Real-time Asset Information Modelling (rtAIM) Protocol for Highways

Graham Starkey

c7198239

A dissertation submitted in fulfilment of the requirements of Leeds Beckett University for the degree of Doctor of Engineering

Collaborating Establishment (Costain)

September 2024

Abstract

To operate successfully, an asset-centric organisation must recognise the need of visually validating the placement of its constructed assets. This is important to organisations but there are limitations and challenges. Building Information Modelling (BIM) has been widely adapted, and its establish methods and technologies offers some potentials in benefiting the highways sector. Hence this study involved the development of a BIM-based protocol and decision framework for real-time collection, validation, and handover of attribute data for National Highways' major schemes, using machine learning from images collected from drone flights.

The study has integrated qualitative and quantitative approaches at rigorous and extensive stages, following the principles of critical realism theory and exploratory sequential mixed methods. The qualitative research further informed the design of a questionnaire which was used to elucidate broader industry experts’ perspective that ultimately guided the design, development and validation of machine learning-enabled real time asset information modelling.

A new protocol to overcome these limitations by applying Machine Learning algorithms for Mask RCNN (Region based Convolutional Neural Networks) and recognising the assets of roads with geospatial images obtained from drones. The prototype looked at a linear asset, as they are the most difficult to capture. Using 150 images of the chosen asset type, these were labelled then processed using machine learning which then highlighted the assets it had

learnt, allowing the output to be sent to client databases in there required file format.

As proposed in the framework and validated through a case study the prototype effectively showcased how drone photogrammetry, powered by Machine Learning, a subset of Artificial Intelligence and Building Information Modelling (BIM) processes, can capture assets in real-time. This process reduces the time for redlining and negates the need for on-site surveys, adding value and reducing programme time.

Student's Declaration

This thesis is presented as an original contribution to earning a Doctor of Engineering degree at Leeds Beckett University, United Kingdom. The work here has not been previously submitted to meet the requirements for an award at any higher education institution under my name or that of any other individual. The thesis does not, to the best of my knowledge and belief, contain any previously published or written works by others unless an appropriate citation is made and acknowledged.

Signature

Graham Starkey

Acknowledgements

Without the assistance of Prof. Saheed Ajayi and Dr Shariful Shikder, the DEng. journey would not have been feasible. It is with sincerely appreciate their generosity and patience, as well as all of their support, direction, and advice.

Also am deeply indebted to Costain, who have sponsored research this journey, especially the innovation and Costain learning team, for their support in allowing the pursuance of this research. Without the financial support of the RDP CJP program, giving means to finish a proof-of-concept, the research would not have been feasible.

My dear wife Jill is the single biggest reason for reaching the milestone, the end date would not be possible without her unwavering love, support, and encouragement appreciate having her in my life.

Table of Contents

List of Tables

List of Images

Chapter One Introduction

1.1 Research Overview

Within the Infrastructure, particularly in the highways sector, 'silo' is a well-known term that has been around for over 30 years, not just between each sector but within the makeup of each project (Gleeson, 2017). Clients are expressing frustration over the lack of collaboration and the absence of connected project information, as outlined in Latham's (1994) recommendations for the industry's response. The report emphasizes that individuals have the choice to decline involvement with the report, but doing so would perpetuate the existing issues and undermine the progress made in addressing them, which has notably increased since the last report.

The government has taken proactive steps to enhance the quality and efficiency of the UK construction industry by establishing a dedicated Construction Task Force, drawing from the insightful recommendations of the Latham report. While initially focused on house building, the implications of its efforts extend across the entire Architecture, Engineering, and Construction (AEC) sector. In line with the initiative, there is a pressing need for a collective reassessment of the construction approach, as noted by Egan (1998, p. 38). His call for improved efficiency and effectiveness remains as pertinent today as it was when it was first proposed. Building upon the foundation laid by Latham and Egan, a subsequent review led by Andrew Wolstenholme reaffirmed the imperative for change. Although recognising the evolution of technology since Egan's report, the review emphasised the enduring relevance of the principles outlined more than a decade ago (Wolstenholme, 2009).

To resolve these issues, BIM (Building Information Modelling) was introduced, and BIM's adoption by the construction industry, particularly within transportation, has been slow. BIM has only just recently been considered as companies need to be increasingly competitive in the transportation market (DfT, 2016) and other infrastructure sectors. The British Standards Institution mention that companies who adopt BIM can reap the advantages from the streamlined approach that it provides, in which information in a collaborative environment is shared (BSi-BuildingSMART, 2010, p. 3).

The term 'Building Information Modelling' (BIM) began to be used at the end of the last century. In the early 2000s, the term became the agreed headline name for structuring and sharing information via a model. Of course, the successful use of a single model environment or project model was already familiar by then, with pioneering use on the Heathrow Express recovery project, Heathrow Europier, and Smithfield Market redevelopment (BSi-BuildingSMART, 2010). The primary reasons for this are to reduce capital costs, future maintenance costs and time and to comply with new government regulations. In 2011 'The Government Construction Strategy' was published, which states that the "Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016" (CabinetOffice, 2011, p. 14)This also implies that BIM technologies will be used on all UK government projects by 2016.

It is now the early 2020s, and the ‘Highways Sector’ clients, especially National Highways, have taken the concept of BIM and rebadged it as ‘Better Information Management’ (Highways Agency, 2014), meaning that their understanding is to have the BIM digital tool kit to enhance the output flow of information into one federated model, including the asset attribute data that is required for the handover into maintenance (DfT, 2016). Because of the current revolution in software and data sources, designers and contractors have been attempting to tackle the issue of associating asset attributes from an external database or having objects with asset information incorporated in them.

The BIM revolution in the realm of Highways emerged from a series of extensive developments and collaborative discussions involving key organisations like HE (Highways England) and their suppliers. These discussions were pivotal and were occurring during numerous meetings and workshops that coincided with the government's announcement of the Construction Strategy in 2011 (HM Government, 2011). Among the various forums, the BIM Task Group is a prime example, comprising clients, contractors, and designers alike. After the announcement, contractors and designers were engaged in HE's Working Group, which is dedicated to BIM implementation. Their involvement extended to participating in several workshops to showcase successful strategies and address challenges encountered along the way (Highways Agency, 2014). These workshops provided platforms for sharing insights into what worked well and where difficulties arose, particularly in navigating the constraints imposed by proprietary software utilised in project design. This collaborative effort underscored a commitment to overcoming obstacles and driving innovation within Highways construction.

Continuing from the workshops, progress has been achieved for the requirements of BIM for Highways this is ‘better information management’ (Highways England, 2016), but now need to address the complex and varied aspects of handover to the maintainer; in line with this, National Highways have produced various documents, including the Asset Data Management Manual (ADMM) (Highways, 2018) issued in May 2018 by the Asset Information Group, a subgroup within National Highways.

In short, the document provides additional information to enable stakeholders to meet the requirements of the ADMM. Another essential document that now includes the BIM requirements for HE is IAN182/14A (Enabling Handover into Operation and Maintenance), which offers instructions to everyone involved in creating large-scale projects and accepting them into operations and maintenance. It sets out best practices and key considerations regarding several activities and responsibilities important to achieving a successful scheme handover. The focus is on providing clarity around known issues, areas of complexity and key risk items (Highways Agency, 2014b).

1.2 National Highways Asset’s Background

The government organisation in charge of running, maintaining, and enhancing England's major "A" highways and motorways is called National Highways (NH), formerly known as Highways Agency (HA) and Highways England (HE). The road network is approximately 4,300 miles long but only makes up 2% of England's roads. It carries a third of all traffic by mileage and two-thirds of all heavy goods traffic (Highways, 2020a). The capturing of assets that make up this network is crucial to the management of the highways.

To improve the quality of asset attribute data held within its systems, in 2013, HE’s Asset Information Group (AIG) engaged with subject matter experts to identify innovative ways of updating its carriageway inventory, as defined in the Asset Data Management Manual Highways England. (2015). As a result of this undertaking, and with an ambition of updating its inventory across the Strategic Road Network (SRN), the AIG commissioned several Mobile Mapping Systems (MMS) (Highways, 2015b)

Asset capturing methods can be divided into two different categories: land-based and air/space-based methods; these methods vary in equipment used, data collection time, data reduction time, accuracy, and cost (Aziz et al., 2018). National Highways predominately use land-based driven Lidar; this has its inherent issues with a significant amount of roadside information, such as roadside slope, grade, roadside fixed objects and density, and offset to the edge of carriageway not being captured in enough detail (Jalayer et al., 2014).

In HE's newly established data warehouse, IAM-IS (Integrated Asset Management Information System), the system houses asset data, including location details for linear assets, such as those delineated by the SRN section and chainage. Further elaboration on the aspect is provided later in this document. The overarching goal is to integrate ADC (Asset Data Collection) data gathered from surveys, inclusive of geospatial location information, with the maintenance and inspection records stored within IAM-IS by asset maintainers (Highways, 2015b). This integration facilitates updating an asset's attributes while preserving its historical maintenance and inspection data.

However, discrepancies exist between the IAM-IS and ADC datasets due to the inherent errors in the feature recording process (Aziz et al., 2018), which relies on a human's ability to correctly identify and record the features on-site or from mobile mapping. To reduce the effects of this error would require a process to be introduced during the matching process to establish whether the error lies in the IAM-IS or the ADC datasets; in terms of completeness, regardless of ADC/IAM-IS dataset amalgamation, the ADC dataset must be reviewed with the latest available imagery to ensure it is of the highest possible quality (Highways, 2015b).

In 2014, the Highways Agency advanced its BIM strategy within its project and asset management activities, including earmarking several projects as 'Early Adopters' to develop the required systems, software, protocols and capabilities that were not widely used in the highways sector. The A160/A180 Port of Immingham scheme had been selected as an ‘Early Adopter’ (CabinetOffice, 2011). Once the project had reached the standard three-month handover period for major projects, the data provider embarked on the asset attribute part of the handover, where they used the documents mentioned above (ADMM, IAN182). However, these were at version 3 for the ADMM and 182/14 for IAN182/14A. While these documents were available, they were in continual flux. With the early adopter status of the A160 scheme, it became a question of how best to provide the data for the Area12 team of HE’s asset maintainers.

Following early engagement with the Area12 team in line with the government's 'soft landings' approach, it became apparent that discussions with HE's AIG and their maintainers regarding the optimal path for implementing ADC were not yielding the most productive outcomes (Highways, 2015b). The maintainers had raised consistent concerns about the accuracy of the captured attributes of the Strategic Road Network (SRN) assets, particularly noting discrepancies highlighted in the 2015 IBI report (Highways, 2015b). These concerns underscored the need for a more effective approach to address the issues.

The maintainers had to deal with changes to their contract with HE and the implementation of asset data needing to be amalgamated with new as-built data and imported into HE’s Integrated Asset Management Information System (IAM-IS). This was supposed to replace the previous databases HE had been using for the prior decade; however, when maintainers were changed, they kept their inventory databases, which their current contracts permitted, resulting in lost data for Highways England. The remaining components of the system were constructed, tested, and brought online in stages; however, IAM-IS has been repurposed and is now primarily used for structural databases (IAM, 2015).

1.3 Challenges faced through poor collaboration

Traditionally, an asset's design and construction have been seen as a different phase from its operation and maintenance (IAM, 2015). As major highways and road development initiatives are transferred from the Design and Construction team to Operations and Maintenance, considerable information is lost. Data processed during the Design and Construction phases might not be compatible with asset management software if data management practises are inconsistent throughout the project life cycle. Information might therefore need to be re-formatted and re-entered. Due to the asset managers' lack of participation and approval during asset design and construction, there may be information gaps or data incompatibilities that only become apparent at the handover stage and cause the handover to be delayed. All of this results in inadequate data management (IAM, 2015).

Due to National Highways' comprehensive approach to managing carriageway assets and the necessity of inputting asset attribute data into multiple databases, challenges persist even with the implementation of the replacement data warehouse, IAM-IS. This warehouse was specifically designed to streamline asset data management, processes, and organisational structure, replacing the previous fragmented system. However, despite these efforts, the ageing National Highways

Asset Data Collection (ADC) system poses a threat to data quality, particularly exacerbated by the continual evolution of the Strategic Road Network (SRN). The influx of new major road projects and the transformation of motorways into Smart Motorway Projects (SMP) further complicates matters, placing additional strain on Area Teams tasked with managing the road network amidst the introduction of new contractual obligations.

Staff from different departments within the area teams are involved in collecting and maintaining this data. The absence of an integrated approach to data set collection and management often leads to the lack of an inventory of crucial asset attributes and condition assessment, leading to maintenance operations that are often suboptimal (Aziz et al., 2018).

NH is taking back ownership of some area contracts, leading to another data warehouse called 'CONFIRM'. CONFIRM is especially a maintenance ticketing system for Jobs for the maintenance staff to carry out; this is also laid out differently to IAM-IS; the ADMM requires the data set to be laid out with the field headings in the Excel spreadsheet in a particular order to enable the loading into IAM-IS to be automated at the handover stage of the project. However, this same order will not load into 'CONFIRM'; therefore, another loader has to be set up for this to populate the CONFIRM database.

Numerous challenges present themselves to the delivery partner, typically the scheme Contractor, regarding the optimal approach to capturing asset data across the entire scope of the project. Certain assets within the scheme will remain untouched, underscoring the delivery partner's responsibility for managing the scheme asset set. Early engagement with maintainers is essential to address this aspect. Moreover, the dataset must undergo a thorough review utilising the latest available imagery to uphold the highest standards of quality and completeness, accurately reflecting the current state of the Strategic Road Network (Highways, 2015b).

Area maintainers know that discrepancies exist between the maintainer's inventory, IAM-IS and ADC datasets due to the inherent errors in the feature recording process, which relies on a human’s ability to correctly identify and record the features from mobile mapping data and the associated quality process or lack of. This has meant that the area maintainers cannot rely on the ADC data provided by HE as a full and comprehensive set of data, thus leading to the maintainers not using the ADC provided by HE. This has had a knock-on effect that the contractors, when embarking on major road schemes, have had to handover not only new asset data but also have had to reprocess the existing inventory and amalgamate the two to have a complete set of asset attribute data for the whole of the scheme (Highways, 2015b).

HE and local authorities have employed a variety of methods to collect the roadway inventory data, including field inventory, photo/video log, integrated GPS/GIS mapping systems, aerial photography, satellite imagery, airborne Light Detection and Ranging (LiDAR), static terrestrial laser scanning, and mobile LiDAR (Zhou et al., 2013). These methods vary based on the equipment needed, the time required to collect data, and reduced data and costs. Each method has its own set of advantages and disadvantages. Vehicle-mounted LiDAR, in particular, can collect a large amount of detailed 3D highway inventory data, but extracting the desired highway inventory data requires expensive equipment and significant data reduction efforts. A traditional field survey, on the other hand, necessitates less equipment investment, training, and data reduction efforts. However, this method is time-consuming and labour-intensive, exposing data collection crews to dangerous roadway environments (Zhou et al., 2013).

1.4 BIM as a promising process and technology

Digital innovations and procedures alter how the industry produces, delivers and manages infrastructure projects (Fewings & Henjewele, 2019). BIM has been widely implemented now for highway projects over the last seven years since the government mandated it. It is a set of technologies, processes, and policies that enable multiple stakeholders to design, construct, operate and maintain the asset collaboratively. As an infrastructure sector, it is time to move into a leaner way of working where the customers come first, make processes visible, drive constant progress, collaborate, deliver, learn and improve (Bolpagni, 2018). However, to advance the current way of delivering roads, there is a need to enhance innovation, reduce construction risks and capture assets of the built road network with more reliable processes that can link to a more accessible data warehouse (Fitz, 2016).

