requirement what data is required for what purpose and how they want it in what format, how they will reuse the stored data […]. C-A1

Interviewees understand that maturity of BIM use depend on technology, people, strategy and process. For scheme B, staff is more knowledgeable in comparison to scheme A. They had ambitious target to comply with government requirements to successfully handover the project. This argument is supported by;

"[…] Case B is the first Level 2 compliant project in the UK …although client requirements were not clearly defined […]. C-B5

2. Lack of Training

Case studies showed that training and education of the highways sector is main challenge, also construction industry notoriously known as an industry which has traditional habits. Although the cases started using BIM in their processes, true value of BIM in the lifecycle of the assets and operations and maintenance is not clearly understood. The organizations have diverse levels of BIM understanding/maturity hence their level firstly should be understood, and accordingly appropriate training must be given. For all the cases there are notable efforts to comply with the government's requirements however integrating new workflows and understanding to conventional practices is very demanding. This is further supported by C-C5

"[…] we are used to paper-based workflows and it will definitely take to get used to change, I think a new breed of engineers needed […]. C-B5

"[…] Majority of people go to their colleagues as the first source of information when they have problems or questions about BIM. This signifies the importance of having capable and competent expertise in the organization who can educate their peers about the use of BIM […].C-B2

Main highways industry-wide barrier is the education and knowledge of BIM. The client does not fully understand the benefits of BIM; this is because of the highways sector currently lacks enough best practices and evidence-based guidance.

Cases showed that the highways civil construction sector lack the best practice cases both for BIM implementation and its use in the operations and management phases. All of the interviewees are aware of the low maturity levels of BIM in the infrastructure sector.

This is further supported by C-B5

"[…] Collaborative environments and common best practices need to be established to ensure an efficient and effective adoption of BIM in AEC industries. […] C-B5

This section presented key research findings derived from the cases based on qualitative research approaches. The following sub-section presents a cross-case analysis providing overall results and comparison of the case studies.

4.15 Cross Case Study Analysis

The researcher has analysed the case studies of the chosen organizations of UK highways infrastructure development schemes to compare the results and find similarities and disparities between them. Depending on the case study findings, BIM based recommendations for highways construction clients will be developed as currently the highways construction lacks the clear guidance for digital asset handover. Eisenhardt (1989) recommended that case study analysis has been chosen as an appropriate research strategy to compare and analyse the case study consequences as per research needs. The present study has been developed in the light of to meet the research questions. The researcher has compared the three case studies as an initial step to develop the proposed recommendations.

1. From the case studies, the researcher has been able to suggest that the highways cases need clear guidance for BIM workflows for data handover for maintenance of the highways assets. Data requirements must be defined at the beginning. BIM based digital handover guide is very essential for all the future schemes for effective information management and maintenance of the assets. In addition, this issue leads to scope creep. The evidence in terms of supporting the value added in context to the BIM process and maintenance of the civil infrastructure assets has been gathered to understand maturity of the new technological workflows for data handover. The cases have depicted the current status of BIM implementation for data handover and maintenance in the highways construction sector. The maturity level of the organizations in terms of adopting streamlined BIM workflows for data handover is still in developing stages. The lack of clearly stated guidance may deviate the expectations of the data management through BIM. Because, the UK Government has high expectations for the BIM adoption for the construction industry.

2. From case studies A and B it has been suggested that the companies that focuses on the training of BIM workflows and career development of their employees holds the stronger position in the highways construction industry. The cases also show effective results in developing the maturity of the new workflow. The main asset of the organization A and B is the human capital along with the knowledge. The knowledge gathered from training, experience and education provides a chance in the BIM process and developing the data management using BIM in the lifecycle. However, this process still in developing stages and it will take some time to get used to new processes and technology. For example, Case C has very low levels of understanding BIM as only managerial staff has knowledge of BIM and its usage especially BIM use in the asset lifecycle and operations and maintenance. The scheme has been using some technology and preliminary BIM interfaces however; this is far from the BIM process and its workflow. Prior implementation of BIM, it is essential that the projects have serious training, and dedication.

3. The case studies have also helped in analysing the skills and competencies of the project teams. This has helped the researcher to evaluate that the skills and competencies of the clients are necessary to develop a quality maturity guide on the data management with BIM-enabled construction workflow.

4. The case studies have highlighted the significance of the global standardization policies and procedures related to information requirements to be used for the lifecycle of the highways civil

infrastructure assets to develop maturity as per the requirements. It has been analysed from the cases that the case study organizations are developing policies, procedures, and documentation for BIM implementation and information management to create a systematic process. However, this should have been provided by the client organization.

5. Communication can be considered as one of the essential factors to achieve greater results on the basis of BIM process for data management in the selected organizations. There is a need of developing the collaboration and communication between the different teams and stakeholders to enhance the right collaboration and communication for the projects' success from design stages to the operation and maintenance phases. The disconnections and miscommunication need to be removed while the management should be allowed to take actions and decisions on the right time. It has been observed from the case studies that with Design/Construction/Operations teams use different technical languages this makes it very difficult to streamline the construction schemes completion and operation and maintenance.

6. Further it has been analysed from the case studies that the current asset management system makes an impact on the development of the BIM workflows for effective handover. Current asset database is very old and have a legacy over 15 years. This situation makes it very difficult for the case study organizations to use the information repository. Also, the database is not suitable for decision-making. Other than that, the asset data was maintained by the service providers. Henceforth, the data maintained in the database is much degraded and data structure and formats used in the project design and delivery differ from those used in the asset management. There is use of different data formats and structure in scheme design, delivery and operations.

7. Getting as-built information is challenging. The client (Highways England) currently manages its assets within 14 areas throughout the country. These 14 areas cover the 6 regions in England. Current approaches used in the data management are not consistent. Asset surveys done over many years and data held on disparate platforms and not easily accessible. Asset data often maintained by service providers. Asset information is poor, fragmented and cannot be relied upon for decision making. Lacking a long-term view and handover is considered to be a date rather than a process.

8. After analysing the case studies, it has been found that early engagement of designers, contractors, asset managers in highways agency supply chain is very essential. There is currently lack of active collaboration between design/construction and operation teams. Organizational behaviour, culture and training are the key drivers in adopting BIM process, and it differs from one organization to another.

Thus, it is necessary to consider that BIM workflow alignment will take some time to get mature. Additionally, it has been observed that the projects teams have traditional habits for construction and they tend to use paper-based workflows although BIM training was given.

9. The cases struggled implementing BIM because of the lack of best practice and guidance, and BIM's use for asset management was unclear for the schemes.

10. It has been analysed that for the case study organization, there is loss of tacit knowledge. Some of the key staff left the project before its completion. Thus, this is enormous information loss because the experts could not share their information to the project fully.

11. The researcher could generate a table showing the competences of the BIM maturity levels of the cases, according the analysis it has been analysed that BIM maturity Level for Case A&B is complying with the governments Level 2 mandate with developing documents, such as EIR, Cobie. On the contrary, BIM Level for Case C is in its initial stages (BIM Level 0-1). (See Table 4.5 and Table 4.6).

Table 4.5: BIM Maturity Levels of the Cases Analysed (Table adapted from GSL, 2012)

Level 0 (No BIM Use)	Level 1 (Design BIM)	Level 2 (Partially mature BIM)	Level 3 (Integrated BIM)
Use of computer aided design(CAD)	CAD is managed and collaboration in design encouraged	3D representation of assets created through the combination of separate discipline models (allowing clash detection)	3D model created and fully accessible via internet (cloud based)
Use of 2D drawings	2D and 3D drawings	File based information display and exchange	Collaboration encouraged and achieved
Paper or electronic paper used to display and exchange information	File based information display and exchange	Standard elements of asset saved in BIM Libraries for recurrent use	Single server
Paper based scheduling and costing	Electronic scheduling and costing, not linked to asset model	Scheduling and costing calculated using BIM model (4^{th} and 5^{th} dimensions)	Lifecycle management of the built asset achievable through study of 3D model
Largely uncoordinated planning	Partial integration (limited to design)	Computer based operation and maintenance manuals out of BIM model	Progress checking using BIM, to compare actual progress to predicted
Paper based operation and maintenance manuals			Further dimensions possible, such as environmental management

Legend:

Case A:

Case B:

Case C:

Result:
According to the BIM maturity Levels Case A and Case B in Level 2 BIM Level as per the requirements they comply. On the other hand, Case C has the Level 0-1 BIM maturity.