Industry professionals often hold the misconception that the advantages of generating virtual 3D models, along with their associated data, are limited to designers and contractors. However, this assumption overlooks the significant benefits that clients can also reap from such technologies. Through these programs, clients gain the ability to actively oversee project progression, closely monitor financial performance, implement robust health and safety solutions, and efficiently manage operations in a synchronised manner (Boyd, 2016).

Information models are crucial when monitoring performances and behaviours in real time and comparing them against planned activities. The capability to manage and capture assets dynamically, as well as the ability to monitor traffic and identify critical or improper usage of the road to mitigate risks for customers in real-time, become key enablers for broader digital evolution within the highways sector in the later stages of BIM (Bolpagni, 2018). However, gaining operational effectiveness and efficiency requires improving data quality across all asset classes. Adding locational clarity and validity has been a challenge in the past for roadside asset data (Kim, 2007).

By using new digital technologies like drone data captures which enables the seamlessly capture continuous real-time data on the asset. This ensures that there is commonly an updated and comprehensive dataset derived from onboard drone video feeds and data collected by handheld devices during asset inspections. Moreover, the platform facilitates ongoing enhancements and maintenance efforts. Drones equipped with advanced capabilities conduct aerial surveys of assets while sensor data monitors their performance. Recognising the challenge posed by historical asset data not readily available in a compatible format for upload, acknowledging the need for a solution. As Kim (2009) points out, converting such data is essential. Utilising various Building Information Modelling (BIM) toolkits, such as document imaging tools, facilitate the conversion process. This enables seamless integration of newly discovered asset information into the platform, ensuring a more comprehensive and up-to-date dataset.

The opportunities of BIM-based asset management and asset capturing for large infrastructure assets are also in line with the broader vision of “smart cities”, in which data should freely flow among data warehouses, mainly through sensory networks, wireless communication, and mobile devices, for better maintenance decisions making (Zanella et al., 2014). For all industry sectors, the digital asset is becoming as important as the physical asset. It should not be regarded as a standalone inventory but needs to be able to be passed on between all the project stages as an accessible, trusted, timely, correct, impartial and complete part of the project deliverables.

Managing assets means having continuous and reliable data on the asset inventory, condition, and performance, starting at the construction process's asset-capturing stage. Regarding the maturity of BIM implementation, it is slowing down, with those yet to adopt it in the sector are unlikely to adopt the process (RICS, 2020). However, operating, for example, a highway network is a complex matter that necessitates the best use of data from many sources such as traffic, casualties, and asset reports. This is because there are many above-ground and below-ground assets (e.g., underwater or underground) and nonlinear maintenance patterns (deteriorations) (National Audit Office, 2014).

BIM can provide a logical data management approach, enabling multiple inspections and decision-makers to use it for many other purposes. In this context, data handover should be classed as a life cycle asset which requires specific data handover manuals and frameworks (Highways Agency, 2014a).

Policymakers and major clients in England have long advocated for greater BIM adoption outside the building sector and during the asset's operational phase. Aziz & Bayer (2018) indicate that the Initial research indicates that practitioners should have access to a comprehensive BIM guideline to use in future handover efforts in the roads sector, despite the fact that certain projects have isolated BIM-based handover implementation. A thorough need analysis and a detailed map of the present handover procedure were found to be the initial prerequisites for this handover guide.(Aziz & Bayar, 2018).

Extensive attention has been devoted to exploring the burgeoning realm of point cloud technology and its transformation into usable assets within the Project Information Model (PIM), addressing the glaring gap of modelled assets within the construction federated model. While numerous studies have delved into diverse data collection methodologies, there remains a conspicuous absence of research on asset attribute data and real-time validation of built assets (Jalayer et al., 2014). Accurately attributing collected data is paramount for maintenance teams to integrate it confidently into their databases, ensuring that asset positions meet established standards and can be readily utilised without cumbersome verification processes.

1.5 Unit of Analysis for this study

When conducting data analysis in business research, the first crucial step is to define the unit of analysis. This is essentially the person or object from which the researcher gathers data. It delineates the 'what' and 'who' of the study. The unit under analysis encompasses individuals, groups, organizations, countries, technologies, and objects that are the focal point of the investigation. In the realm of business research, there exists a vast array of potential units of analysis. While individuals are the most common choice, other types of units can provide more accurate answers to various research problems (Kumar, 2018). For the specific research at hand, the unit of analysis is focused on individual expert team members, given the small group of subject matter experts involved.

1.6 Aims & Objectives

- Aim

To develop a BIM-based protocol and decision support framework for real-time collection, validation and handover of attribute data for National Highways major schemes.

- Objectives

The following objectives will be fulfilled to fulfil the study's objectives:

- To analyse the state of practice for asset information and the potential of BIM implementation.

- To investigate the strategies for capturing real-time asset information to facilitate life cycle asset management.

- To investigate and validate the effective strategy and protocol for capturing highway asset information.

- To develop the BIM-based framework and associated protocol for real-time collection, validation, and handover of attribute data for National Highways's major schemes.

1.7 Project Sponsor

Costain Group Plc. (referred to as Costain in this thesis), an engineering solutions provider founded in the construction industry in 1865, sponsors this study. The business began by constructing housing in the northwest of England before moving south to build houses in London in 1920, which marked the start of the business' expansion. A 10-million-gallon-per-day water distillation plant in Kuwait, an 11-mile section of the Trans-Iranian Railway, and airports in Bahrain and Dubai were among the foreign projects the company undertook in 1930. In the UK, Costain has contributed to constructing iconic projects like the Thames Barrier and the Channel Tunnel (Costain, 2015).

The infrastructure delivery company Costain is well-known; their revenue for 2018 (including the Group's share of joint ventures) was £1.7 billion, an increase of 4% from the previous year (Costain, 2017). Costain's forward order book is currently at 4.2 billion (Costain, 2019). With its headquarters in Maidenhead, Berkshire, Costain has twelve additional offices nationwide, including ones in London, Manchester, and Aberdeen. Six infrastructure sectors make up the business: rail, nuclear, roads, water, oil and gas, and energy. Each division of Costain works with different customers, partners in joint ventures, and suppliers. As of April 2019, Costain has approximately 4000 employees in over 100 active projects across the sectors.

This research is anchored within Costain’s Highway Sector. While the proposed framework of this research is designed to be versatile and applicable across various sectors and infrastructure companies, it is worth noting that the specific case studies involved exclusively pertain to projects led by Costain.

1.8 Significance of the study

This study aims to develop a BIM-based protocol and decision support framework for the real-time collection, validation, and handover of attribute data for National Highways’ major schemes. Traditionally, the handover of roadside asset attributes for major highway schemes in the UK has been one of populating spreadsheets (KPMG, 2017). With the required data, an individual who has been given the task by a construction manager is, at best, an engineer who has been involved in the road's construction; at worst, it is someone who does not know the scheme at all.

The information required to populate the data for these fields in the spreadsheet can be found in the current ADMM (at present, this is version 13); this information can be broadly split into two parts: geospatial and informative. The geospatial part has GPS coordinates based on the British National Grid and chainages based on the SRN chart and node settings; these are explained in IAN/182 and ADMM. The informative data for the population can be found in many different areas, and often, the information required has not been captured; schedules, inspection & test plans, and subcontractor drawings are just a few of the different places to find the needed information.

For roadside assets alone, encompassing 40 to 50 diverse asset types, each averaging around 50 attributes, thus looking at a minimum of 2000 attributes. A recent survey of just 5 kilometres of smart motorway, focusing solely on the 'Verge' as a linear asset, yielded 930 rows in the asset spreadsheet, amounting to 37,200 asset data fields (Aziz & Bayar, 2018). While it is true that certain fields may repeat, it is important to note that geospatial fields do not, emphasising the complexity and depth of the data involved.

Analysing the state of practice for capturing attribute data and the potential for BIM processes to deliver the geospatial data is a key implementation. Using the construction output drawings/objects from the federated models can be used, as the intelligence from the cad/model data can output the coordinates to British National Grid (BNG) and FME (Feature Manipulation Engine) workbenches can gather the chainages that reflect the SRN network nodes. The output can then be a compliant ADMM spreadsheet with all the spatial information added.

Therefore, while using BIM to make a lean and timely output of asset attribute information, the asset location needs validation and proof that the asset is in place. This would traditionally be done by a surveyor at the end of the project just before the ‘Traffic Management’ is taken away for ALR (all lanes running). This wait is unnecessary and can prolong the handover into operations and maintenance, this study looks at the strategies for capturing real-time asset validation to facilitate the speedy and accurate handover of asset attribute information for the area maintenance teams.

1.9 Overview of the Research Approach

This exploratory study aims to develop a BIM-based protocol and decision support framework for real-time collection, validation, and handover of attribute data for National Highways major schemes. The framework is developed to identify the location of highway assets on construction sites in real-time. Considering the framework intends to make the site engineers locate assets safely using the latest BIM and AI technologies, a literature review was conducted for each of these items, i.e., BIM, Asset Capture, Asset Management, Statutory Standards and AI. Understanding how assets are collected in the traditional sense and the programming of this element of work within the overall program of the works on site needed to be fully understood from both a construction and handover process, and an operator's maintenance team's needs were considered in the literature review process. The importance of knowing the location of assets early for expedient redlining purposes was examined. An overview of AI technology was explored, including the various ways it is utilised.

The research focused on integrating Computer Vision (CV) and the sophisticated capabilities of AI and Machine Learning (ML) within the construction industry. Delving into the realm of literature, this study provides insight into the broader context of Building Information Modelling (BIM) and its applications within the Architecture, Engineering, and Construction (AEC) sector. Through a comprehensive review of pertinent literature, this chapter underscores the rationale behind synergising AI and BIM methodologies for streamlined asset information collection.

Since this study suggests a framework to help construction engineers and maintainers gather asset data in real-time, it is vital that the views of engineers and operators are considered in developing the proposed framework. Ten industry professionals were interviewed to gather their opinions regarding the above aims and objectives. The interviews discussed issues relating to meetings and workshops that had taken place with HE concerning BIM and ADMM and their operational databases, what challenges there had been with collaboration with BIM processes and asset attribute handover, what influenced handover on their schemes and what has been done to capture and validate assets in newly constructed highways. The interview information was analysed using inductive thematic analysis techniques and quantitative content analysis techniques. The results from the analyses are used to develop a BIM-based protocol and decision support framework for real-time collection, validation and handover of attribute data for National Highways major schemes.

The BIM-based protocol and decision support framework was developed using qualitative data from interviews with ten industry professionals. A survey was created using the interview data and conceptual framework to verify the results reached. The study asked experts in the infrastructure sector specifically highways for their opinions on the framework's components as well as its overall design. The analysis revealed that the proposed conceptual framework was a valid approach to enable real-time collection, validation and handover of attribute data for National Highways major schemes. The framework was approved when no additional revisions were required based on the quantitative and qualitative examination of the Internet survey results.

To demonstrate the practical application of the proposed framework within the context of significant schemes for collecting assets in real-time, a "Proof of Concept" (PoC) was meticulously developed. This PoC encompassed existing and newly produced assets, employing cutting-edge AI tools such as Machine Learning (ML) through TensorFlow and various Computer Vision (CV) software. It is important to note that while the study does not delve deeply into the intricacies of AI, providing sufficient detail for clarity where necessary.

1.10 Organisation of this Thesis

The chapters of this thesis are as follows:

Chapter 1: This chapter provides a summary of the research issue that this thesis addresses. It describes the purpose and goals of the study, the justification for carrying it out, and the methodology used. A brief discussion follows a review of the findings from the primary data study. This thesis also includes a summary of how its many chapters are organised.

Chapter 2: This chapter critically examines the literature pertinent to the study's main topic. These issues include the BIM process and the current state of the uptake of BIM in construction, particularly the highways sector, what statutory standards are available in the highways sector, both government and private, asset management of highways and how this differs from other sectors. The use of drones and other BIM technologies in capturing assets on construction sites is explored. A rationale for combining AI and BIM for safely capturing assets is presented.

Chapter 3: This chapter summarises the research approaches available for this study. It also addresses and supports the methods for gathering data and analysing that data.

Chapter 4: This chapter adopts an approach involving three exploratory case studies. The cases were selected because the researcher was allowed to access the BIM models and project information and, more importantly, access to personnel on those projects. On-site observations were also carried out to get a clear picture of the design and actual site conditions. The duration of the data collection and analysis was from April 2014 to November 2023.

Chapter 5: Here, an industry survey was developed to validate the support framework from the previous chapter. A quantitative analysis of the respondents' industry survey results is presented. Along with explanations for thinking the framework has been verified, qualitative data from open-ended questionnaires supporting or disputing the quantitative data are examined.

Chapter 6: The prototyping chapter presents an overview of the development and the processes that allow the AI software to develop a BIM-based protocol and decision support framework for real-time collection, validation and handover of attribute data for National Highways major schemes. The software solutions used to create the data and image libraries required for the PoC's are discussed. Descriptions of implementing selected scenarios utilising the framework in a live construction environment are discussed.

Chapter 7: The last chapter summarises the research presented in this thesis. It explores this research's contribution to knowledge from an academic and industrial standpoint. The restrictions on this research are considered, as are potential directions for further study.

Chapter Two Literature Review

2.1 Introduction

In the preceding chapter an overview of the issues that underpin the research conducted for this DEng thesis. Delving into the study's aims and objectives, looking into the rationale behind the research endeavours. Additionally, outlining the strategic approach adopted at different stages of the investigation. This chapter embarks on a comprehensive literature review, delving into topics crucial to the thesis. Exploring the intersection of highway regulatory standards with Building Information Modelling (BIM) processes, examine the landscape of available technologies, and scrutinise current asset capture methods. Furthermore, tracing the evolutionary trajectory of BIM within the highways sector.

2.2 BIM as a process & within Infrastructure

A building information model is a computerised depiction of a facility's structural and operating aspects (NBIMS, 2007). As a result, it acts as a shared knowledge repository for data about a facility, providing a solid foundation for decisions made throughout the building's life cycle, beginning with construction (WBGD, 2022). Eastman et al. (2008) define BIM as a modelling technology and related procedures for creating, expressing, and evaluating building models. Also, The UK BIM Framework accept many definitions of BIM are supported by the production, collection, and sharing of shared 3D models and the intelligent, structured data that is connected to them, which is essentially a collaborative effort that adds value over an asset's entire life cycle (BIMTaskGroup, 2016). Furthermore, BIM has also been stated as allowing the contractor to maximise the project's schedule and cost by utilising 5D capabilities via specialised software while allowing for an effective handover of assets to owners for maintenance and operation (Azhar, 2011).

BIM, or Building Information Modelling, is an advanced process for representing design intent in construction projects, encompassing buildings and infrastructure in a comprehensive 3D model. These models are not just visual; they encapsulate crucial data about the project's physical and functional aspects, intricately linked to distinct digital elements within the model. With the increasing complexity of building projects, BIM has garnered significant traction. It serves as a conduit for conveying the designer's vision with precision. This clarity in communication facilitates seamless collaboration among multiple stakeholders, ultimately enhancing construction productivity. According to Clark (2019), leveraging BIM to communicate design intent promises substantial productivity gains in construction.

Shou et al. (2015), noted in a recent comparative review that BIM uses in the building industry have focused on developing and analysing BIM 3D models and gradually using 4D schedule applications and 5D cost planning. In contrast, the BIM uses in infrastructure projects have only reached an average level of implementation in the sector (Shou et al,. 2015).

Chong (2016) also noted that BIM road design and planning simulation was to create efficient transportation management through the proper design and planning of the road. It was also possible to avoid traffic congestion caused by site works during construction. Virtual information from the BIM model could effectively simulate various alternatives based on the surrounding environment.

BIM tools include many software platforms that combine different stakeholders' data within a spatial environment. A BIM model is built of 3D objects. Each object has a unique identifier known as an object ID; the unique object IDs allow BIM users to select an element. Object IDs are also a tool for referencing relationships to other object parameters of model elements store data. These parameters enable stakeholders to add data, especially asset attribute data that communicates information (ADEB-VBA, 2015).

The use of COBie The Construction Operations Building Information Exchange (COBie) serves as a non-proprietary data format for the dissemination of a subset of building information models. Its primary focus is on providing asset data rather than geometric information. COBie was created by a consortium of US public agencies with the aim of enhancing the handover process to building owner-operators. It is commonly presented in the form of a Microsoft Excel spreadsheet, although other spreadsheet applications are also suitable for use (NBS, 2019).

The focus of the strategy is to harness the power of BIM and reusable data to bring about cost reductions and mitigate carbon emissions. COBie has been selected as the preferred format for sharing and exchanging non-graphical data. This decision was influenced by various factors such as cost, availability, and compatibility with future exchange formats, all with the aim of establishing a valuable dataset for built assets (NBS, 2019).

National Highways do not need to use COBie because their asset maintenance database system has a graphical component, and the main database utilises asset loader files based on Microsoft Excel. The graphical aspect of the system uses ESRI shapefiles to indicate the asset's location, which is linked to the Excel file through a unique code.

Chong et al. (2016) also agreed that the application of BIM in infrastructure projects is still gradual, as evidenced by the analysed case studies, which were the first BIM attempts on road projects performed by the top designers or contractors in the respective nations.

2.3 BIM Evolution

BIM has been on an evolutionary journey from the 2008 Bew-Richards maturity model to 2019 and beyond. In contrast, BIM documentation has moved on from the BS1192 suite of documents to the BS EN ISO 19650 set of documents, which is more of a fully integrated information model. The ‘single collaborative model’, where all stakeholders work on one model, is no longer the utopia it was thought to be. The BIM federated model system, where design, construction and maintenance teams use their software and ‘plug into’ a federated model as and when required, is now recommended (RICS, 2020). There is also a proliferation of digital technologies, industry acronyms and terminologies that need to be considered, which may lead to some confusion. The timeline below has now been documented (RICS, 2020).

Various terms have emerged within Building Information Modelling (BIM) in recent years. Fundamentally, they all converge on the same objective: the digital transformation of the built environment through what is often referred to as the fourth industrial revolution. This entails embracing collaborative methodologies, leveraging early contractor involvement, and harnessing digital technologies alongside robust data collection processes. Such advancements aim to streamline the entire lifecycle of assets, from initial design stages to ongoing maintenance. As highlighted by Begic and Galic (2021), these approaches emphasise combining digital technologies with innovative concepts such as the Internet of Things (IoT), advanced data analytics, data-driven manufacturing, and the broader digital economy. This integration is poised to revolutionise planning, constructing, and managing built environments. Moreover, as HM Government (2016) outlined, this digital evolution promises significant cost efficiencies throughout infrastructure projects' production and operational phases.

The industry is in flux with terminologies, acronyms, and digital innovation definitions, and their usage, standards and incorporation into the built environment are in their infancy, with pockets of excellence forging ahead. In contrast, others struggle to keep pace with the change (RICS, 2020). Therefore, BIM and the digitalisation of the built environment need to be an evolutionary rather than a revolutionary process to enable everyone in the sector to deliver the transformational opportunities that digital transformation represents. Digital Engineers must stop searching for a definition of BIM level 3, as it does not exist. Figure 1 shows the RICS definition by showing that many technologies feed into BIM to make it a successful process (RICS, 2020).

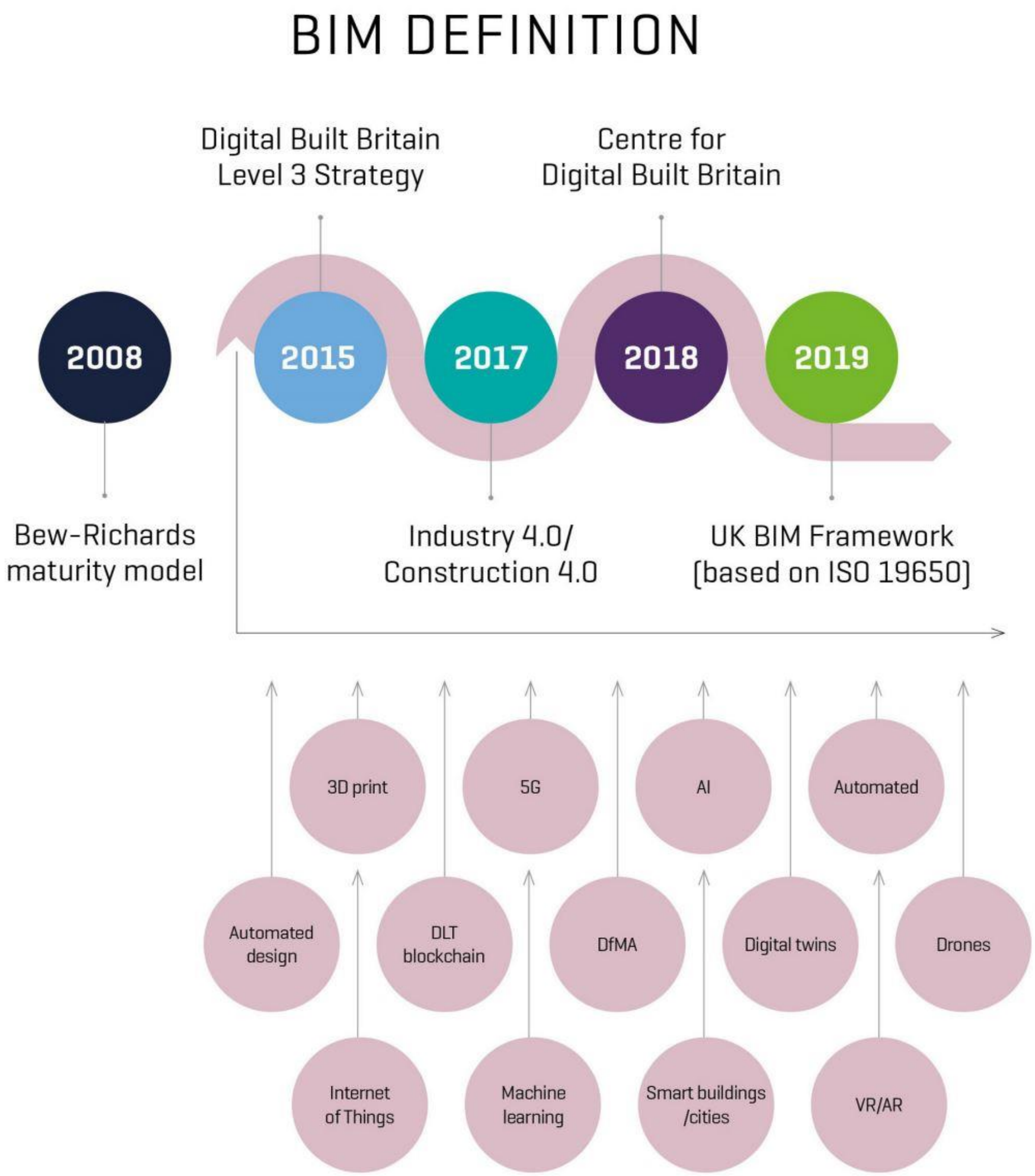


Figure 1 Image showing the Definition of BIM (RICS, 2020)

Contractors need to approach every project with a blank page and implement bespoke requirements from the myriad of technologies in line with the information management framework of BS EN ISO 19650. The customer must also understand that requesting 'BIM' is insufficient because it is not a single notion or object. BIM deployment is an important first step towards digitalising the built environment, but only that: a first step (Alliance, U.K.B.I.M., 2019).

2.4 Current Asset Capture

The desire for rapid reality capture on projects has developed considerably over the last few years to evaluate the environment, record construction progress and integrate with 3D design models. Outcomes have provided tremendous safety benefits, such as in briefings, identifying safety issues with designs and reassessing how processes could be improved. As technology has progressed, several forms of reality capture are available to engineers. Those are laser scanning, surveys on foot, drone surveys, and surveys from a vehicle. Each delivers varying degrees of output but ultimately captures the environment around them (Turnbull, 2018).

As drone usage has become more widespread across highway assets nationally, a new policy was written by Highways England to increase governance over operations for all its drone operations, ensuring that they have been thoroughly assessed in terms of safety and impact upon its customers (England, 2021).

HE schemes generate as-built drawings and accompanying documentation, which are essential components that are subsequently passed on to the dedicated database champions for upload. Each database requires a distinct approach to uploading this information effectively. Initial data capture is facilitated by a third-party entity working on behalf of HE. The data often contains errors, though not consistently saw. Consequently, significant time and financial resources are expended in manually verifying and rectifying these errors (Highways England, 2021).

However, new assets can be added by tracing over as-built drawings within MapCapture software, which is a bolt-on to IAM-IS. Again, as-built drawings drawn with the correct scale and projection can provide this. Unfortunately, the traditional methods are still the best, only because of the capability of HE databases. That is with an early conversation between contractors, service providers and HE. BIM remains of little use without a significant shift in the compatibility of HE databases. Massive investment by HE is required to get the databases working with BIM (Jon, 2021).

While the benefit of accurately obtaining data is beginning to be understood, data must be kept, enhanced and accessible at the handover stage. According to several studies, the costs of inefficiencies due to poor data and information transfer from the design and construction stage into operations and insufficient interoperability across multiple legacy software systems total billions of pounds. This emphasises the need for client organisations to define their information requirements precisely and create an integration strategy to guarantee that data adds value to their everyday operations. As a result, clients frequently maintain and run assets without having enough knowledge of or comprehension of the assets that have been constructed. Conventional data transfer methods have significant drawbacks, such as missed opportunities to improve asset performance and lifespans (Aziz et al., 2018).

2.5 Highways Asset Capturing Technology

A significant challenge for Highways England and its maintainers and contractors that build new highways is collecting necessary asset information per the ADMM (Daly et al.,2020). Notably, a significant amount of highway information, such as location information, especially for linear assets as they require both geospatial (Northing and Eastings) and ground referencing data in the format of chainages; both of these pieces of information need a start and end of each length of the asset to allow maintainers system to geographically position the asset. Therefore, a literature review of different technologies is to evaluate which data collection method can collect those highway features most economically and effectively (Highways England, ADMMv12, 2021).

Collecting highway asset inventory data often incurs high but unknown costs. To date, Highways England and local agencies have used a variety of methods to collect highway inventory data, including field records, photo and video logs, integrated GPS mapping systems, aerial photography both by Plane and Drone, satellite imagery, airborne Light Detection and Ranging (LiDAR), static terrestrial laser scanning, and mobile LiDAR ((Zhou et al., 2013). These methods vary based on the equipment needed, the time required to collect data, and reduced data and costs. Each method has its advantages and limitations. Mainly, vehicle-mounted LiDAR, a relatively new mobile mapping system, can collect a large amount of detailed 3D highway inventory data (point cloud). Still, expensive equipment and significant data reduction efforts are required to collect highway inventory data. Although, a traditional field survey requires less equipment, investment, training, and data manipulation efforts. However, this method is time-consuming and labour-intensive and exposes data collection engineers and surveyors to dangerous highway environments (Jalayer et al., 2014).

Some questions that should be asked when deciding which technology is best are: How accurate does the information that is gathered need to be? Photogrammetry or point cloud? The focus will be on comparing image data captured by drone with LiDAR data captured via a ground-based laser scanner (Barnes, 2018).

According to Barnes (2018), while surveyors have long relied on terrestrial LiDAR for obtaining usable data, advancements in drone photogrammetry technologies now offer increasingly viable alternatives. Historically, the primary hurdle to adopting laser scanning has been its expense. This expense remains a central point of contention in the ongoing photogrammetry versus LiDAR debate despite LiDAR technology becoming more affordable than ever. However, as emphasised by experts on both sides of the debate, the decision should not be solely driven by costs. Instead, the focus should be on understanding the limitations and capabilities of each technology (Barnes, 2018).

2.6 Drone Technology and its uses in Construction

Hubert (2018) claims that when inspecting a large outdoor area, it is generally advisable to utilise a drone. Drone technology can cover a huge region with a single device and a few batteries. The region may be exponentially enlarged with a few teams, but scalability restrictions exist. Such an application is suitable for a site that is hundreds of acres, but it will not be the best approach for an area that's hundreds of miles in size. "Will drone data collection be beneficial?" "How can data automation help gain a competitive advantage?" What Obstacles are in the way (Hubert, 2018). Drones are sometimes the best tool for mapping around a power line or another impediment. Ground-based laser scanners are frequently incapable of doing such operations as effectively as drones" (Hubert, 2018).

The impact of drones on engineering cannot be underestimated, and with predictions of 76,000 drones being in use by 2030, this impact is likely to continue to be substantial (UCEM, 2018). Currently, drones are used in land surveying, creating efficiency savings in labour and time. However, the advantage they bring regarding employees' health and safety is of value when it is too dangerous for humans to gather data. They can capture images for site inspections and topographical surveys. Figure 2 shows images used for surveying. In conjunction with smart apps, they can analyse data in real-time to offer solutions and support faster, more accurate decisions. Surveying drones boast quick data-collection times, excellent positional accuracy and safe operator experience (RICS, 2019).

Figure 2 Image showing burrow pits in inclement weather conditions; these can be measured using appropriate software (Starkey, 2019).

The use of drones has increased over recent years, they have some drawbacks that must be managed and planned. Drone applications are limited by load capacity, airspace regulations, and nuisance and privacy issues, especially when flying over public highways (Turnbull, 2018). Drone capability through surveying and surveillance used to prevent individuals from working in a live environment if necessary and identifying hazards where inaccessible areas occur is pivotal for improving H&S. Particularly critical for site inspections which can then be done from a safe vantage point and data gathered is then linked to the PIM (Project Information Model) through the Common Data Environment (CDE) providing live and regular site updates as agreed within the contractual arrangement, Employer's Information Requirements (EIR) and BIM Execution Plan (BEP). These live and regular updates allow the workforce to be made aware of any risk/hazardous areas before entering the construction site, and the more frequently the updates occur, the more knowledgeable the construction team becomes (Turnbull, 2018).

In late 2020, Highways England took a proactive stance by temporarily suspending drone flights across all highway projects. This measure aimed to prioritise safety while undergoing a meticulous evaluation process to guarantee the utmost safety standards for future operations. Various methodologies were meticulously scrutinised against the GG104 guidelines to pinpoint the safest and most efficient approach for capturing the surroundings of Highways England projects. Consequently, the directive to finalise the 'Use of Drones (UAVs) for Mapping and Visual Surveys' document was issued, mandating its completion before any drone activities could resume on Highways England projects (Highways England, 2021).