The process necessary to achieve level 2 BIM are set out in the Table 4.6 below;

Table 4.6: UK Government Level 2 Compliance Requirements shown per Case Study organizations (Table adapted from BSI, 2018)

Criteria	Case A	Case B	Case C
Compliance with Employers Information Requirements	X (missing EIR Document from the client)	X (missing EIR Document from the client)	X (missing EIR Document from the client)
Project BIM Execution Plan (BEP) (based on EIR)	x	x	x
Common Data Environment (CDE)	√	√	x
PAS 1192-2 PAS 1192-3	X (partially achieved)	X (partially achieved)	x
Digital Plan of Work (CIC BIM Protocol)	√	√	x
Industry Foundation Classes (IFC)	√	√	x
Intelligent 3D models	√	√	x
3D Based Collaboration	√	√	x
Asset performance optimization	√	√	x
3D Digital Survey	√	√	√
CoBie	√	√	x
Classification (Uniclass 2015)	√	√	x

In addition, to have a clearer picture of the results, the researcher developed a table of overall findings below Table 4.7. and categorised the key elements of the overall findings. To analyse the interviews the researcher used themes and sub-themes based on their frequency of occurrence in the interviews. When specific factor occurred in all Cases, it implies that this is a common concern among all the Case studies. However, single occurrences were present, and these were considered unique occurrences thus threated with equal importance as they could present unique element for consideration. According to this, the researcher developed Table 4.7, key findings effecting the highways construction derived from the Case studies.

Table 4.7: Overall summary of the key findings affecting the cases in the highways construction

Key Aspects	Findings
Opportunities and Benefits of BIM for Facility/Asset management	• Real-time data access in the field • Reduced hard copy information • Validation of the asset design prior to construction • Performing preventive maintenance • Single source of Truth • Working in a common data environment • Effective collaboration/communication • Qualified data • Defined workflow, end product
Collaboration between design, construction and FM/AM teams	• Collaboration between design, construction and FM/AM teams is fundamental for BIM for the O&M • Collaboration culture helped teams to work together, although some members of supply chain have resistance to change for the new workflows • Construction industry has traditional habits, and do not naturally collaborate • Supply chain use different language and knowledge gap of BIM and BIM in the asset lifecycle and maintenance • Collaboration needs improvement with the construction professional bodies and chartered institutes
Importance of Asset/Facility Management	• Asset Management involvement early on is crucial, but asset managers are not often involved until the projects end • AM/FM has a wide variety of backgrounds. Some asset/facility managers lack of construction knowledge and unable to contribute • Asset managers are not perceived as valuable stakeholders. Misinformation about what facility managers know and do • Great cultural challenge to embed AM/FM teams with design. Designers do not believe facility managers could contribute to the project effectively and Asset Managers do not believe they would be listened.
	• Training of Asset/Facility managers merits of BIM for lifecycle and maintenance. • There is lack of solid evidence of Operational Expenditure (OPEX) savings

Barriers to BIM implementation and engagement of BIM for FM/AM	• BIM projects are often evaluated out due to lack of evidence of benefits and merits, there is lack of best practice • Clients lack of understanding BIM merits and how much money is spent in operational phase of the built assets.
BIM and AM/FM data specification	• Asset managers lack of BIM and technology knowledge of specifying data is a challenge • Asset /Facility managers expect a BIM is a panacea for every problem that transfers all appropriate data into CAFM systems with little work or effort • Asset/Facility managers want a data centric model rather than graphical data
BIM and CAFM software integration	• Software integration is critical for BIM for the maintenance of the assets • Data definition and standards are essential to linking with CAFM. Data should be defined suitably • Integration between BIM authoring platforms is a challenge • Software integration can be successful, but It takes a great deal of work and Asset/Facility managers need people, process and technical skills
Data Standards and Classification	• Current standards are too building sector centric • Data standards and classification critical for the success of BIM for maintenance purposes • CoBie needs work not only for civil infrastructure but in all the construction industry. • CoBie is not developed with industries but developed for specific projects for the clients. • CoBie for linear infrastructure (highways, rail etc.) is under development.
	• Lack of best practice examples of BIM for AM/FM especially in the highways construction sector • Most of the case studies are building-centric and anecdotal (lack of showing highest benefits without focusing on challenges) • Lack of trained people with competence and skills in BIM in the highways infra. context.

BIM for AM/FM knowledge and best practice	• Training and education is a barrier to BIM for AM/FM, considerable time and skills needed to change traditional habits such as paper-based approaches. • Lack of data exchange capability between BIM and computer-aided AM/FM practice. • New generation of facility managers are required, BIM for FM specialists that are trained to contribute to BIM projects

4.16 Summary

This chapter presented Case studies analysis. The cases provide current situation of the highways civil infrastructure in the UK. The key challenges faced by the project teams analysed and the main criteria in adoption BIM towards developing recommendations for enhancing data handover in highways organisations in the UK were identified. The presented qualitative analysis of the data from semi-structured interviews with 15 experts in the three highways civil infrastructure organizations.

The qualitative findings show that case study organizations have issues implementing BIM to have a smooth transition for the maintenance of the civil infrastructure assets. Adequate training for the advanced BIM workflows, information accessibility, and information interoperability are the most critical criteria in the all cases for current highways infrastructure development projects. Although the schemes initiated BIM-enabled workflows, the maturity level is still in developing stages. Moreover, this chapter identified that the level of BIM implementation in all cases in main BIM dimensions. Although the cases are large companies with considerable budget from the government, the maximum potential of BIM is not mature yet. The following chapter presents, validation of the recommendations generated by the researcher based the analysis of the case studies.

CHAPTER 5

Development of Recommendations and Validation

5.0 Validation

The previous chapter presented the qualitative analysis of the three case studies for the highways construction schemes in the UK, and a cross-case analysis was presented. Based on the cross-case analysis the data collected from the three case studies and connecting them with guide formed a theoretical source of reference. The developed guidance was very theoretical and was limited to three organizations that were involved in the case study judging by the source of data that was used for the development. Thus, a validation is required to obtain a broad view of perspective to generalize the findings. This chapter, therefore, focuses on the validation for each criterion of the recommendations to have in-depth insights. The main purpose of the focus group discussion is to validate the findings by measuring the importance and investigating the underlying justification of the individual criteria that will make the final recommendations. The data and findings that were collected during the validation process then were used to refine the findings in the form of recommendations table, and the validated version of it is presented as Table 5.2.

Table 5.2: Presentation of the BIM-enabled Recommendations for the Highways Construction Clients

	COLUMN NAME	DESCRIPTION / CLARIFICATION	ACTIONS REQUIRED
Commercial /Contractual	**Employer Information Requirements (EIR)**	The client to provide EIR in tender documentation in detail as specific as possible (data requirements, standardization of equipment/product needed)	Discipline Lead to specify
	Cost Considerations	The client to consider whole life costs. All changes to be considered from a whole life cost perspective as part of the approval of the project.	Discipline Lead to specify
	Incentivization	The client to reward the project parties if the scheme is well-delivered. (This will foster collaborative working and mitigate the risk of deterioration of the project)	Discipline Lead to identify the specific project parties to be rewarded according to their success ratings.
Process	**Handover**	The client to consider handover a process not a date. The planning should start from the beginning of the project and the project should be considered as an incremental transfer of knowledge and operation.	Discipline Lead to ensure it is achieved.
	Benefits & Deliverables	The client to ensure deliverables are measurable and communicable from the beginning. The targets of the projects are to be benchmarked from the start (survey, staff recruitment etc.).	Discipline Lead to specify benchmarks of the specific requirements of the project and ensure the tasks are achieved.
	Early Engagement	The client is to ensure involvement of end users from the beginning of the project. (Ensure stakeholders understand the project to facilitate the delivery of the benefits and how the output will the project outputs impact them. The related stakeholders made to be consulted to support decision making at the beginning).	Discipline Lead to action
Data / Knowledge Transfer	**Documentation for End Users**	The client is to make sure documentation to be made meaningful, applicable and relevant to the end users (all information to be readily accessible in CDE, this may require different sets of documentation for various users)	Discipline Lead to ensure readily accessible documentation
	Lessons learned	The client to collate lesson learnt documentation (This will provide meaningful data sets to be used in the future highways projects, should be recorded as the project progresses)	Discipline Lead to document the lesson learnt.
	Information Requirements	The client to specify the information requirements at the beginning of the project (this is to agree all project parties have a clear standardized deliverables).	Discipline Lead to specify the information requirements
People	**Staff for project**	The client to encourage and recruit skilled staff capable of understanding advancements and willing to work towards continuous development as the technology related advancements progress (this is crucial for the projects' development)	Discipline Lead to action
	Stakeholders	The client to define stakeholder in detail make sure all the parties and participants well explained in terms of their roles as well as to ensure their engagement in the appropriate time (identification of the integral roles e.g. facility /asset manager, IT support)	Discipline Lead to action
	Education/Training	The client to provide essential BIM training programmes for the project team (this programme to include BIM workflows, technology integrated processes, highways infra. specific workflows)	Discipline Lead to action