2.6.1 Data Collection with UAV

Drone photogrammetry is a powerful tool for gathering asset data for building projects, especially those involving civil engineering, as it enables engineers to do extensive inspections more quickly and affordably. Numerous studies have been conducted on technological advancements that may simultaneously benefit from vast quantities of raw data (big data) collected from satellite images and unmanned aerial vehicles (UAV), along with cutting-edge machine-learning techniques. In this proof of concept, the aim is to provide an approach that fulfils the necessities of rapid asset collection, assessment, planning, exploitation, and management of highway resources by introducing a pipeline for the automatic localisation and classification of highway asset types (safety fencing end terminal (RRET), linear lengths of box or corrugated safety fencing (RRVR) and the recognition of trunk roads (A19), using high-resolution aerial imagery (Saldana et al., 2019).

Meetings occurred with AI/ML engineers to strategise the optimal approach for labelling images intended for machine learning models. The initial drone image has been carefully saved while zoomed-in, ensuring that users can still effectively identify the asset intended for capture. In this proof of concept (PoC), leveraging high-resolution imagery captured by Unmanned Aerial Vehicles (UAVs) in contrast to satellite images, which are prone to distortion in cloudy conditions. Additionally, freely accessible satellite images often exhibit lower resolution compared to UAV imagery (Omar et al., 2018).

2.6.2 Data collection using Photogrammetry with geo-referencing

Millions of people use highways for travel and transportation daily. To safeguard the safety and security of public goods, frequent inspection of road surfaces, point assets, and linear assets is essential. Data collection of roadside and road surface geospatial elements on newly constructed highways is critical to efficiently maintaining highways. Asset Support Contractors (ASCs) need to know the extent of features like curbs and safety fencing (Vehicle Restraint). In some cases where the asset has not been removed and if it has only been partially renewed, they need to know the conditions of these features to budget for and plan activities.

The traditional methods contractors use to capture the extent and quality of roadside point assets and road surface linear assets' geospatial features were manual measurements by project surveyors walking or slowly driving along the highway. While these methods are usually simple to learn, require simple equipment, and provide data of sufficient quality for most decisions and applications, they are also slow and cumbersome, often moving at speeds of no more than a few miles per person per day. (Findley 2011) In addition, the safety aspect of having humans out and near traffic concerns modern safety standards. Also, if these locations are not captured during construction, then night closures would be required, and disruptive traffic control must be provided at a greater cost to the contractor. During the past few years, there have been many advances in how data is collected. Vehicles are often outfitted with diverse sensors that can automatically collect data without post-processing. Data collection from a vehicle moving with traffic means safer and faster data collection, higher data volumes, and more data types, and ultimately eliminates the need for any traffic control (Findley, 2011).

Achieving reliable results with drone imagery hinges on a thorough data collection. Various factors influence the colour properties of a construction scene, including illumination changes, background differences, and the characteristics of the image sensor and viewpoint (Seong et al., 2018). Consequently, the study has created a comprehensive dataset for asset type detection to address these variables. Each image in this dataset showcases multiple assets, facilitating detection across various locations within each image collected from drone imagery.

Traditionally, highway surface inspection is carried out using a human inspector or through a driven vehicle, which is an infrequent and complex process. Advancements in technology and demand for effective and better road monitoring have increased the use of computer vision-based monitoring systems. Various researchers have proposed prototypes of vision-based inspection systems that use cameras mounted on cars to capture data for analysis (Neilands, 1995). This automation has helped achieve cost-effective solutions with a higher performance level, often unattainable through human inspection.

However, with all the latest technology, there seems to be missing the use of combining both drone photogrammetry and video (Saur, Günter Krüger & Wolfgang, 2016) from standard car dashcams; this merged imagery could be overlayered into global user sites like 'Google Maps'. For Contractors of Highways, this, in turn, can be amalgamated with construction asset drawings and area maintenance chart drawings. This ability to have almost real-time asset capture will enable handover to ASCs to be faster and much more reliable. The data for this study was collated by using individual GeoTIFFs from drone flights that look straight down onto the site; this gives the best quality needed for viewing assets. The drone flights create many images that must be checked to see if they have any assets within the image boundary.

2.7 AI and Machine Learning

The behaviours that AI systems often exhibit are planning, learning, reasoning, the capacity to solve problems, the ability to represent knowledge, the perception of motion and change, the capacity to control objects, and the extent of social intelligence and creativity (Konar, 2018). Artificial intelligence (AI) is employed in various applications, including online shopping recommendations, voice recognition in virtual assistants like Amazon's Alexa and Apple's Siri, spam detection, and credit card fraud detection (Marr & Ward, 2019).

Whilst these applications are outside the asset data collection and management field, there are many potential applications within highways. These include the use of AI to auto recognise defects from CCTV inspections and standardise pipe condition grading; organisations benefiting from improved search and discovery of data, allowing people to extract value from their data more efficiently, and allowing AI software and machine learning to undertake time-consuming manual checks of data against data attribute schemas and field-collected data. (Burchett. S, 2020)

Traditional physical inspection techniques, such as visual inspections, remain prevalent in many industries. Nonetheless, with the rapid advancement of technology, the utilisation of drones for asset data collection is experiencing notable growth. Drones offer versatile solutions, including conducting aerial surveys of construction zones or generating intricate 3D models and thermal maps (Marr, 2019).

Infrastructure and buildings are becoming more intelligent thanks to sensors, connected assets and AI developments (Baduge et al., 2022). A maintainer can collect valuable data on assets, energy and people that can be used to predict performance and maintenance and, ultimately, improve the future performance of built environments. AI and machine learning are also emerging in pockets of excellence in cost estimating and programme forecasting/delay analysis. Technological advances in data analytics have enabled algorithms to be developed to allow machine learning to have predictive capability. For example, historical project programme data is collected and fed into the system, enabling the algorithm to learn from past projects, even to the extent of planned programmes versus actual, to give confidence in proposed programmes and highlight areas of high risk. This means informed decisions can be made in any potential risk or mitigation measures. (Amratia, 2019).

Automating asset capturing and real-time asset validation is essential to a construction partner's ability to deliver a BIM lead maintenance phase of highways sector projects. According to recent construction reviews (RICS 2019), the adoption of BIM is still very low among highway maintenance personnel, and the lack of research in this sector is still pronounced. Figure 3 image shows the literature review that has been used to understand what research has been done in the area of 'real-time collection, validation and handover of attribute data for Highways England Major schemes' has had to be broken into different themes to help get a picture of what has been done concerning this.

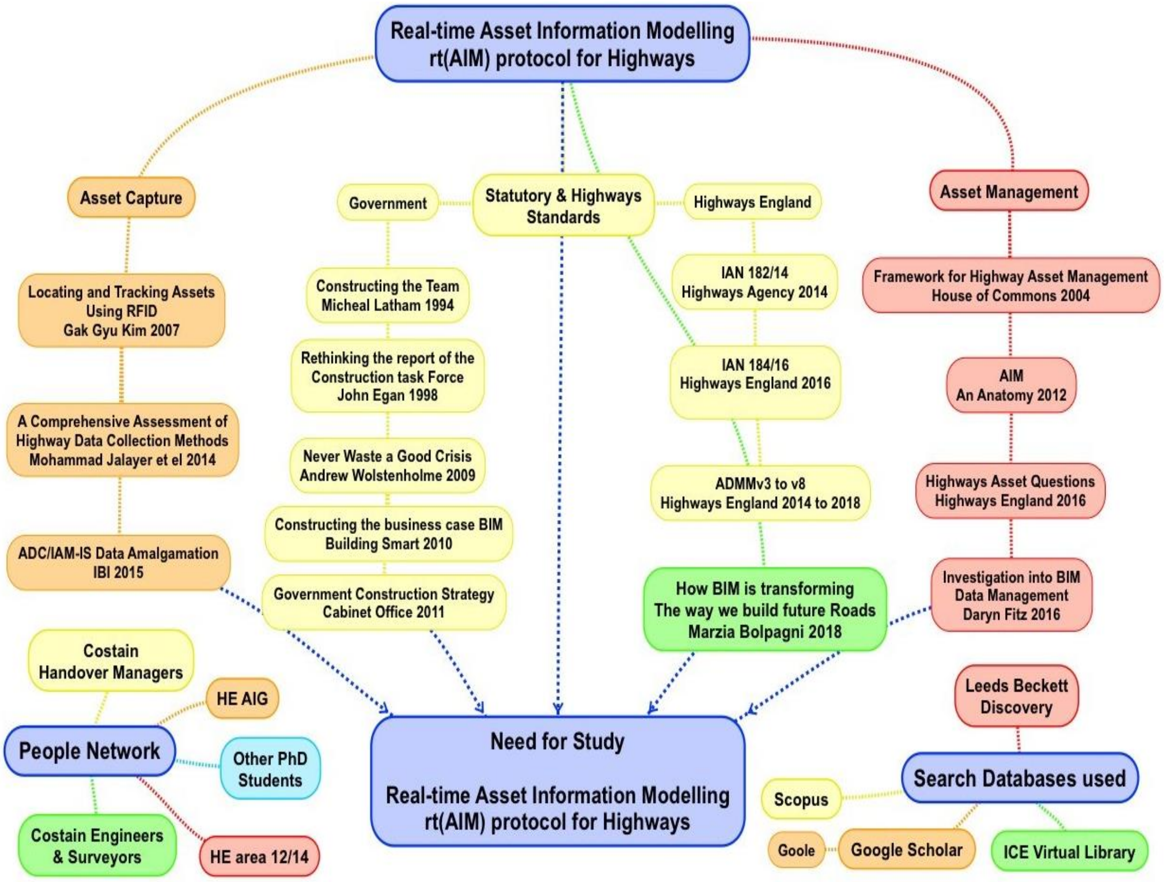


Figure 3 Image showing Literature, people, and databases searched for this paper, (Starkey, 2019).

2.8 Summary

This chapter provided an overview of difficulties with real-time asset capture of highway assets, technology and its applications in construction, notably the use of drones in construction and safety, the usage of BIM, the evolution of BIM, and its applications in the infrastructure sector. The usage of BIM in asset-capturing applications in construction was examined. The industry's developing landscape of digital visualisations was described. The existing literature identifies that emerging technologies have a beneficial capacity to improve current methods of construction projects to capture assets. However, on the other hand, reluctance to adopt an initial investment prevents newer ways of delivering construction projects whereby traditional methods are satisfactory. The next chapter explores this study's philosophical and methodological options and the relevant explanations for adopting such decisions.

Chapter Three Methodology

3.1 Introduction

Chapter two critically reviews the literature on issues relevant to developing a BIM-based protocol and decision support framework for real-time collection, validation and handover of attribute data for Highways England major schemes. The review provided a foundation that this research is based on literature that analysed the state of practice for asset information and the potential of BIM implementation, strategies for capturing real-time asset information to facilitate life cycle asset management and effective strategy and protocol for capturing highway asset information. This chapter reviews the design and methodological aspects used for this study. The chapter also discusses the study design and methodology's rationale, appropriateness, and usefulness. The rationale for this study and the data collecting and analytic methodologies used are described.

3.2 Research Philosophy

Saunders et al. (2009) delved into the intricacies of research philosophy, highlighting the diverse perspectives that inform its selection. As Creswell (2007) articulated, the concept of' Research Philosophy' delves into the evolution and essence of knowledge. Moreover, as Collins (2010) points out, the chosen research philosophy shapes the researcher's fundamental preconceptions about the world. The assumptions intertwined with a chosen research philosophy lay the groundwork for the research approach, as Creswell (2007) emphasised. A positivist approach, often quantitative in nature, is frequently employed in rigorous scientific inquiry. Within this paradigm, adherents assert the existence of an objective reality independent of human subjectivity. Näslund (2002) elucidates that from the positivist viewpoint, new information is integrated into existing knowledge through a methodical and cumulative process predicated on removing erroneous assumptions.

According to Denzin and Lincoln (2011), qualitative research is rapidly replacing quantitative research, particularly in social research. These variables differ by industry, location, and, most significantly, individual. A pragmatism philosophy points to an inquiry process built around combining the strengths of qualitative and quantitative methods (Morgan, 2014). This research uses a phenomenological strategy to comprehend different approaches to gathering asset data on-site and their perspectives on automating specific portions of operations. As a result, for the sake of this study, a pragmatism philosophy is used. Ontology and epistemology are two fields of philosophical decisions, according to Ballantyne (2008). Bryman (2012) defines 'Ontology' in the context of social research as the study of reality in relation to social entities and 'Epistemology' as the evaluation of the acceptability of knowledge.

3.3 Research Method

Research can be classified as quantitative or qualitative; it is quantitative if the data collected can be measured or collated as numbers. Quantitative reasoning is based on the philosophy of rationalism and, as such, adheres to rigid and predetermined procedures (Kumar, 2010). However, some information gathered as part of the research cannot be reduced to numbers, such as participant beliefs, opinions, behaviours, experiences, and attitudes; these are recorded as qualities rather than quantities, and thus, this type of data collection is referred to as qualitative (Walliman, 2010; Bandolier, 2007).

While quantitative studies are frequently encountered in research, it is essential to note the specific guidelines and regulations governing them. Researchers often find themselves well-versed in the systematic techniques characteristic of quantitative research. However, embracing qualitative and transformative approaches to inquiry, which have the potential to challenge established paradigms, may evoke discomfort among certain individuals (Creswell, 2014).

Contrarily, qualitative methodologies give freedom for creativity and a greater degree of adherence to the frameworks created by the researcher. They permit more imaginative writing in the literary tradition, a style that some people may want to utilise (Creswell, 2014). Qualitative data is derived from the philosophy of empiricism and follows a less structured, open and more flexible approach to inquiry. Qualitative techniques allow the researcher to explore rather than diversify (Kumar, 2018). Careful consideration has been given, and the primary research to be used is a qualitative case study, an in-depth investigation of a small number of events (Creswell, 2014); this allows the focus of the research to be on Highways England's major schemes and the event of the 'Handover' of road surface asset attribute data by BIM teams and field engineers.

The researcher's approach aligns with recognised principles in epistemology and ontology, as Bryman (2012) outlined, ensuring a solid foundation for the study. This deliberate alignment paves the way for selecting an appropriate research strategy, be it quantitative, qualitative, or a blend of both, as Creswell (2013) advocates. In Creswell's terms, the research design serves as the blueprint, integrating philosophical underpinnings, inquiry methodologies, and specific techniques. Drawing from both Creswell (2013) and Bryman (2012), the chosen framework embraces a mixed-methods approach, recognised for its versatility and ability to capture diverse perspectives. By integrating qualitative and quantitative methodologies into the data collection process, this approach leverages the strengths inherent in each, thereby facilitating triangulation (Rowa-Dewar, 2010; Greener, 2008). This holistic approach enriches the research endeavour, comprehensively exploring the subject matter.

3.4 Research Strategy

The research strategy has been referred to as the instruments used to carry out the research; research methods utilised include 'experiment', 'survey', 'action research', 'grounded theory', 'archival research', and 'case study'. Each strategy has its own set of rules that are accepted as standard operating procedures for that strategy (Saunders et al., 2009).

3.4.1 Experimental

Numerous individuals believe that an 'experiment' stands as the pinnacle of rigorous scientific inquiry because it aims to systematically eliminate alternative explanations for observed phenomena (Trochim, 2006). This rigorous pursuit is achieved by randomly allocating participants into experimental and control groups, either by administering treatment to one group and not to another or by randomly assigning different treatments to distinct groups (Creswell, 2007). The experimental research paradigm is closely associated with quantitative methodologies and is commonly employed within positivist research frameworks.

3.4.2 Survey

A survey is a method for generalising conclusions based on data from a sample group. As a result, a survey strategy entails self-completion of a questionnaire or a structured interview to collect data that can discover patterns of correlations between variables (Bryman, 2012). Survey research, which involves input from a questionnaire or a lengthy interview, is a frequent approach in applied social research (Trochim, 2006). Data can be collected from a self-completion questionnaire, which can be conducted under supervision, by mail, or, more recently, via email or the Internet. A face-to-face or telephone interview can also be used to collect survey data. A representative sample that correctly reflects the population is critical to the validity of the survey technique's results (Bryman, 2012).

3.4.3 Action Research

The term "action research" embodies a collaborative approach between a researcher and a stakeholder to pinpoint and tackle an issue (Bryman, 2012). Those seeking deeper insights into organisational practices to enhance interpersonal dynamics in social contexts engage in action research, a methodology that gained prominence in the 1980s and 1990s (McNiff & Whitehead, 2001). Widely practised in disciplines like business management, this methodology involves the active involvement of individuals within the organisation to diagnose problems and devise viable solutions, emphasising a departure from imposing preconceived remedies (Bryman, 2012).

3.4.4 Grounded Theory

Glaser and Strauss coined the phrase "Grounded Theory" in 1967 (Glaser & Strauss, 2009). Grounded theory entails developing and refining a theory with qualitative evidence (Bryman, 2012). The construction of theory through data is a major component in grounded theory, and as such, data collection and analysis occur concurrently (Oktay, 2012). Data is regularly collected and processed to develop the theory until' saturation' occurs, at which point no new themes emerge from the data (Oktay, 2012).

3.4.5 Ethnographic Research

In 'Ethnographic Research,' the researcher spends a lengthy amount of time immersed in the social lives of the people being investigated and derives findings based on participant observation (Bryman, 2012). Ethnographic research is qualitative and employs various methods, including observation, informal interviews, and informal contacts such as e-mail and letters (Szewczak & Snodgrass, 2002).

3.4.6 Archival Research

Archival research suggests that the researcher uses data from existing archive documents that were not collected by the researcher (White, 2012). According to Bryman (2012), this type of study is 'unobtrusive' since the researcher is not involved in monitoring the interactions or events being examined. Archival research includes the use of government-collected data, such as census data.

Archival research methods encompass a wide range of activities used to aid in analysing documents and textual information produced by and about companies, frequently as instruments to support other research strategies (field methods, survey methods). As a result, archiving approaches can also be used to analyse digital texts such as electronic databases, emails, and web pages (Ventresca et al., 2001). This study highlighted the use of documents from workshops and meetings that have taken place since BIM was mandated in the construction sector. Data collection from project documents or artefacts such as minutes of meetings and action lists, along with team interviews of clients, partners and third-party software developers. This helps with the first objective,' To analyse the state of practice for asset information and the potential of BIM implementation.

3.4.7 Case Study

A case refers to an individual, a subject, a group, or an organisation (Corbin & Strauss, 2008). Case study research spans various objectives, ranging from descriptive to explanatory or exploratory, and may involve the examination of a single instance or multiple cases. Descriptive case studies elucidate phenomena or processes, while explanatory case studies are often grounded in theory and employed to formulate hypotheses within broader research endeavours (Fellows

& Liu, 2009). On the other hand, exploratory case studies are frequently utilised to delve into hypotheses and draw reasoned conclusions (Yin, 2009).

According to Yin (2009), mixed-method research forces the same questions to be addressed while enabling the gathering of complementary data and the execution of counterpart analyses. According to Yin (2009), this strategy enables the researcher to assemble a stronger chain of evidence than is possible when using a single method. A mixed method research strategy is adopted as the overall approach to conduct this research; the following strategy tools are chosen for this thesis.

3.5 Adopted Research Strategies

The strategies employed in this thesis are substantiated by examining various approaches outlined by Saunders et al. (2009). Within their framework, 'Qualitative,' 'Quantitative,' and 'Mixed-Method' methodologies emerge as viable options for research endeavours. The selection of a methodology hinges on the nature of the research and the data acquisition process. Frequently, a blended approach, integrating qualitative and quantitative methods, is preferred. Creswell (2013) asserts that such a fusion facilitates result convergence, a concept epitomised by the triangulation process.

Survey research is a strategy in which a researcher asks an entire group of individuals a planned set of questions. This is particularly effective when a researcher wants to describe or explain the features of a group (Hancock et al., 2021). In order to prepare for a more focused, in-depth study using time-consuming methods like semi-structured interviews or field research, this method is also useful for quickly gaining general information about the population of interest in a particular inquiry (Sutrisna & Abbott, 2017). In this situation, a survey might assist a researcher in pinpointing particular people or places to interview for more information.

Because surveys are standardised, and the same questions, phrased the same way, are posed to participants, survey research tends to be a dependable method of investigation. Qualitative interviewing, for example, does not have the same level of consistency as a quantitative survey. A poorly phrased question can lead to respondents misinterpreting its meaning, lowering the question's reliability. One strength of survey methodology is its ability to produce reliable results, assuming well-designed questions and questionnaires (Blackstone, 2018).

Survey research is a quantitative procedure that can be done in person, over the phone, via mail, or online. It can also be long or short. Although survey data are often analysed using statistics, many questions lend themselves to more qualitative analysis. To gather information that can be used to identify patterns of relationships between variables, a "survey" approach is thus one in which a questionnaire or semi-structured interview is self-completed (Bryman, 2012).

In applied social research, survey research stands out as a widely adopted method, drawing on responses from questionnaires or in-depth interviews (Trochim et al., 2006). Utilising a self-completion questionnaire, distributed under supervision, via mail, or in modern times, through email or the Internet, serves as a reliable means of collecting pertinent information. Alternatively, conducting telephone or in-person interviews offers another avenue for gathering survey data. It is crucial to note that the validity of survey outcomes hinges upon securing a representative sample that faithfully mirrors the broader population (Bryman, 2012).

3.6 Case Study used in the Research

The case study has been regarded as an essential research strategy and remains controversial as a research methodology despite its widespread use in various fields of study. Many academics have expressed their pessimistic opinions by dismissing case studies as a lessor option that might be acceptable as an exploratory precursor to "more scientific" experiments or surveys or simply as a complement to such "more scientific" approaches, but which has questionable value as a stand-alone approach (Robson, 2002).

Case studies serve as a valuable method for data collection within research. They effectively encourage participant involvement and support, as individuals are directly engaged in providing information through methods such as interviews and focus groups. This approach allows participants to provide their unique interpretations of events, while also feeling recognized as integral contributors to the research process (Marrelli, 2005).

Case study research is an empirical enquiry that analyses a current phenomenon in depth and the context of real-world events, mainly when the distinction between the phenomenon and environment is unclear, according to Yin (2009). According to Corbin and Strauss (2008), a case can be characterised as a single person, subject, group, or organisation. Case study research can be classified as "descriptive," "explanatory," or "exploratory" in nature and may involve the investigation of one or more cases. A descriptive case study is used to explain a phenomenon or a process as opposed to an explanatory case study, which is frequently theory-driven and may be used to establish a hypothesis in a significant research effort (Fellows & Liu, 2009). In order to test a hypothesis and arrive at logical conclusions, an exploratory case study is typically employed (Yin, 2009).

Utilising four industry case studies, including an area maintenance team (Area 12) and one of Highways England's ASC (Asset Support Contractor), area teams will be included in developing this framework. The ASC team provides the area O&M requirements while managing costs, planning and scheduling works, and commencing new road assets. Other case studies include the A160 Improvement scheme, M1J28-35a, M1J23a-25, and A19 TaDL scheme.

3.6.1 The A160 Scheme

Delving into this scheme with meticulous attention, this project marked an early foray into the BIM process by HE, positioning itself as a pioneer. The handover process necessitated a dual approach: traditional delivery and integration of BIM methodologies for asset attribute data collection. Within a tight timeline of three months from the road's inauguration, the ASC team needed to access the asset data for seamless new road maintenance. The case study will explore the factors contributing to the 18-month duration of integrating the asset data into HE's new IAM-IS database.

3.6.2 M1 J28-35a

The case study for this scheme, which the area team was the same as the A160, suffered similar difficulties with the asset attribute data handover. Using lessons learned from the A160 construction team, the case study will investigate how the data handover was improved and understand how time had been reduced in collating the information.

3.6.3 M1 J23a-25

This project area maintainers where different from the previous case studies; the ASC team also used a different database called 'CONFIRM'. This has a different layout to the IAM-IS database, therefore understanding what this meant to the handover needs to be investigated. Also, the construction BIM team started the handover before the as-built drawings were produced, allowing more time to collate the asset attribute data. However, it was held up by confirmation of the actual location of the built asset. Each case study will also look at how data collection for handover was achieved and what the resultant timescales of handover compliance had been met.

3.6.4 The A19 Scheme

The construction of this scheme is over the period of this research study, therefore it will be able to take into account what has been learned from the previous 3 case studies and engage with a trial study of capturing images of assets that are newly built, this will be done either with drone images or images from site vehicle video cams, the most appropriate approach will be investigated as part of the trial. This will allow for the real-time asset information capture with the output being of shapefiles (output required by the IAN182) that will, in turn, form a framework for the rtAIM. A trial was undertaken on the A19 scheme using machine learning and will be done working with an industry partner; funds for the trial were agreed. Working with the construction and engineering team, testing new processes agreed upon from lessons learned on previous schemes.

3.7 Population and Sampling

Sampling is a strategy, procedure, or technology researchers use to systematically pick a comparatively smaller number of representative items or individuals, a subset from a population, to act as participants for observation or experimentation per the study's objectives. Researchers typically use sampling because it is hard to test every individual in the population that pertains to the study topic. Despite being a subset, it is typical of the population and appropriate for study in terms of cost, convenience, and time. However, every researcher must remember that the ideal case is to examine all persons to achieve reliable, valid, and accurate results. When testing all individuals is unfeasible, thus rely on sampling approaches (Sharma, 2017).

The primary objective of this research is to develop a comprehensive framework protocol that enables real-time recording of assets on roadways. Consequently, the study focuses on engaging stakeholders within the roadways sector as its primary demographic. Eligibility for participation in the study extends to individuals whose roles align with or are affiliated with stakeholders, consultancies, or partners involved in receiving asset data. To ensure a well-rounded representation, the study employs a critical sampling technique for interviews, as outlined by Blakstad (2009), which necessitates the inclusion of professionals involved in the handover delivery process and maintenance management.

The population for this study is very small about thirty, just a few professionals work with data regularly; these are Highways England maintenance managers and data analysts for asset information transfer. Purposeful sampling is a series of techniques that rely on the researcher's judgement when choosing the individuals to study. Study designs can include multiple phases, with each phase building on the one before it. In such cases, several sample strategies could be needed at each stage. Purposeful sampling is advantageous since it gives the researcher access to various non-probability sampling approaches. Before using an expert sample technique to analyse further specific concerns, critical case sampling may be used to determine whether a phenomenon is worth further investigation (Sharma, 2017).

3.8 Methods of Data Collection

According to Saunders et al. (2009), gathering and analysing data is the most crucial part of conducting research. Saunders et al. (2009) included 'Sampling', described in the preceding section, 'Secondary Data,' and 'Primary Data' as three of the major problems related to data gathering. These topics are further developed and explored in this part within the framework of the study.

3.8.1 Secondary Data

"Secondary data" encompasses pre-existing data utilised in research endeavours. Such data is often collected by researchers pursuing separate or tangentially related objectives compared to the present study (Saunders et al., 2009). It may comprise raw or synthesised information from prior studies, organisational archives such as meeting minutes, and governmental repositories containing demographic, sociological, and economic metrics. Leveraging secondary data offers researchers the advantage of conducting investigations discreetly, often with reduced resource requirements, thereby facilitating the implementation of long-term studies (Saunders et al., 2009).

The drawbacks of depending on secondary data, however, include the potential that the information is not legitimate nor reliable, that access may be challenging or expensive, that the information may have been gathered for a different original purpose, and that it may not be able to address the issues at hand thoroughly. This exploratory study intends to use BIM and AI technology to influence the capture of assets on road projects.

3.8.2 Primary Data

Information the researcher has personally acquired is called "Primary Data." Saunders et al. (2009) list three methods of gathering primary data: "observation," "Semi-Structured, In-Depth and Group Interviews," and "Questionnaires."

3.8.3 Primary Data Collection through Observation

A typical method of gathering data for social research is watching people in their natural settings (Sapsford & Jupp, 2006). The benefits of observation include allowing researchers to directly acquire data on the environment and human behaviour and helping them to spot problems. The researcher can gain information on subjects who cannot directly engage in the study, such as newborns and small children, by asking questions regarding the surroundings and behaviour of issues that may be taken for granted and are not elicited by other data collecting techniques (Sapsford & Jupp, 2006). However, there are drawbacks to using observations to gather data, including the inability to observe the environment or behaviour in question in person, participants' subliminal behaviour changes during the observation process, observer bias leading to incorrect interpretation of what is being observed, and the lengthy nature of observation (Sapsford & Jupp, 2006).

Saunders et al. (2009) introduce two distinct methods of gathering observational data: 'Participant Observation' and 'Structured Observation'. Rooted in qualitative research traditions with anthropological and ethnographic foundations, participant observation aims to grasp the behaviours and interactions of the observed individuals. In this approach, the observer may participate actively in the observed activities while sometimes concealing their role from those being observed. In contrast, 'Structured Observation' leans towards a more quantitative perspective, focusing on tallying the occurrences of specific phenomena or behaviours rather than delving into the underlying reasons behind them. Archival research serves as the primary data source for this study. Archival materials are primary sources as products of firsthand experiences or observations by participants or witnesses. These materials, often called "records" (Kings College, 2023), provide a direct snapshot of events and thus offer distinct insights into the subject matter.

3.9 Interviews

Using qualitative interviews, the Interviewees are given time to expand their views of their experiences and feelings. To be as receptive and adaptive as possible to the interviewee's personality and priorities, an individual interview is conducted in an "Informal, Conversational Interview" where no predefined questions are asked (Valenzuela & Shrivastava, 2014).

In group interviews, the strategy aims to guarantee that the same broad categories of data are gathered from each interviewee; this improves focus relative to the conversational strategy while still allowing for some flexibility and adaptation in gathering the information from the interviewee (Valenzuela & Shrivastava, 2014 p4).

Qualitative research employs diverse methodologies to explore individuals within their work environments. These encompass interviews, audio-visual recordings, scrutiny of documents, and direct observations (Creswell, 2014). While observation offers the invaluable advantage of first-hand immersion in the context being studied, it presents a notable challenge in ensuring accurate recording. Conversely, documents and audio-visual materials may provide first-hand perspectives, yet difficulties interpreting these accounts can impede a comprehensive understanding of a given issue (Lahlou, 2011). Interviews, on the other hand, grant researchers a degree of control over the information obtained. However, they come with their own set of challenges, particularly in extracting sensitive data. Furthermore, recording and transcribing interviews adds another layer of complexity. Semi-structured interviews offer a less rigid format than structured interviews, as they allow for some flexibility in questioning without sacrificing the overall coherence of the inquiry (Flannery et al., 2019).