5.1 The Focus Group Discussions

As discussed in the Research Methodology (Chapter 3), this research engages a focus group discussion to validate the findings derived from the multiple case study analysis and to gain insights to produce recommendations for the highways construction clients. The discussion was conducted by the researcher as the moderator. The selection of the participants was made based on the experience and professional area associated with BIM in the highways construction sector, coming from industrial players, government agencies and academia. Table 5.1 shows the profiles of the workshop participants. The selection of the participants was made based on the criteria below;

a) The participant must be trained in the UK construction environment with experience of BIM.
b) The researcher selected the academics that have construction experience in the UK so that they will consider the dynamics of the industry.
c) The participants must be form middle or top level experienced experts in their fields.

Hence, the selection of the experts for the validation process was based on purposive sampling technique. According to Teddlie and Yu (2007), purposive sampling techniques involve selecting of units or cases based on specific purpose rather than randomly. The purpose is to invite experts with experience working in the UK construction with a specific role and having BIM experience. Purposive technique was used deliberately to choose experts based on the qualities and expertise they possess (Tongco, 2007). Table 5.1 presents the profiles of the focus group discussion participants.

Table 5.1: Profile of the participants for the Focus Group discussions

Designation	Background	Industrial Experience	BIM Experience
Senior Manager	Architect	20 years	3
Academic	Civil Engineering	5 years	5
Senior Architect	Architecture	11-15 years	4
Senior Engineer	Civil Engineering	10-12 years	3
Academic	Mechanical Engineering	5 years	5
Principal	Project Management	24 years	2
Asset Manager	Civil Engineering	25 years	3
Senior Architect	Architecture	16 years	5
Senior Manager	Quantity Surveying	25 years	2
Senior Engineer	Civil Engineering	18 years	3
Principal	Planning Engineer	20 years	4
Senior Architect	Architecture	16 years	5

Focus Group discussion was designed as guided discussions with the first-hand knowledge of public Highways Agency, UK practices and infrastructure relevant to BIM implementation that might not emphasized on Web sites, in annual reports, or official organizational literature. The participants were telephoned for agreement to take part and on confirmation the guided discussion forms with questions was emailed. Their answers were entered, and the completed guide document was emailed back to them. On the day of the event, a discussion guide was used to engage attendees and direct the flow of discussions. Participants were asked to discuss the findings of the researcher and posed questions as the discussions were audio recorded using a voice recorder. The proposed guide was distributed to the participants and their expert views were recorded for each criteria of the guide to refine and validate the final form. Focus group session lasted approximately 2 hours and included 12 participants. Follow-up questions were asked based on the flow of discussion, along with the specific probe topics to be explored in detail if the discussion yielded an appropriate opportunity. Probe topics tended to focus on how to achieve better continuity of information flow via streamlined handover processes, existing assets, health and safety issues, data sharing practices, life cycle, and other practices that would fall under the umbrella of BIM and data management for operations and maintenance. The findings from the validation exercise refined in the enriched table form of the recommendations.

5.2 Validation of the Recommendations

Bryman (2004) defined validation as a process that the researcher requests feedback on the research conducted. In this research, recommendations for highways construction clients was validated with the focus group discussion. Each aspect of the research findings was discussed, and expert views noted down. This aid the researcher to enrich the developed recommendations with expert-verified points.

Focus group discussed the critical aspects of the pre-defined guide. Each criterion of the guidance was discussed in depth, the feedback given was noted by the researcher. The evaluation enriched the critical aspects further for the implementation of BIM and data handover within the highways construction sector. The researcher entered the data evaluated with the experts into the pre-developed guide document. Table 5.2 shows the evaluated aspects derived from the case studies and interviews, accordingly these were discussed, and feedback was given to generate a complete guide document for the clients of the highways civil infrastructure.

5.2.1 Recommendations Development

As suggested by the research aim of this thesis, the researcher aiming at developing recommendations for the highways construction clients. Previous chapters presented that the current highways construction sector is having issues implementing BIM in their construction workflows and they lack BIM-enabled guidance from the client. To implement BIM, there are certain criteria and challenges to be overcome. These issues are commercial/contractual, process, data and knowledge transfer, and people related issues. To effectively maintain the highways infrastructure assets, barriers to implement BIM must be solved.

Based on the validation of the findings researcher generated final BIM based recommendations for the research. Figure 5.1 shows the schematic presentation of the proposed BIM-enabled recommendations for the highways construction sector.

The interaction between the focus group participants was of a prominent level and fully engaging. The experts were satisfied the proposed recommendations, and all the experts agreed the terms offered by the proposed guidance. Feedback obtained during the focus group discussion captured the areas where improvement to the recommendations was possible. Furthermore, the experts stated and justified that there is necessity for such guidance for the highways construction clients to effectively maintain the assets for the future projects. Furthermore, the experts appreciated that the proposed recommendations are flexible in nature allowing the capacity for modifications. In addition, the experts agreed that the recommendations represent a clear and understandable support for the highway construction sector.

Figure 5.1: Schematic presentation of BIM-enabled guide derived from the findings

However, some issues were identified, several examples of constructive criticism were raised to improve the recommendations. It is crucial to mention that the highlighted views regarding the weaknesses, suggestions and barriers are connected to the scope and limitations of the research, however they provide useful guidance for future research. In short, the involvement of the experts has added value to the recommendations, and points raised during the discussions were beneficial.

The experts did not highlight any specific missing issues from the proposed recommendations. However, a few experts suggested that recommendations should be in the form of tool, this was applied to the final presentation of the recommendation table. The researcher amended the recommendations as per the constructive criticism of the focus group discussion, the Table 5.2 present the final version of the recommendations.

5.3 Summary

This chapter explained further validation of the critical aspects collected from the cases studies interviews via focus group discussion. In the validation process each criterion was validated and perceived as crucial aspects of the recommendations for the highways construction clients. The recommendations consist of four main criteria, commercial, process, people, data/knowledge transfer. These were further clarified in the guide document. Table 5.2 shows the BIM-enabled recommendations for the highways construction clients. The next chapter provides the conclusions of this research and discusses achieved aims and objectives of the study. It also makes recommendations for policy makers, industry and research community. The recommendations are based on the research findings of the study. In addition, researcher discussed the possibilities for future research.

CHAPTER 6

Conclusion & Recommendations and Future Research

6.0 Conclusion Recommendation and Future Research

This chapter aims to provide conclusions, recommendations for the industry and research, and suggest future research as a result of the findings, encapsulated in the research that was carried out and detailed. To achieve these aims, the overview will be provided by revisiting the research objectives, process and main findings, and these will be discussed critically to evaluate the extent to which the research objectives were met. The evaluation will highlight the limitations and weaknesses which can be improvised by future research. In addition, the discussion of the main findings will provide some ideas about interesting aspects of research questions for the future. Further recommendations for the industry and research community will also be given.