In group interviews, the strategy aims to guarantee that the same broad categories of data are gathered from each interviewee; this improves focus relative to the conversational strategy while still allowing for some flexibility and adaptation in compiling the information from the interviewee (Valenzuela & Shrivastava, 2014).

Qualitative semi-structured interviews are one of the most utilised data collection strategies in research. They are useful because they allow researchers to investigate subjective perspectives and compile detailed reports of people's experiences. An interview schedule is typically employed, allowing the researcher to address a specific topic while allowing the respondent to speak in their own words and explore issues and themes that are significant and relevant to them (Evans & Lewis, 2017). The interviews were carried out by sending out the predefined set of questions related to each objective stated in section 1.5 of this thesis to each participant, including documents that set out the university's requirements for these types of interviews. The sending out of the questions beforehand gave the participants time to think about their answers; all the interviewees were experienced professionals in a very limited pool of knowledgeable individuals.

3.10 Data Collection Accuracy

Drone data presents various pre-processing challenges, including rectification, ground sample distance calculation, and video frame extraction. Once still images are acquired, they undergo resizing and cropping using a script within the user software, such as Bentleys ContextCapture, chosen for its accessibility. Subsequent processing steps are tailored to meet specific project objectives, often involving noise removal through smoothing techniques. The output quality varies across images captured under different weather conditions and with dashcam video and GPS unit capabilities. As Wierzbicki et al. (2015) noted, these factors collectively influence the resultant data.

Therefore, this means using drone imagery (accuracy of +/_50mm) and 2d model of construction drawings to place the asset geospatially and use video imagery to prove the asset visually. The images in Figure 4 show how the accuracy differs between drone imagery referenced using several ground control points (GCP) and Video imagery using GPS. Whilst an inaccuracy of 16m with the GPS-located video seems unusable, the captured assets are much more spaced out; for instance, an end terminal at the start of some safety fencing is rarely repeated with, say within 50m.

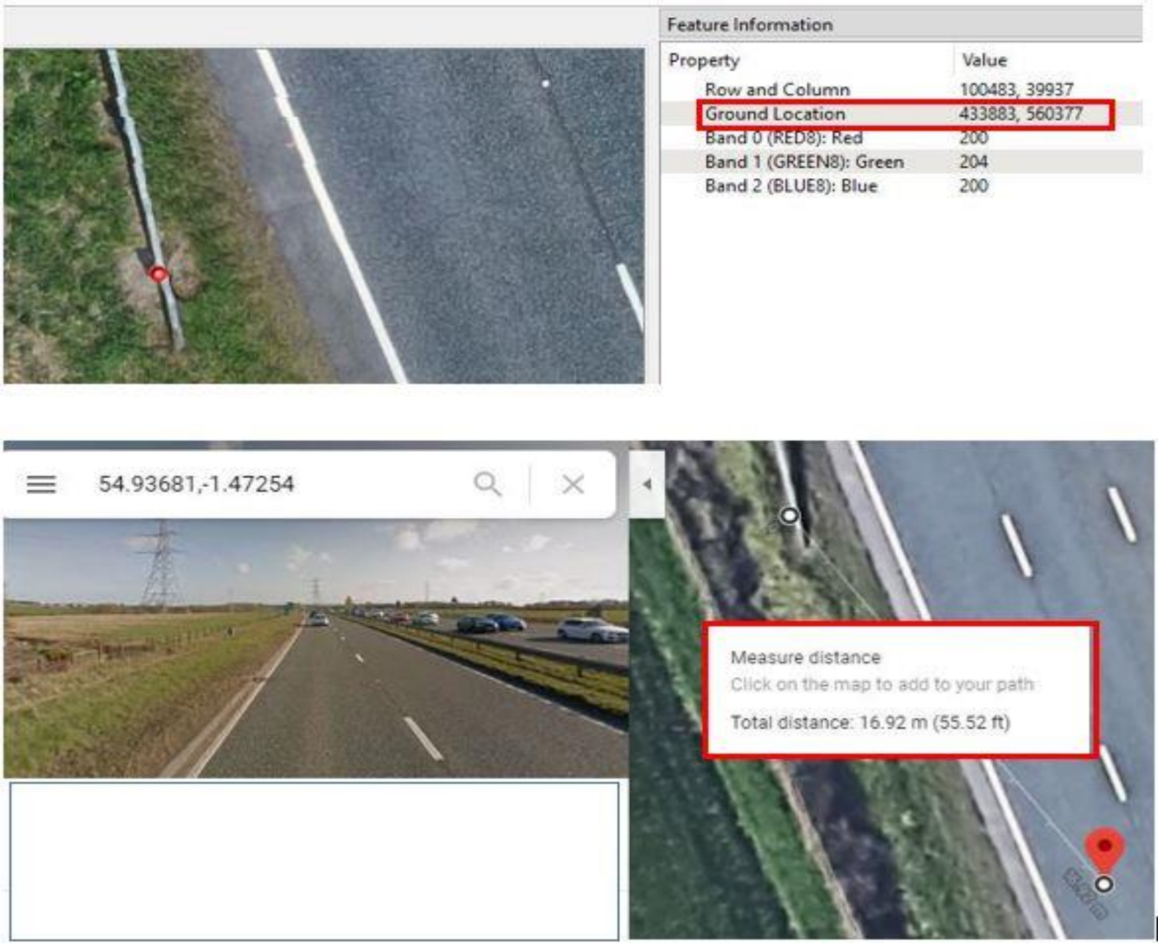


Figure 4 shows how drones (top) and dashcams (bottom) differ for positional accuracy (Starkey, 2020).

3.11 Methods of Data Analysis

The development of machine learning approaches provides researchers with a conceptual alternative to solve problems in the mentioned domains without predefining the rules for a specific task. Instead, models can learn the underlying features emerging from extensive data. Convolutional Neural Networks (CNN) are one of the most well-known methods in image processing and computer vision. The algorithm is based on an end-to-end learning process, from raw data to semantic labels, which is an essential advantage compared to previous state-of-the-art methods (Nogueira et al., 2017).

Given realistic limits, the data collected should be chosen based on the investigation's required outputs. Especially for new researchers, to plunge into the most complex statistical techniques they can find, often using computer packages, only for the data analysis to be confusing and misunderstood by the researcher (Fellows & Liu, 2015).

For qualitative research that uses methods such as case studies and interviews of individuals and groups of people from organisations, Thematic Analysis could be used; one of the hallmarks of this form of analysis is its flexibility - not just theoretical flexibility, but flexibility in terms of the research question, sample size and constitution, data collection method, and approaches to m This suggests that, unlike many qualitative procedures, it is not constrained by a particular theoretical or epistemological attitude. This gives it much versatility, which is great given the wide range of investigations (Maguire, 2017).

Thematic analysis offers simple and systematic methods for deriving codes and themes from qualitative data. Yi (2018) defines codes as the smallest units of analysis that capture intriguing data elements that are (possibly) relevant to the research subject. Codes serve as the foundation for themes, which are (bigger) patterns of meaning supported by a fundamental organising notion. During analysis, the complete data collection, the coded extracts of data are been analysed, and the analysis of the data to be produce are constantly switched back and forth (Braun & Clark, 2013).

The thematic analysis outlines an iterative procedure for transforming jumbled data into a map of the key themes. Thematic analysis was used for the semi-structured interviews and the transcribed recordings of those interviews. There are six steps in the procedure:

1. Understand the data.
2. Assign preliminary codes to the data describing the content.
3. Search for patterns and themes in codes across the different interviews.
4. Review themes.
5. Define and name themes.
6. Produce the report (Mortensen, 2018).

Saunders et al. (2009) state that quantitative data must be examined using diagrams and statistics since it attempts to derive meaning from numerical and standardised data. The quantitative analysis of the study will be based on Likert scale data from an Internet poll. Because the survey data will include open-ended questions, qualitative analysis will be performed to supplement or refute the quantitative analysis of the Likert data, which will be performed primarily using quantitative methods. The conceptual framework, which will be developed from the qualitative analysis of the interview data, should be able to be validated and/or modified as a result of the analysis from the Internet survey. The scale of measurement for the study is the Likert scale. The Likert scale was created to measure attitude, opinion, and belief by asking people to indicate how much they agree with a statement or topic. It is named after its creator, Rensis Likert (Joshi et al,. 2015)

Saunders et al. (2009) illustrate that numerical data from surveys can be effectively assessed through descriptive or inferential statistics. Descriptive statistics illuminate both the central tendency and dispersion of the data, providing a comprehensive overview. Central tendency, as elucidated by Saunders et al. (2009), offers insights into the prevalent values within the dataset, offering a holistic understanding. Conversely, inferential statistics delve deeper, scrutinising correlations, differences, and trends beyond the central tendency. By employing inferential statistics, researchers can assess the strength and significance of relationships between variables, enhancing the depth of analysis (Saunders et al., 2009).

3.12 Ethics

Researchers in qualitative studies bear a tremendous deal of responsibility and play a variety of functions. It is believed that qualitative research that delves deeply into difficult themes can expose both participants and researchers to emotional and other hazards. Clear guidelines for coping with distress should be in place that allows people involved in the research can use them, if necessary, as it is not simple to forecast what topics will cause difficulty (Creswell, 1998). Therefore, the qualitative method is utilised to explain, clarify and elaborate on the meanings of different aspects of the human life experience; researchers can interpret people's experiences because they are involved in human activities. The 'no harm' concept to participants should be considered by researchers, who should be mindful of the possible harm that may be imposed on study subjects (Sanjari et al., 2014).

Selecting a research problem is of paramount importance as it ensures relevance and significance not only to the individuals under study but also to a wider audience beyond the researcher. To accomplish this, proposal developers can undertake pilot projects, conduct needs assessments, or engage in informal discussions with participants. These actions foster trust and respect, enabling researchers to identify any instances of potential marginalisation of participants throughout the study's progression (Creswell, 2018).

Ethical and regulatory issues do not finish once the data collection is completed. The need to have a responsibility to produce certain outputs, and the responsibilities concerning the way that subjects and participants are portrayed in the way that the report is written up (Research Ethics Guidebook, Webpage, 2019).

Some ways to address the ethical issue are: -

- Conduct a needs assessment or an informal talk regarding participants' needs.

- Tell participants that they do not have to sign the form.
- Learn about the cultural, religious, gender, and other diversity that must be respected.
- Obtain appropriate consent
- Build trust and convey the extent of anticipated disruption in gaining access
- Discuss the purpose of the study and how data will be used
- Avoid leading questions. Withhold sharing personal impressions. Avoid disclosing sensitive information. Involve participants as collaborators
- Report honestly (Creswell, 2014)

3.12.1 Informed Content

One of the guiding principles of research ethics is informed consent. Its goal is to ensure that human participants can participate in research freely (voluntarily), that they are fully informed of what it entails for them to take part, and that they express consent before participating. Before a participant participates in the study, their consent must be obtained (prospectively). To be considered informed, the participant must have a fundamental comprehension of the research and what they are consenting to (Oxford Uni Webpage, 2019).

Oral consent is used due to knowing the participants and the randomness of chatting with people on live sites; most engineers would rather talk about experiences and issues in a relaxed and free-flowing environment, therefore having to deal with written consent forms would discourage participation. Having to either record discussions or take a set of notes, which will then be copied to the participant for clarification of the discussion.

3.12.2 Participants are not harmed

Ethics committees expect a thorough assessment of potential harm to research subjects or others within the study. While recognising that certain harms, such as anguish, shame, or anxiety, are subjective and challenging to predict, the requirement to consider all conceivable risks associated with the research. The level and potential severity of harm must align with the potential benefits of the research. Studies presenting a high risk of harm or significant danger to individuals must undergo meticulous evaluation by the researcher and the ethics committee before approval (Cambridge University Webpage, 2019).

Participants will be engaged only if they are willing and happy to take part; most engineers openly discuss issues that affect or improve their working day. Careful consideration will be given to ensure interviews will be with members of staff or consultants involved in the day-to-day processes of capturing data and users who are using that information to process maintenance on highway schemes. Engineers will not be asked to capture asset information that has not had the customary risk assessed. Surveying engineers who take part are fully trained and experienced in on-site operations by the company they work for. No one will be asked to divulge any information that may unintentionally create any embarrassment or discord with line managers who manage operations.

3.12.3 Anonymity and Confidentially

Making data 'anonymous' entails concealing the contributor's identity. However, to secure a participant's identity, there is a need to go beyond this fundamental step. Other information, such as work title, age, gender, duration of employment, club membership, and strongly expressed beliefs, can assist in identifying people. The more information displayed collectively, the easier it is to identify someone.

The term "confidentiality" refers to the safeguarding of the gathered data. Be explicit about how the confidentiality of that material will be honoured when the purpose of the study is to specifically access private sentiments, tales, and anxieties (Tolich, M., 2023).

Using name tagging, such as Engineer 1, 2, etc., and Survey 1, etc., thus reducing the possibility of anyone being able to identify the participant easily. The work carried out is all on a work computer that is encrypted therefore no one else can easily obtain the data. Work sent to LBU is also protected with passwords, and work is only seen by supervisors and other senior staff within the institution.

3.12.4 Respect for Privacy

Control over how much, when, and under what conditions one shares themselves with others (physically, behaviourally, or cognitively). Someone could, for instance, not want to be seen entering a location where they might be stigmatised. In addition, how the researcher obtains data from or about potential volunteers is considered when evaluating privacy (UCI webpage, 2019). Respect for each person who will be allowed to express their autonomy fully and whose information will be kept private. The participants are better shielded from potential harms by maintaining their privacy and confidentiality, including psychological injury like shame or distress, social harm like losing a job or damaging one's reputation, and criminal or legal liability.

3.12.5 Vulnerable group of people

Research involving children and young people requires careful consideration due to the unique sensitivities involved. It is essential to approach such research with thoughtfulness and care. Additionally, under the Mental Capacity Act 2005, any intrusive research conducted on adults lacking mental capacity must receive approval from a designated research ethics committee to ensure its legality (UoL, Webpage, 2019).

It is not envisaged that children or vulnerable adults will take part in this research project. Also, no interviews will be conducted with apprentices or any other group of people who do not have the required experience.

3.12.6 Data protection during and after research

The Data Protection Act of 1998 is in effect in Scotland, England, Wales, and Northern Ireland. It governs the processing of personally identifiable information, including how it is received, kept, utilised, and disclosed. Individuals have the right to access personal data about them under the Act, which means that participants can request copies of personal data gathered by a researcher (Research Ethics Guidebook, 2019). The study will be conducted following ethical guidelines, and any specific issues will be addressed with supervisors and/or an appropriate data protection officer. All data will be kept secure in encrypted storage sites or computers.

3.12.7 Machine Learning Using Imagery

This study does not seek to comprehend the architecture of 'Machine Learning' (ML). Even still, knowing how several photos of the same details might be used to evaluate a highway's asset will help. Machine Learning (ML) has progressed from an outmoded part of computer science and artificial intelligence (AI) to a cutting-edge research horizon in both AI and computer systems design (Lewis & Denning, 2018).