6.1 The Research Process

This research was initiated by reviewing the literature to form knowledge of current issues in the highways construction industry and subsequently identify the research problems and develop the research aims and objectives. It was identified that lack of communication, fragmentation and paper based traditional approach associated problems among contributing factors of data management in the highways sector construction projects, hence as an advanced workflow, BIM was identified as a potential solution for the inefficiencies in the highways construction sector. A research gap was identified on evaluating the highways construction sector. It was found that the industry is having significant issues to implement newly adopted workflow and guidance from the client. BIM for data management for maintenance of the highways assets. This led to formation of research aim and interrelated objectives. Hence, the research aim is to develop BIM-enabled recommendations for highways client organizations for effective maintenance of the highways assets.

Subsequently a more detailed and specific literature was conducted to form the fundamentals of the research and develop guide recommendations. The literature review was first conducted on the background of highways civil construction industry to understand the current challenges of data management for maintenance of the infrastructure assets and the potential of BIM within the industry. Subsequently, a thorough literature review was conducted to explore, evaluate and synthesise relevant literature related to BIM on the specific concept, usage, implementation requirements and its potential on the data handover and management for the maintenance of the highways civil infrastructure to achieve objectives 1 and 2.

The case study research was conducted to achieve Objectives 3 and 4. The cases studies were conducted in the highways development projects in the UK. Thorough observation was conducted in the available cases for the research. In conducting multiple case studies research, the current level of BIM implementation and data management and handover challenges for each company was first analysed and investigated to support Objective 3 and to understand the BIM implementation status. After that, researcher conducted semi-structured interviews and directly observed organizations on their sites. Each interview was audio recorded using a voice recorder. As for the analysis of the data collected, it was first transcribed in to an interview script before thematic analysis conducted. The findings from each company were then cross analysed to determine the pattern of answers. Subsequently, recommendations were developed and validated via focus group discussion with the experts in the field. The focus group discussions were conducted with the construction industry experts. In the focus group discussions participants were asked to discuss the proposed recommendations and questions. In addition, the discussions were audio recorded using a voice recorder. Like case studies analysis, the qualitative data of the discussions analysed using content analysis. The findings from the validation exercise refined in the enriched the final recommendations.

6.2 Achieving the Research Aims and Objectives

The aim of this study was to develop BIM-Enabled recommendations to improve the data management for the highways sector construction projects for the clients in the UK. The aim has been achieved effectively through the research objectives. The objectives of this research defined as:

The first objective the research was: 'To review the current barriers and bottlenecks for data handover in the Highways construction sector'. To achieve this objective, a critical review of the literature was made in Chapter 2. The chapter provided background of highways construction, data handover, its principles and procedures as well as the key challenges in existing practices were identified.

The second objective was: 'To explore potential of BIM in supporting public sector highways construction sector'. The researcher reviewed the literature to understand the potential of BIM and its relevance to highways infrastructure assets, the challenges of the interoperability, current UK standards and policies for BIM, facilities management and interoperability issues were covered. Therefore, by reviewing the literature, the second objective was successfully covered.

The third objective was: 'To identify the challenges faced by project teams in the management of data within the highways public sector infrastructure in the UK context'. To achieve this objective, the researcher conducted three highways development case studies in the UK and detailed data collected. Furthermore, semi-structured interviews were conducted with the 15 participants from the case study organizations. Interviews helped a great deal developing the backbone of the research by forming first hand data. The interviews were triangulated with supporting document analysis which improved the research validity.

The fourth objective was: ‘To specify BIM-enabled recommendations that will encapsulate methods and processes for enhanced data handover from construction to maintenance’. To achieve this objective, findings from the qualitative analysis were used. By in-depth analysis of the findings, the researcher could develop the recommendations to be validated through focus group discussions.

The fifth objective was: ‘To validate the BIM- enabled recommendations by examining the opinions of construction sector experts and provide recommendations for the Highways construction clients’. To meet this objective, the researcher conducted a guided focus group discussion with the 12 leading experts in the built environment. Based on the focus group discussion the validation was achieved successfully and the final recommendations produced.

In conclusion by reaching the fifth objective, the main aim was achieved by providing validated recommendations for the highways sector clients. Consequently, research questions were also answered.

6.3 Originality of Research

There are many previous research related to building handover practices around the world mainly in the building sector. Mostly because of the BIM’s origins from the building sector. However, BIM’s relevance in the highways infrastructure has not been explored particularly in the data management and handover for maintenance. This situation makes the highways industry lagging the other construction sectors due to highways specific conditions as per multiple data requirements as being largest linear infrastructure.

This study provides original research outputs for the highways construction clients. As the advanced BIM workflows recently been introduced to the highways sector, it has been identified that there is a significant requirement for the client to effectively manage the data related to asset operation and maintenance in the UK. Furthermore, in the body literature, no case study research has studied this topic due to BIM’s new introduction to the highways sector in the UK. Thus, it is expected that this research provides a solid foundation for the improvement of scientific research in the highways construction.

This research provides significant original contribution to knowledge by investigating specific factors affecting the data management in highways construction in the UK and provides original recommendations for the highways construction public sector clients. Therefore, this research reduced the gap in the knowledge in the UK highways construction sector specifically, and the entire highways construction sector in general. Furthermore, other researchers in this particular construction field would benefit from this research.

This research highlighted the specific factors affecting the data management in the highways construction sector for UK public projects. They are:

- Lack of knowledge and best practices in the highways sector
- Lack of exploration of digital technologies
- Lack of adequate communication during the project phases
- Complexity of linear infrastructure projects,
- Fragmented process
- Lack of transparency
- Lack of training people
- Lack of standardisation
- Lack of integrated approach
- Lack of highways specific guidance from the client
- Lack of FM/AM involvement during the projects

6.4 Contributions to Knowledge

The primary contribution of this research is that the study identifies the factors affecting data management in the highways construction sector in the UK due to industry's newly adopted BIM workflows. As previously stated the aim of this research was to provide BIM-enabled recommendations for the highways construction clients in order to adequately manage the data of the infrastructure assets for operations and maintenance in their lifecycle.

This study provides original case studies from the highways construction sector detailing their BIM implementation and current asset handover processes.

The research highlights the significance of data management in asset handover for the highways construction industry, thereby increasing the ability to train people from the industry on data management practices and its practical application.

The research is valuable resource for academics, researchers and specialists who would like to benefit from the research outcomes as the research provides valuable understanding for data management in the highways infrastructure sector.

Hence, this research provides considerable body of knowledge for assisting and supporting highways construction clients and project decision-makers in the UK to understand the use of BIM based technology laden workflows that could affect highways industry activities, allowing them to work towards improving the quality of their provided programmes related to this industry.

6.5 Conclusions

This research arose from the UK Government's BIM mandate for the publicly acquired projects by 2016. A review of the relevant literature that has been undertaken in BIM use in Highways sector shows that there is a need for this type of research. Literature review and best practice cases show the current barriers and bottlenecks that have been encountered by the highways sector reinforce the need for the research. There is minimal literature regarding the implementation of BIM as a process for managing data handover in the highways sector. Additionally, there is little research known on the effectiveness of the HM Government's initiatives and support strategies for BIM adoption of the current highways infrastructure. This highlights the need of industry demonstration projects within Highways sector. Highways construction clients need clear guidance to maintain public sector infrastructure assets.

1. Offered recommendations for improving policies, incentives and plans of the Highways England (HE) as the main client for the public infrastructure, to encourage the implementation of BIM for the maintenance of the civil infrastructure assets in highways construction sector. This will help all project parties gain a better understanding of the BIM process, as well as an understanding of its efficiency in improving data handover of operation and maintenance.

2. Offered recommendations for improving BIM implementation strategies in the Highways construction industry by producing recommendations.

3. Developed BIM-Enabled recommendations for clients to improve the processes of asset data handover to adequately operate and maintain the highways civil infrastructure assets.

In this case, the recommendations have all the information intended to advise the client organizations for the highways sector, providing practical instructions to be taken during the BIM-enabled digital data handover process of the built assets.

6.6 Recommendations for Future Research

Supplementary studies should be done to examine the further issues affecting the asset data management in the highways construction sector both public and private sectors in the UK. This research provided the results by categorising them into several themes. Additional research may need to take the study further as every theme might be studied independently to gain more understanding of key elements. More research may be conducted as the best practices in the highways sector emerge. This way a deeper understanding can be developed for the BIM based data management for the operation and maintenance of the facilities.

This research offers further recommendations intended for policymakers, practitioners, and researchers. These recommendations are;

- **Recommendations for policy makers**

  - It is very crucial the policy makers develop civil infrastructure laden approaches for the construction industry, so that a standardized workflow will be reinforced throughout the highways sector.
  - Current standards for BIM workflows are very building sector centric, highways specific considerations should be done.
  - The Policy makers should consider small and medium-sized enterprises in order to make them active participants in the supply chain using incentivization.

- **Recommendations for practitioners**

  - The project manager should capture the best practices of highways construction regarding BIM workflows in data management and share the lessons-learned with the entire highways industry.
  - BIM-savvy workforce should be provided to public sector projects in the UK, therefore skilled resources will be available for the project teams.
  - The project team should be aware of implementing BIM requires changes in the process and practice by all stakeholders. Hence, there will be resistance to change and traditional mindset barriers. This situation will make a considerable time to get used to.
  - BIM provides a remarkable development that is challenging the built environment sector to consider improvements in technology, work practices and processes. It is crucial that all the supply chain in the sector works together.

- **Recommendations for scientific researchers**

- The researchers should be encouraged to do more research in the field of civil infrastructure providing the relevance of advanced technologies in the data management of asset lifecycle.
- As the BIM is an emerging concept, the researchers must be encouraged to test the capabilities of other technological advances that could be integrated to BIM process, such as laser scanning and virtual/augmented reality.
- It is recommended that the researchers should carry out research on interoperability issues with FM/AM databases, as it is still a problem to be solved.

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Whyte, J., Lindkvist, C., and Hassan Ibrahim, N. (2010) Value to Clients through Data Hand-Over: A Pilot Study, Summary Report to Institution of Civil Engineers (ICE) Information Systems (IS) Panel

APPENDICES

APPENDIX (A): Ethical Approval

University of Salford MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

4 November 2016

Dear Sanem,

RE: ETHICS APPLICATION SBSR1617-06 – Enhancing the Operation and Maintenance of the Facility For Highways in the UK

Based on the information you provided, I am pleased to inform you that your application SBSR1617-06 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

[redacted]

Prof Mohammed Arif
Chair of the Science & Technology Research Ethics Panel
Professor of Sustainability and Process Management
School of Built Environment
University of Salford
Maxwell Building, The Crescent
Greater Manchester, UK M5 4WT
Phone: + 44 161 295 6829
Email: m.arif@salford.ac.uk

APPENDIX (B): Participant Invitation Letter

Participant Invitation Letter
(Interviews)

Dear Participant,

I would like to invite you to take part in a research project entitled: BIM-Enabled Digital Handover Process for Enhancing the Operation and Maintenance of the Facility for Highways in the UK.

The purpose of this interview is to determine the current perception of Building Information Modelling within the Highways construction industry for data handover, to identify the barriers and obstacles within Highways construction industry to the adoption of BIM to control data handover .The collected data along with the observation will support developing a BIM-Enabled Guidelines for Highways construction industry in order to maintain effective data handover.

There are no identified risks from participating in this research and it is completely voluntary and you may refuse to participate without consequence. Furthermore, according to Data Protection ACT 1998 and Social Research Association Ethical Guidelines 2003 in the UK, all data collected will be kept safely and will be erased completely from the computer that is used for data analysis after the results of the study are published.

Attached to this invitation is a Participant Information Sheet. This will provide you with further information about the interview and who to contact if you have any questions.

I hope you choose to take part in this interview and to consider sharing your experience, which will help me identifying ways to improve UK Highways construction industry.

Sincerely,

M.Sanem Bayar
PhD Researcher
School of Built Environment
University of Salford
Maxwell Building
mobile [redacted]
e-mail m.s.bayar@edu.salford.ac.uk

APPENDIX (C): Participant Consent Form

Participant Consent Form

BIM-Enabled Digital Handover Process for Enhancing the Operation and Maintenance of the Facility for Highways in the UK.

Name of the researcher: M Sanem Bayar

Name of the supervisor: Dr. Zeeshan Aziz

<u>The use info in this consent is being granted for:</u>

The aim of the research is to develop a BIM-enabled Guidelines for UK Highways Construction that would define tools, methods and processes to enhance and maintain the data handover process from construction to maintenance stages in the Highways supply chain.

Please tick the appropriate boxes:

	Yes	No
• I have read and understand the project information sheet.	☐	☐
• I have been given the opportunity to ask questions about the project.	☐	☐
• I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part.	☐	☐
• I agree to take part I n this interview.	☐	☐

Name of the participant: ………………………………………………………………………

Signature: ………………………………………………………………………………………

APPENDIX (D): Interview Plan

INTERVIEW PLAN

(14.08.2016)

Interviewer introduction and proposed questions.

Hi, my name is Sanem Bayar, I am currently conducting research focusing how as Highways client organizations can achieve a better continuity in the flow of asset information from design and construction to Operations and Maintenance phase .I have invited you to participate in this research given your expertise and knowledge of the field. I intend to conduct a semi structured recorded interview. Please find a list of initial questions I would like to ask below.

Your background and work within the field.

Main question	Additional questions	Clarifying questions
Please could you tell me want your experience is with regards the Building Information Modelling (BIM) and its associated technologies?	Please could you tell me about your specific area of interest within the construction industry?	Could you tell me anything about your perceptions of Building Information Modelling within the Highways construction industry, or areas you think might become crucial in the near future?

Current perception of BIM in Highways construction sector for accurate data flow during the facility's life cycle.

Main question	Additional questions	Clarifying questions
What do you think of current perception of BIM in Highways construction sector in terms of the accuracy of data flow of the infrastructure assets?	Looking forward, where do you think BIM will be in the short to medium term, what do you think of successful BIM implementation will be achieved and what will be its impact on the interactions and communication within the Highways construction sector.	What do you think of UK Government's BIM mandate on publicly acquired projects and how will it affect the Highways construction industry?

The perceived barriers and bottlenecks to BIM adoption and the challenges ahead.

Main question	Additional questions	Clarifying questions
In terms of the UK Government's BIM mandate and the technologies being emerged in the AEC industry, what do you see as the main barriers to implement BIM for the construction assets?	What do you think client organizations do in terms of successful BIM implementation?	Are there any strategies that you think should be done by government as client to accelerate the adoption of BIM processes and technologies?

Benefits of implementing BIM for data handover process.

Main question	Additional questions	Clarifying questions
Do you have any thoughts on the benefits of acquiring the BIM, how the data will be protected, maintained, organised and distributed to other parties for effective collaboration from the perspective of clients/designers /constructors?	Do you have any thoughts on how data is shared and organised as a user utilises various information or components available to them?	Have you considered how achieve effective training will be given to the users of BIM applications and how to assure security of the information that is being circulated among stakeholders?

The effectiveness of UK government, for Highways sector to enhance data handover through BIM adoption.

Main question	Additional questions	Clarifying questions
In Highways sector what is the effectiveness of UK Government policies to enhance data handover through BIM adoption?	What do you think can be done for a successful handover through BIM for the Highways infrastructure assets?	What are requirements should be considered and developed first (by the client organizations) in order to successfully deliver an asset data that can be adopted by the Highways construction companies?

Additional Discussion + Questions

- What practical steps can be taken to ensure data collected through project life cycle is used to support decision making during operations and maintenance stage?
- What is the impact of emerging standards such as PAS1192-2: 1192-3 .What steps are required to enhance Highways England and it supply chain operational readiness to adopt BIM workflow?
- What steps required to enhance use of structured approach to information management (i.e. reducing reliance on paper based information transmission mechanisms)?
- What practical measures are required by Highways England to better manage data (digital documentation, graphical, and non-graphical data) related to key assets.
- What role BIM can play in better asset management?
- What is current level of understanding of UK Government Digital Plan of Work across Highways England assets?
- How can better alignment be achieved between data generated through major schemes delivery with long term activity of operations and maintenance of Highways England assets?
- What are challenges in existing data handover practices?
- What are key data requirements from operations and maintenance viewpoint from Highway England and its service provider’s perspective?