Computational statistics, with its emphasis on leveraging computers for predictive modelling, shares a profound connection with the core principles of machine learning. The latter greatly depens on the tools, theoretical frameworks, and diverse application domains derived from the extensive study of mathematical optimisation (Wuest et al., 2016). Within the realm of machine learning, a pivotal area of focus lies in exploratory data analysis through unsupervised learning techniques. This domain falls under the broader umbrella of data mining, serving as a critical subfield within the landscape of machine learning. Moreover, machine learning finds its application in solving real-world business challenges, often referred to as predictive analytics (Machine Learning, 2019). This recognition underscores the practical significance and impact of machine learning methodologies in addressing contemporary organisational needs.

Data abundance, particularly from online social networks like X and Facebook, wide-scale sensor networks like smartphones providing positioning data for traffic maps, or searches for correlations across previously distinct huge databases. The question that could be answered is whether that data could be processed by identifying and suggesting, which was a powerful motivator. The spread of low-cost, massively parallel hardware, such as the Nvidia GPU (Graphics Processing Unit) used in graphics cards, is another significant reason. GPUs process massive matrices encoding object coordinates quickly. They are linear algebra machines that are extremely fast. Training a network entails computing connection matrices, and using a network entails matrix multiplication evaluations (Lewis & Denning, 2018).

Machine learning tasks are classified into several major groups. The algorithm in supervised learning creates a mathematical model given a set of data that contains the inputs and the desired outputs (Bansal et al., 2022). For example, if the task were to determine whether an image had a specific object, the training data for a supervised learning system would include photos that contained and did not contain the object, and each image would have a label indicating whether it contained the data. In other circumstances, the input may be just partially available or limited to unique feedback. Semi-supervised learning techniques construct mathematical models from incomplete training data in which a portion of the sample input lacks labels (Seong et al., 2019, p2).

3.12.8 Machine Learning Ethics

Machine learning raises many ethical issues since it can digitise cultural prejudices by using algorithms trained on biased datasets. In the healthcare industry, other ethical problems unrelated to personal prejudices are increasingly prevalent (Behroziam A, 2020).

In the landscape of diverse AI systems both now and in the foreseeable future, coupled with the intricate nature of ethical behaviour heavily dependent on context, it becomes evident that constructing machine ethics solely upon existing technical frameworks poses significant challenges. This prompts a deeper consideration of the broader complexities underlying intelligent decision-making and the intricate social environments that humans and machines will navigate together in the years to come (Brundage, 2014, p. 15). Thus, while research in machine ethics holds societal significance, it must be approached within the broader framework of the inherent complexities of intelligent action and the evolving dynamics of human-computer interactions.

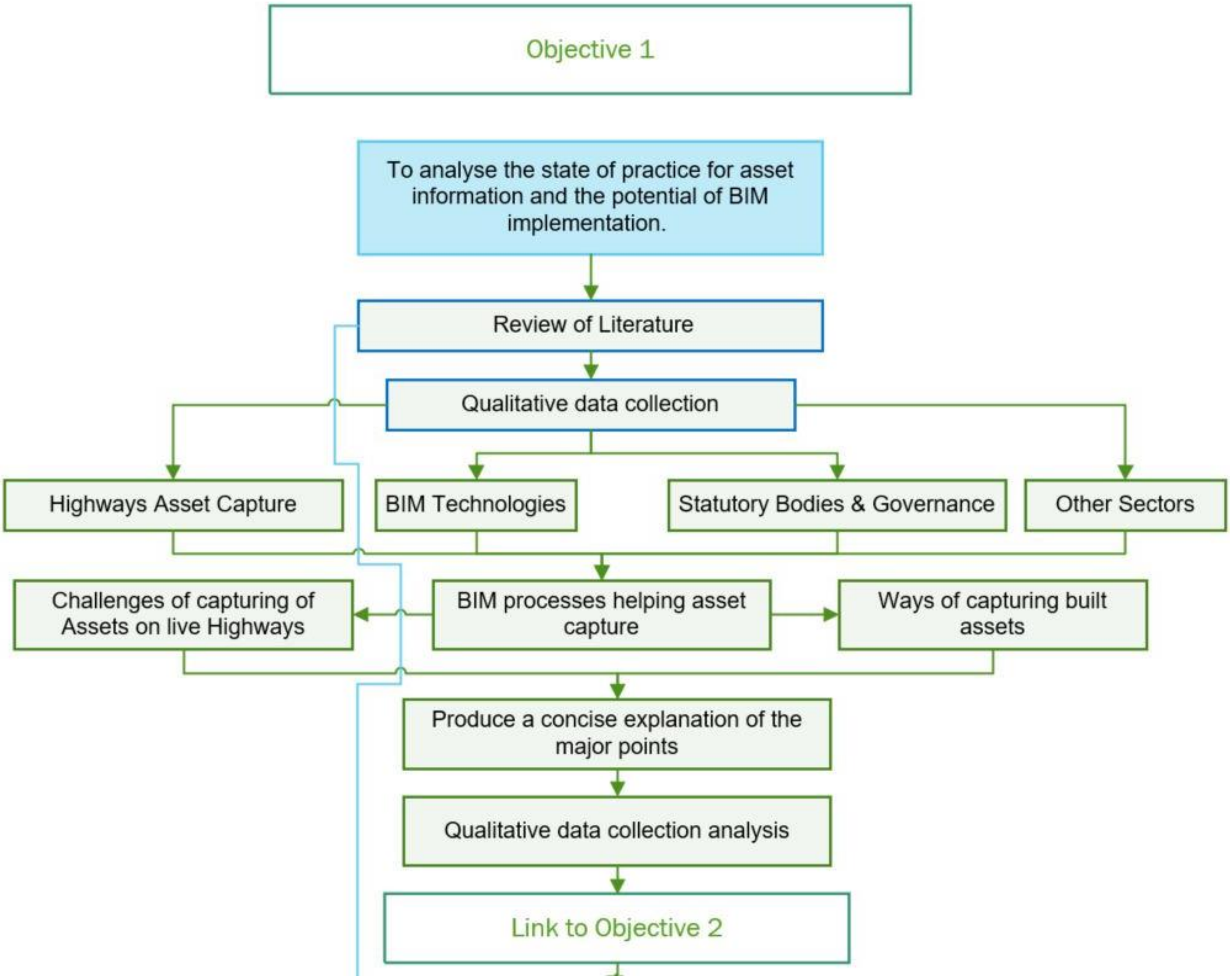
The machine learning used in this research does not pose questions or involve any personnel information of test subjects; there was no ethical reason not to proceed with the machine learning models.

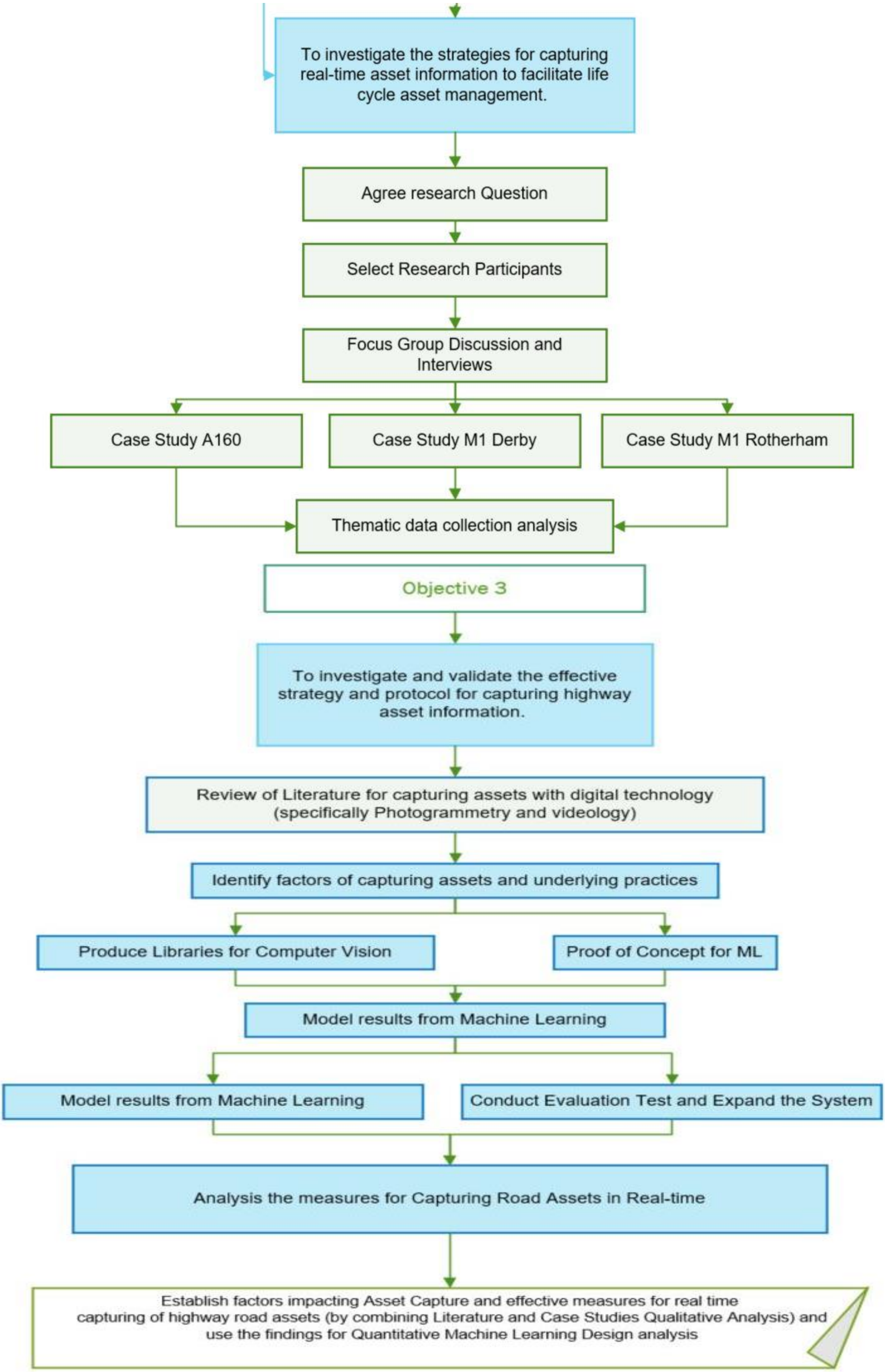
3.13 Research Summary

According to Mertens (2005, p. 2), research design is a methodical approach to comprehend, characterise, forecast, or regulate an educational or psychological event or to empower people in such situations. Research can be designed as either a quantitative or qualitative study. Quantitative research uses measurable data in a more structured way than qualitative research to discover patterns. Qualitative research is used to gain insights through semi-structured techniques such as focus groups and interviews to gather unmeasurable and non-numerical data to uncover trends. Outcomes from qualitative research can be used to develop hypotheses for potential quantitative research. Therefore, this research uses exploratory sequential qualitative and quantitative approaches to answer the objectives.

Descriptive design can be both quantitative and qualitative; the researcher uses methodologies such as surveys, observations, and document reviews that describe the current status of a phenomenon or variable. This approach is very relevant as this research aims to understand how geospatial technology is utilised within an industrial setting and how geospatial tools and processes can be applied to academic research. The research also uses a case-study design approach due to the research concentration on large infrastructure projects and management practices, specifically by the sponsor company, Costain Group Plc.

Given the significance of each method in the investigation, it is evident that leveraging both qualitative and quantitative methodologies holds promise in illuminating various facets of the study. However, it is important to acknowledge that both approaches have limitations in fully encapsulating the comprehension, progression, forecasting, and elucidation necessary for formulating a BIM-based protocol for real-time asset collection on highway schemes, primarily due to the intricate nature of the research focus (refer to Figure 5 for a visual depiction of the Research Design and Methodology).





To investigate the strategies for capturing real-time asset information to facilitate life cycle asset management.
Agree research Question
Select Research Participants
Focus Group Discussion and Interviews
Case Study A160
Case Study M1 Derby
Case Study M1 Rotherham
Thematic data collection analysis
Objective 3
To investigate and validate the effective strategy and protocol for capturing highway asset information.
Review of Literature for capturing assets with digital technology (specifically Photogrammetry and videology)
Identify factors of capturing assets and underlying practices
Produce Libraries for Computer Vision
Proof of Concept for ML
Model results from Machine Learning
Model results from Machine Learning
Conduct Evaluation Test and Expand the System
Analysis the measures for Capturing Road Assets in Real-time
Establish factors impacting Asset Capture and effective measures for real time capturing of highway road assets (by combining Literature and Case Studies Qualitative Analysis) and use the findings for Quantitative Machine Learning Design analysis

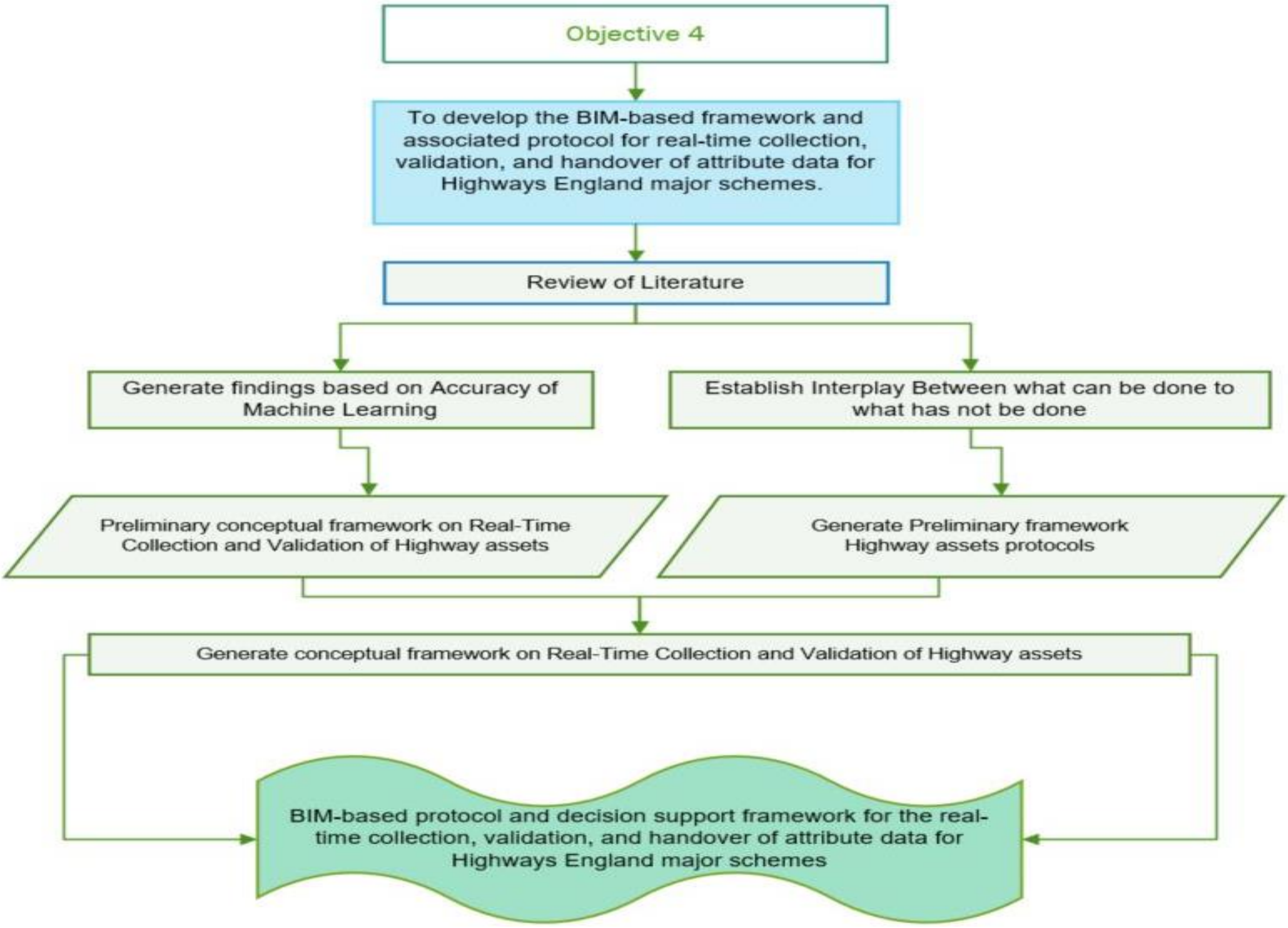


Figure 5 Graphic showing Research Design and Methodology (Starkey, 2020).