APPENDIX (E): Publication 1

OPTIMIZING HANDOVER OF AS-BUILT DATA USING BIM FOR HIGHWAYS

M.Sanem Bayar[1], Dr Zeeshan Aziz[2] , Dr Algan Tezel [3], Prof Yusuf Arayici[4], Dr Sara Biscaya[5]
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Abstract
An efficient maintenance of the UK's transportation network is of critical importance to the country's economy and among the top priorities of the government and public agencies (e.g. Network Rail, Highways England). The public transportation agencies have huge data sets related to asset management and maintenance. However, those data sets are usually held in disparate platforms and have been historically developed using multiple standards and formats. As a result, full value of such data is often not fully realized. Effective management of asset data and availability of reliable information as and when needed, could bring in key benefits for effective management of the transportation network. This paper aims to present the initial findings of a research effort understanding the potential of Building Information Modelling (BIM) in handover processes for a more efficient maintenance of highways assets, and discuss the way forward. The research methodology applied is systematic literature review and two recent best practice cases in the Highways Sector. The research findings suggest that efficient data management through BIM could provide a structured framework to improve asset handover and maintenance. However, it is important to capture the current handover practices between the construction and maintenance phase, and maintenance processes in the UK's highways sector, both of which seem to be absent in the literature at the moment.

Keywords: BIM, Handover, Asset, As-built Data, Highways

Introduction

The benefits of using the Building Information Modelling (BIM) process (i.e. reduction in construction costs, improved quality of design information, integration of project systems, reduced change orders, improved interoperability, and whole life-cycle asset management) for asset project management, as a unified project-life cycle data management repository of form and function, have been widely discussed in the literature (Succar, 2009; Azhar, 2011; Eastman et al., 2011; Love et al., 2011; Barlish and Sullivan, 2012; Bryde et al., 2013). While those benefits have been readily observed in practice during the design and construction stage, particularly in controlling and managing projects' costs and schedules, such benefits are marginal when the duration of assets' life cycle, and maintenance and operations are considered (Love et al., 2014). For instance, as of 2012, the cost of operating England's strategic highways network mounted up to 0.3 British Pence/vehicle mile (DfT, 2011) with more than 800 million British Pounds/year spent on the network's maintenance (NAO, 2014) amidst a serious public dissatisfaction with the current level of road conditions and significant budget cuts from the government (Glaister, 2013; NAO, 2014). A study undertook in the US revealed that there are huge costs associated with inadequate interoperability and mismatch among design software, and software systems and processes used in capital facilities/asset management (NIST, 2004), which suggests a cost reduction opportunity in capital asset management practices through better synchronizing asset life-cycle data management (from end to end) by using BIM.

In May 2011 the UK Government Construction Strategy was published detailing the government's intention to require BIM in all of its capital projects by 2016 through a 5 year staged implementation plan. BIM has been seen as central to the government's objective in achieving 20% saving in asset costs and higher value for money (Cabinet Office, 2011). The 2016 version of the strategy further emphasizes the importance of using BIM in the entire asset lifecycle (Cabinet Office, 2016). Highways England (HE), the main body managing the strategic highways network, is an active participant in the BIM Task Group which is supporting and helping deliver the Construction Strategy objectives.

Despite its significant potential for an improved project-life cycle performance, research on the data requirements for BIM-based asset management have remained scarce (Becerik-Gerber et al., 2011; Love et al, 2014). Beyond building assets, this scarcity is even more notable for large civil infrastructural assets. Recent industry surveys also show that the use of BIM is still relatively low both among asset managers and for asset management purposes (McGraw Hill Construction, 2014; Malleson, 2016). Given the UK government's and large client organizations' (i.e. Highways England, Network Rail) vision to further penetrate BIM into the life-cycle project management of large infrastructure assets (i.e. railways, highways etc.), it can be stated that there is a clear need to better understand the data requirements for a BIM based-asset management for large infrastructural assets to guide the current handover practices, to improve the overall asset management performance for a higher end-user satisfaction and to reduce the associated asset management costs, as explained by Kemp (2016); "the need for accurate asset information for large infrastructure managers (e.g. utility companies, Highways England, Network Rail, Environment Agency) is an essential enabler for the safe and efficient operation and maintenance of those assets and for decision support."

The opportunities of BIM based asset management for large infrastructure assets are also in line with the broader vision of "smart spaces" or "smart cities", in which digital data should freely flow among inanimate objects (capital assets) mostly through sensor networks, wireless communication and mobile devices, for informed decision making (Perera et al., 2014; Zanella et al., 2014). For the construction industry, the digital asset is becoming as important as the physical asset. Therefore, the asset data cannot be regarded as proprietary but need to be passed on between the project-life cycle stages as accessible (e.g. open to stakeholders and free of interoperability issues), trusted (timely, correct, impartial and complete), and just enough in detail and content (Kemp, 2016). Managing assets means to have continuous and reliable data on the asset inventory, condition and performance. The infrastructure sector needs to catch up with the building sector in terms of its BIM implementation maturity. However, with many visible and invisible assets (e.g. underwater or underground) and nonlinear maintenance patterns (deteriorations), operating, for instance, a highways network is a complex matter, requiring best use of data from multitude sources such as traffic data, casualty/accident data, asset report and so on (NAO, 2014). BIM can provide an analytical approach to data management which enables multiple analysis, thereby, enabling decision makers to use it for a variety of purpose. In this context, data handover should be considered as a life cycle component like any asset and therefore, specific data handover manuals for BIM based infrastructure asset management operations are required.

In view of these circumstances, in order to set the scene for further investigations, this paper presents the initial findings of a research effort aiming at better understanding the data requirements for BIM based digital asset handover in major highways projects in England. Based on a detailed literature analysis, the paper outlines the current handover situation and recent BIM-based asset management efforts, illustrates some best practices and discusses the way-forward for research on the subject matter. The following sections present those initial findings.

Current handover situation at the highways supply chain

In current practice, the maintenance and operational handover of a major highways project from the project team (construction contractor) to the Network Delivery and Development service delivery team (maintenance and operations teams) should take place on the date of project completion/road opening. However, the project team will retain responsibility for issues arising from the construction during the defect period. According to HE's project control framework (Highways England, 2013), those documents are normally required for the handover; (i) as built drawings/documentation, (ii) updated health and safety file from the option selection stage prior to the preliminary design stage, (iii) template for handover schedule, (iv) civil assets maintenance handover certificate – including outstanding matters checklist, (v) technology commissioning plan, (vi) technology assets maintenance documentation and certificate, (vii) operational handover documentation and certificate for traffic management and regional control center, and (viii) updated permit to connect from the construction preparation stage. The documents have been developed starting from the design phase through the end of the construction phase in a highways project.

Documents required for the handover are generally deposited in Highways England's document management system (SHARE). Some documents for certain assets may be stored in other relevant Highways England systems such as Highways Pavement Management System (HAPMS) or Structures Management Information Systems (SMIS). Also, mandatory road safety audit reports are produced during the development and construction phases of a major project to help identify potential safety issues and mitigate these where possible. The project control framework underlines the importance of coordination between the project team and maintenance/ operational bodies from the very early stages of the project-life cycle. There are efforts to integrate the fragmented data management systems at HE and promote automatic digital data collection for assets through sensor-fitted highways plant (Aggregate Industries, 2015). The degree of data loss in-between the phases and the compatibility of the current practice with the BIM vision are not well-known.

UK public sector transportation clients have a huge portfolio of aging assets. Historically, their data sets have been usually held in disparate platforms and developed utilizing multiple standards and formats. As a result, full value of such great data is not fully realized. Aging assets require economic life extension through efficient data management. With the increasing portions of smart systems and structures, the current network is becoming even more complex. According to Aziz (2016), newly generated information in new formats such as RVT, PLN, IFC is a great challenge for industry stakeholders that are already struggling to make sense of the CAD file formats (DWG,DGN, DXF etc.). As with the CAD formats, these are often proprietary and undocumented. It also presents a great challenge that the current closed and open formats are in need of specific versions of tools to work with. As per multi-decade lifespans, it is a huge bottleneck. Previously generated data are held disparate media; in the model, in CAD files, PDFs, printed paper, in spreadsheets and in the binders. Also, the current condition of asset information is hard to quality check. Stakeholders of the data handover of assets have limited BIM knowledge and experience. The industry's traditional habits and resistance to change are also forming other challenges. Additionally, what should be delivered, at what cost, and the ownership of information raise legal/contractual challenges.

The handover process forms the greatest information division bridging the gap between construction and operation phases. The amount of information generated is huge; however, the information is not tailored for upcoming processes and bottlenecks. The existing information should also be merged with newly generated, gathered and structured information. The major advantage of replacing BIM with the traditional disparate methods is BIM's greater ability to control projects with a minimized risk of errors and data loss at the handover for complex and specific built assets (see Fig.1).

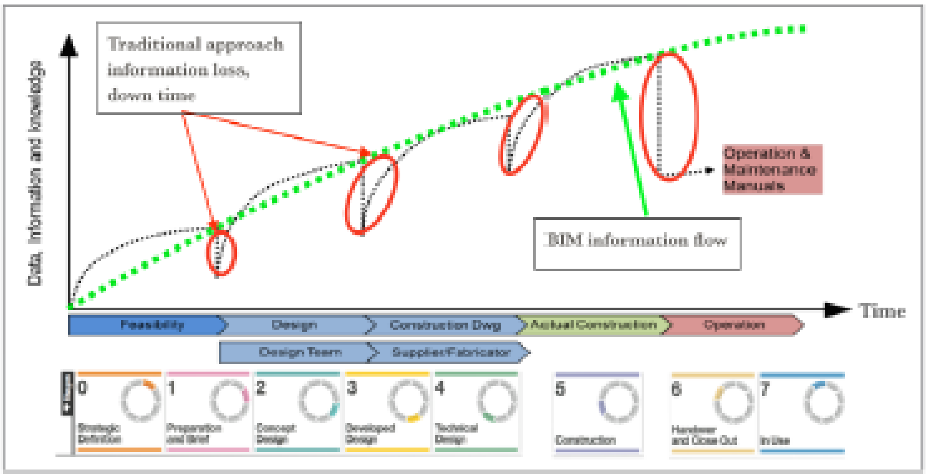


Figure 1: Reducing data losses at handover stages using standardised workflows (adapted from Aziz (2016))

The current situation in the highways sector raises issues that are mainly related to information losses, duplication of work and unreliable asset information due to disparate formats and archives. The current issues associated with the situation at Highways England and its Tier 1 suppliers are (Aziz, 2016):

- Asset surveys done over many years –data held on disparate platforms and not easily accessible;
- Asset database are legacy –over 15 years;
- Asset information is often poor, fragmented and cannot be relied upon for decision making;
- Reliance on the 'find a patch and amend it 'approach. Lacking of a long-term view;
- Asset data often maintained by service providers;
- Data degradation at the handover stage;
- Lack of a clear definition of client need leading to scope creep;
- Data structure and formats used in the project design and delivery differ from those used in asset management;
- HE currently manages its assets within 14 areas throughout the country. These 14 areas cover the 6 regions in England. Approaches used in the data management are often not consistent;
- Use of different data formats and structures in scheme design, delivery and operations;
- Key project staff leave before project completion resulting in loss of tacit knowledge;
- Getting as-built information is challenging;
- Design/Construction/Operations teams use different technical languages;
- Data requirements are not defined at the beginning.

Initiatives to support BIM based asset handover

PAS 1192: 3 specifications

PAS 1192:3 is a specification that has been set to sit alongside PAS 1192:2. Its purpose is to provide a structure for information management through the whole life cycle of asset management (BSI, 2014). PAS 1192:3 looks at the assets at an operational level by creating an asset information model. To use the model, the 'asset owning organization' must identify their assets and numerous pieces of information about those assets to enable creation of the asset information model. The key elements of standard information being available, transferable and having integrity. It includes how a Project Information Model (PIM) is transferred to become an Asset Management Model (AIM) (NBS, 2015). This is an important step in the project lifecycle, as the user of the information changes meaning information should be mature enough for the purpose.

Government Soft Landing (GSL) policy

Another way to enable whole life cycle information management and prevent information losses at the project handover stage is to use the GSL policy (Cabinet Office, 2012). Created in 2012, it sought to align design and construction better with operation and asset management. The client is involved at an early stage, engaging with design and construction teams to identify their requirements and expectations at the end of the process (NBS, 2015). HE needs to ensure capturing all the information it requires, and that it engages with its stakeholders, in order to be able to meet their expectations as the network operates. As HE currently seeks to update its asset management policies, it may not be able to initially implement a PAS 1192:3 model but it can certainly begin to adopt some aspects of GSL practices, such as stakeholder engagement to inform information requirements and to ensure smooth delivery. GSL makes information available to the client prior to the handover so that they understand the asset before they are tasked with operating it and work together with client team for optimizing asset performance.

The GSL framework and PAS 1192:3 standards provide structures, which can inevitably help HE and its supply chain deliver more efficient information as they are supported by a formal process. In order for these processes to be effective, early and active client engagement and support is essential. Teams involved need to have a clear understanding of Asset Information Model required to effectively operate and manage assets. Information in the final models will naturally mature through the design and construction process, provided the teams maintain it throughout, so it is effective and ready to use at the point of handover. These processes should enable a project team to compile and transfer project information for handover in a manner that flows.

Common Data Environment (CDE)

Common Data Environment (CDE) is defined as a "single source of information for the project, used to collect, manage and distribute documentation, the graphical model and non-graphical data to the whole project team" (Boxall, 2015). This collaboration of data helps minimise risks and avoids mistakes/duplication. Creation of a CDE is also recognized in the PAS 1192:2 framework where cloud-based sharing uses an accessible project server or piece of software to store and share the data, creating a shared knowledge resource. Implementing a CDE across all HE schemes will ensure that there is a consistency in which assets are constructed and information is shared. Consistent data from multiple projects could enable easier access to information and cross comparisons between different projects/asset classes.

Best practice examples

In this section, two recent best practice examples from HE's database with respect to highways handover will be presented. The best practices suggest that despite some efforts, BIM based asset handover in the highways supply chain is currently in its infancy.These two major best practice examples form initial lessons learned cases for future projects.

M1 J33 handover pilot

The M1 J33 Pinch Point Improvement Project formed part of the M1 J28 to 35a Smart Motorway Improvement Project (See Figure 2). The scheme received national recognition as it was the first major highway project to be Level 2 BIM compliant in the country. The budget was £2.2M and the scheme was required to be delivered in a period of 4 months from

January – April 2014. The project team worked with the management team and supply chain through collaborative monthly workshops, to develop the model which contains detailed design and contractual information, existing management asset data, pavement data, as-built information and the contents of the Health and Safety File. Good collaborative relationships were maintained throughout the development and construction phases of the project between all parties. This led on to a smooth handover of the scheme into maintenance, due in part to the development of the BIM model. The model is now being used as an asset maintenance tool for the first time in the country. Important lessons learned include; (i) current HE databases are very high level and do not capture the granularity of data available, as required by the maintainers, (ii) further work is needed to capture all stakeholder requirements, so that a comprehensive recording system can be developed, which will enable maintainers and stakeholders to better interrogate and use captured data.

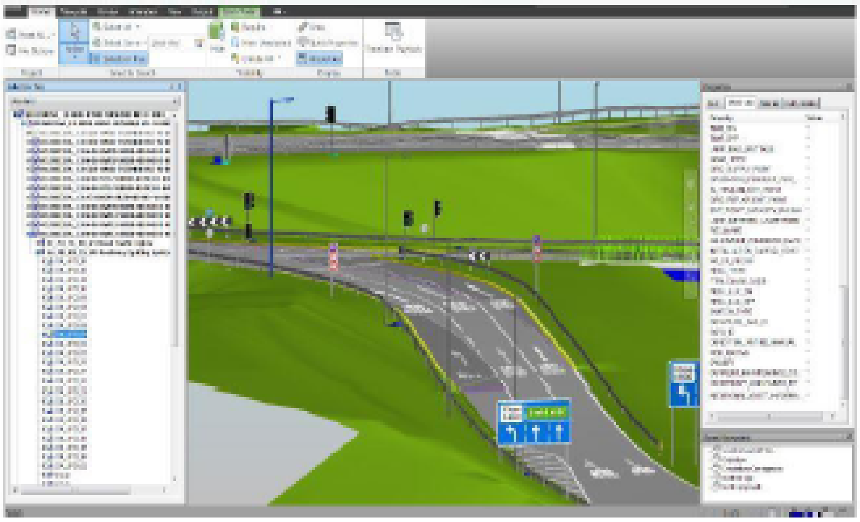
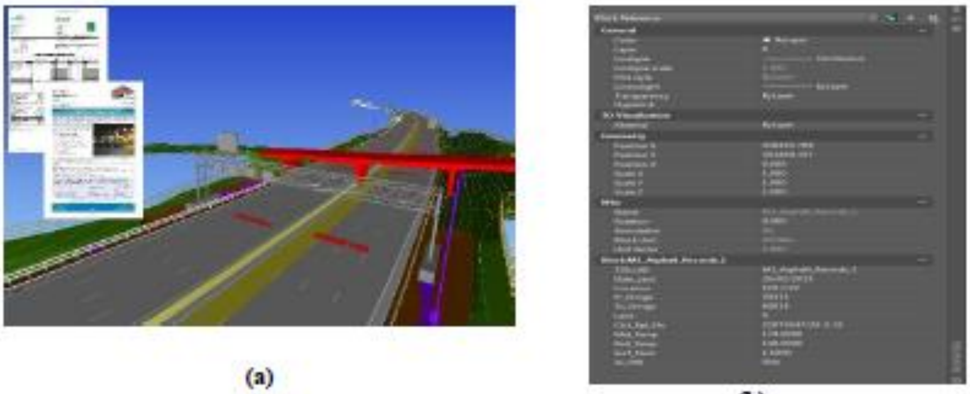


Figure 2: Screenshot of the M1J33 BIM Model (Mouchel Consulting,2015)

M1 J32-35a pilot

The M1 J 32-35a Smart Motorway Improvement Project forms part of the M1 J28 to 35a Smart Motorway Improvement Project. The M1 Motorway is a strategic route for local, regional and international traffic. In respect to handover, and building on the work undertaken on the Pinch Point Scheme at J33 and J31 to J32, a consultation exercise with all the key stakeholders to better understand their aspirations in respect to the benefits that can be achieved has been undertaken. The results of this have been used to develop templates to facilitate future data capture across the Smart Motorway Programme including for example: risk assessments; carbon capture and incident response proposals. Some of the other achievements in respect to handover include: (i) development of the current asset management system compliant linked data spreadsheets; (ii) Provision of feedback to software developers to deliver improved base software which will be more highway sector friendly in the future; (iii) inclusion of data rich surfacing information captured remotely on data loggers located on the paving fleet. It is felt this will deliver a step change improvement in future pavement asset management when compared with the current 2D HAPMS recording system; (iv) the ability to more robustly identify and design-out clashes between the proposed drainage and existing services; (v) promoting the adoption of BIM within the local highway maintenance team and obtaining feedback over its successful usage. See Figure 3 for some examples of BIM based digital handover practices from the case project.



(a) (b)

Figure 3: Material data sheets (a) and digital surfacing data metrics (b)

Future research

While the value of capturing accurate data is starting to be realized, it is important for captured data to be retained, enhanced and accessible at the handover stage. Inefficiency costs resulting from inadequate interoperability between various legacy software systems and poor transfer of data and information from the design and construction stage into operations sum up to millions of British Pounds. This highlights the need for client organizations to spell out clearly their information needs and develop an integration strategy to ensure data adds value to their daily operations. As a consequence, clients often maintain and operate asset, without sufficient knowledge and understanding of assets that have been built. Traditional approaches to data handover present many difficulties, including failed opportunities to optimise performance and life spans of assets (see Figure 4).

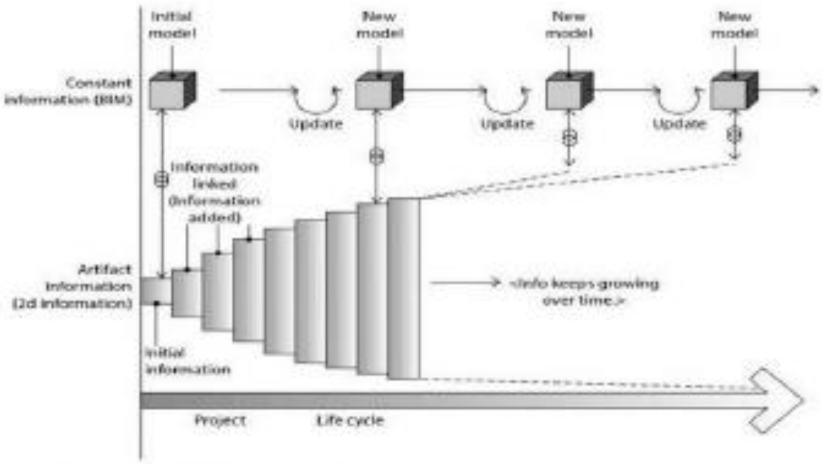


Figure 4: As information artefact grows through the project life cycle stages, more effort is required to maintain the data and more time consuming to access it (adapted from Hardin et al (2015))

In the near future, the highways network will face increasing pressures and impacts from a range of issues including changing weather patterns, population growth, capacity constraints, shortages of land and capital, rapidly changing technologies surpassing the pace of new infrastructure development. New concepts and emerging technologies and emerging solutions shall provide a better understanding in the long term challenges and maintenance of current construction infrastructure.

Following on the discussion presented in the paper, a handover guide for BIM based digital handover of different highways assets with respect to their data requirements, data responsible, level of detail, data format etc. seems to be needed. The guide should hold a project-life cycle view clearly defining the responsibilities of each project phase. The first step towards identifying the handover guide will be to map the current handover data flow in the highways supply chain. Another important aspect to the guideline will be a detailed requirement analysis for BIM based highways management. The handover guideline will need to be validated by expert view and preferably an implementation case.

Conclusion

BIM provides a systematic approach to collate design, construction and product specifications data in a single information model. Effective information management, as enabled by BIM could offer numerous potential benefits to HE. Firstly, simply capturing up to date, accurate information means the work that follows will be of value with waste reduced; information is accurate, up to date and accessible. Taking a road surfacing example, looking at what the road was constructed of, how it was repaired, how long it took, what materials were used, what the cost was, capturing potential reasons for degradation (i.e. weather, increased traffic flow) a valuable knowledge base that can be taken into account on future projects. Accurate information can be fed into electronic collaborative workspaces allowing HE and their supply chain to work together more efficiently. Developments in cloud computing and intelligent design modelling using BIM, further allows for seamless integration of asset information from diverse sources into a single source, to support operations and future planning.

Use of interoperable systems and standards are crucial for data continuity across the life-cycle as the main data structures, formats and uses in the delivery of projects differ from those used in asset management. Existing processes involve data submittals using variety of formats including CAD Drawings, PDFs and Excel spreadsheets. It has to be noted that employing BIM alone will not work but an increased effort to involve operations teams in early stages of projects will help. In addition, there needs to be a handover process to check whether quality data is being handed over. More importantly, HE needs to constantly foster skills to use and update project data in operations. This effectively means maintenance staff could effectively pull up the model on iPad and be on site with all the information they need to locate and correct a maintenance issue, helping to prevent network downtime.

This paper discussed and gave a brief overview of the current BIM based handover management in the highways supply chain in England. A deeper penetration of BIM in the construction industry beyond the building sector and in the operations phase of assets has been on the agenda of policy makers and large clients in England for a while. Regarding the highways sector, the initial findings suggest that although there are some BIM based handover implementation islands within some specific projects, there should be a systematic BIM guideline available for practitioners to use in their handover efforts in the future. Initial requirements for this handover guide were determined as a detailed map of the current handover process with respective information flows and a comprehensive requirement analysis.

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