Chapter Four Case Studies

4.1 Introduction

As mentioned in section 3.4.2, the case study approach employs a variety of empirical material-gathering strategies to provide the most comprehensive answers to the research questions. Semi-structured interviews, meeting observations, and document collection can be conducted. Collecting empirical material from multiple sources allows triangulation (Yin, 2009). Combining multiple sources of empirical material in a case study approach is best understood as a strategy to increase the study's rigour, length, complexity, and depth (Flick et al., 2004).

Drawing upon four industry case studies, encompassing an area maintenance team (Area 12) and one of Highways England's ASC (Asset Support Contractor), this framework may be further enriched by the inclusion of additional area teams in its development phase. The ASC team not only fulfils all area O&M requirements but also adeptly handles financial considerations, meticulously plans and schedules works, and manages the initiation of new road assets. Among the case studies featured are the A160 Improvement scheme, M1J28-35a, M1J23a-25, and the A19 TaDL scheme.

The case studies in this research are all Highways schemes with a different understanding of BIM and the 'Handover' of asset data for Highways England's maintainers. The information gathered was vetted and verified by key persons from the organisations engaged in the case studies. This is to ensure the analysed data accuracy and avoid reporting confidential information. Eventually, the findings will contribute to and extend the knowledge of the current uses of BIM in road projects. They will also provide insights into the effective adoption and use of BIM protocols in other infrastructure projects that may be procured.

4.1.1 Assessing Case Studies Information

The case study method has been widely used in research involving construction projects for various purposes. When investigating construction projects, data is primarily provided by construction industry stakeholders, either directly via interview and survey or indirectly by providing access to relevant documents or even observations of the projects. Inevitably, these construction industry practitioners are part of the research findings' audience, if not the research findings' most important audience. The construction project investigations aim to identify gaps and improve current construction industry practices (Sutrisna & Abbott, 2017).

Integrating archival research with interviews and surveys offers a wealth of advantages tailored to the specific research objectives and inquiries. The strategic combination of data sources and methodologies not only enhances the credibility and dependability of the research but also strengthens its validity. Moreover, by harnessing interviews and surveys to gather recent and diverse data, which allows effective bridging of any gaps inherent in archival research, such as the absence or incompleteness of certain data points. These personal narratives, subjective experiences, and quantitative indicators not only serve to enrich but also to deepen the scope of historical analysis. By intertwining archival research with contemporary issues, the research gains relevance, enabling the researcher to draw actionable insights and recommendations based on the findings (Welch, 2000).

Evaluation of the archive source's value and applicability to the research project constitutes assessment. Evaluating an archive's contents can take a while if it is incompletely catalogued. According to Scott (2014), the four criteria of authenticity, credibility, representativeness, and meaning should be used to assess documentary evidence. Verifying a document's authorship and determining whether it is an original or a copy are two requirements for determining authenticity. An assessment of the researcher's objectivity and dependability is necessary for credibility. In general, documents produced solely for internal purposes, such as policy papers and memos, are likely to be much more revealing than those created for external consumption, such as annual reports and chairpersons's statements (Welch, 2000). Different types of archival records may be more informative and candid about events than others.

Interview subjects were chosen based on standard criteria, in this case, their prior work experience in the infrastructure industry, specifically the highways industry.

Participants in the judgmental sample were chosen from the researchers' network of contacts due to their participation in the case studies. They had prior experience working in the industry. The list of participants is shown in Table 7 of Chapter 5.

Because the cases analysed ranged from 2014 to 2019, the researcher aimed to maintain a certain level of secrecy and sensitivity with the material provided. The validity and reliability processes were conducted internally using two approaches. First, several discussions and workshops were organised with the BIM teams in the companies during the data collection and analysis period. Second, semi-structured interviews were conducted with the professionals involved in all the stages of work. These procedures would, therefore, support the validity and dependability of this case study approach.

4.2 Case Study 1: A160 Scheme

4.2.1 Background for A160 Scheme

Immingham and Grimsby Ports are the largest ports in the UK by tonnage, handling some 10% of the UK’s cargo market. The South Humber Bank also contains 20% of the UK’s oil and gas refining capacity. It remains the largest undeveloped land fronting a deep-water estuary in the United Kingdom. Approximately 1000 hectares of land are available for future development (Highways England, 2015).

The objective outlined in the scheme brief is to enhance road access to the Port of Immingham, aligning with both existing traffic demands and anticipated growth resulting from planned development projects. Central to this initiative is the A160, a key national thoroughfare spanning approximately 5.2 kilometres to and from the port. Presently, the A160 presents a blend of single and dual carriageways traversing through areas characterised by agriculture and heavy industry, notably associated with the petrochemical sector. Highlighted in Figure 6 are pivotal zones within the scheme. Notably, the A160 has significant congestion issues, particularly along its single-carriageway segments, attributed primarily to the substantial volume of Heavy Goods Vehicle (HGV) traffic, surpassing 42% as reported by Costain News Article (2018).

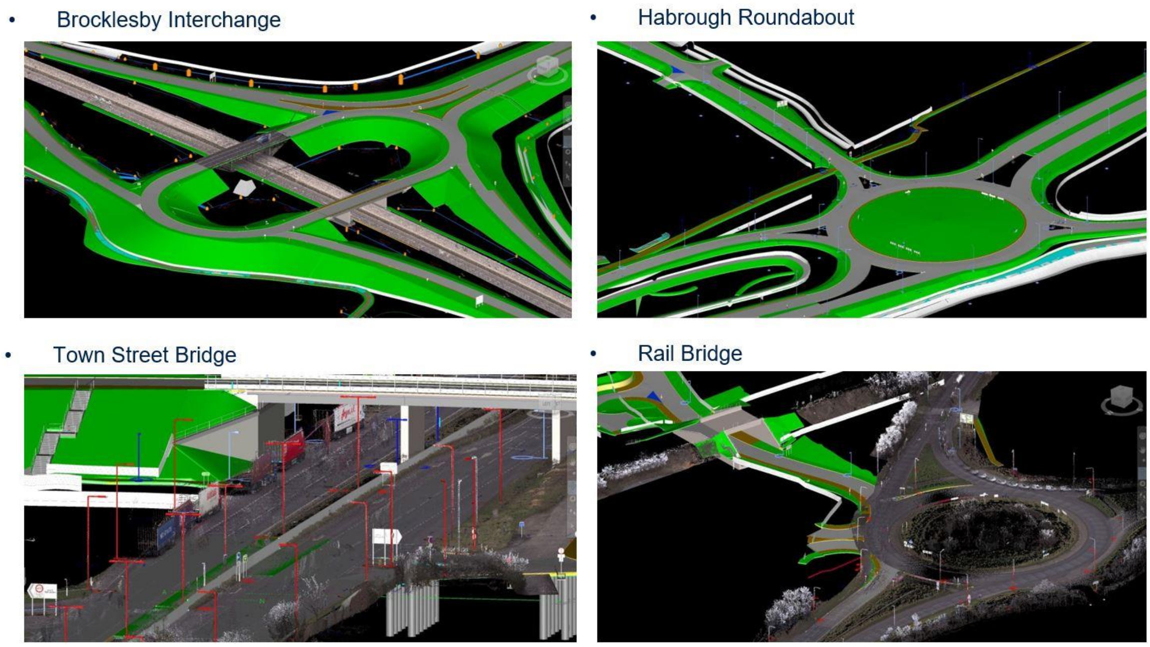


Figure 6 Images critical parts of the A160 Scheme, 3D model combined with point cloud (Starkey, 2018).

The A160/A180 Port scheme had been selected as a BIM 'Early Adopter' project, one of only a few in the country. The team progressed through the learning curve, and at times, adopting these methods may add additional time and cost that would be expected if a job of this size is built using traditional methods. In 2014, when the project went into construction and onto the site, there was very little knowledge of BIM as a process and how to deliver a ‘Digital Handover’. Therefore, the handover had to be delivered in a traditional style (hard copies of drawings and data on hard drives and memory sticks) and as a process of BIM processes for collecting asset attribute data output. The handover of this asset data had to be done within three months from the end of construction to the road opening to allow the ASC (Asset Support Contract) team to maintain the new road.

From the start, it was clear that the contractor had very little knowledge of how to deliver an ‘asset rich’ 3D model of the scheme; the designer also had to learn how to use different software that would enable the move from 2D to a 3D model environment, that was both capable of exporting 2d xref’s and attaching asset data attribute information. Whilst this was a complex process, it became clear that the operation of the JCT contracts outweighed what was achieved in the modelling. The contracts stated clearly that the output of PDFs was the only contractual requirement that the designers had to accomplish for the handover and O&M Health and Safety file (Interview Participant 4, 2021)

4.2.2 BIM Uses in the Preconstruction Stage

BIM was adopted by the entire project team from the beginning. The major stakeholders each participated and contributed to developing the BIM model. This was an early adopter of BIM on a Highways scheme. All processes, such as file storage, folder structure, naming, etc., were developed from the current project standards BS1192.

The common BIM uses of engineering analysis, quantity-take-off, and clash detection were carried out to support and coordinate the BIM 3D, 4D, and 5D modelled information. The information was then used and demonstrated in the project's virtual design and road safety audits, as shown in Figure 7 . The benefits in terms of both accuracy and visualisation for project stakeholder consultation were found to be significant, as it could compare and demonstrate different details and needs for the subcontractors.

Figure 7 Image showing drivers view for ‘Safety Road Audits’ (Starkey, 2018)

As mentioned above, the quantity take-off was one of the main items tested in the preconstruction stage, the idea being that quantum was all measured from the federated model that was developed from several models from various pieces of software. The QS team working on the project used free software, which enabled them to view, integrate and measure from the model. Whilst anything that was modelled in the structures software had embedded quantities that could be exported to a spreadsheet, all other models had to be measured with the measuring tab of the software; this was no different to them measuring from scaled-up pdf drawings in many ways was a failure of the modelling process at that time.

The preconstruction stage was one of the main processes for the BIM uses and development in the project. This was a tedious and somewhat complicated process as it was the first time they had used BIM for a road project and coordinated many key stakeholders per the procurement system.

4.2.3 BIM Uses in the Construction Stage

As the contractor was one of the key stakeholders involved in the design development, the data from the BIM model could be used to export coordinates directly into machine control for the plant to dig the earthworks.

The design and construction teams integrated both virtual and physical perspectives of the onsite space and potential obstructions. Utilising cutting-edge technology such as drones, as depicted in Figure 8, enabled a comprehensive view of the spatial layout. This imagery underscores the precision of the model's data, particularly evident when utilities are intricately modelled, and site engineers incorporate site trenches into the interactive interface. Such integration facilitates informed decision-making and enhances overall project efficiency.

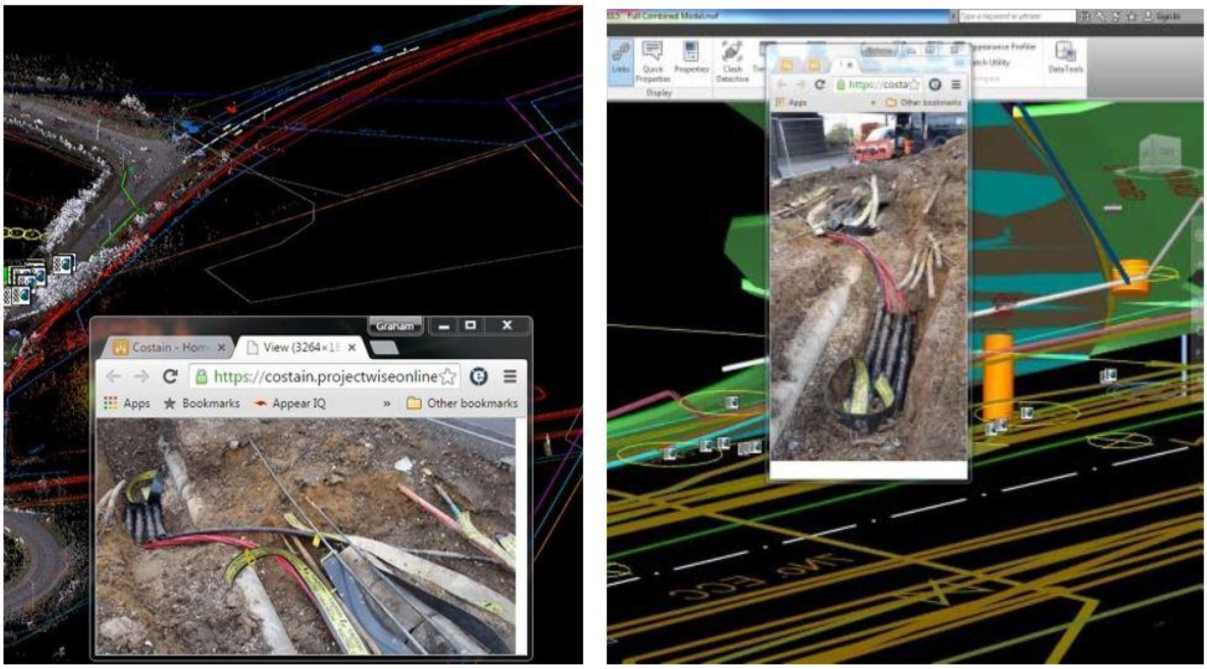


Figure 8 Images showing modelled utilities against trench investigations (Starkey, 2019).

The project team had been given access to mobile tablets to an enhanced version of the web-based software interface containing their added layers of information. The project BIM team regularly updated the model and synchronised it as soon as updates were finished, allowing the construction team to use the information in near real-time.

During the construction stage, there were several pilot projects using asset capture software and onsite gathering of completed work that fed into the overall programme of works. One such pilot was the ‘Redbite’ pilot, a UK government-funded IoT project called HyperCat that aimed to provide IoT capabilities to the UK private and public assets; for the A160 scheme, this captured asset location data using QR codes and RFID tags, Figure 9, shows this in operation.

Figure 9 Images showing asset tagging taking place on a live project.(RedBite, 2018) adapted (Starkey, 2019).

A fully sequenced programme-led integration (4D BIM) is to be developed in detail for the Rail Bridge allowing the technology can be demonstrated and used for stakeholder discussions. Network Rail has approved handing over the site to the contractor for 48 hours to complete the bridge slide, figure 10 shows this.

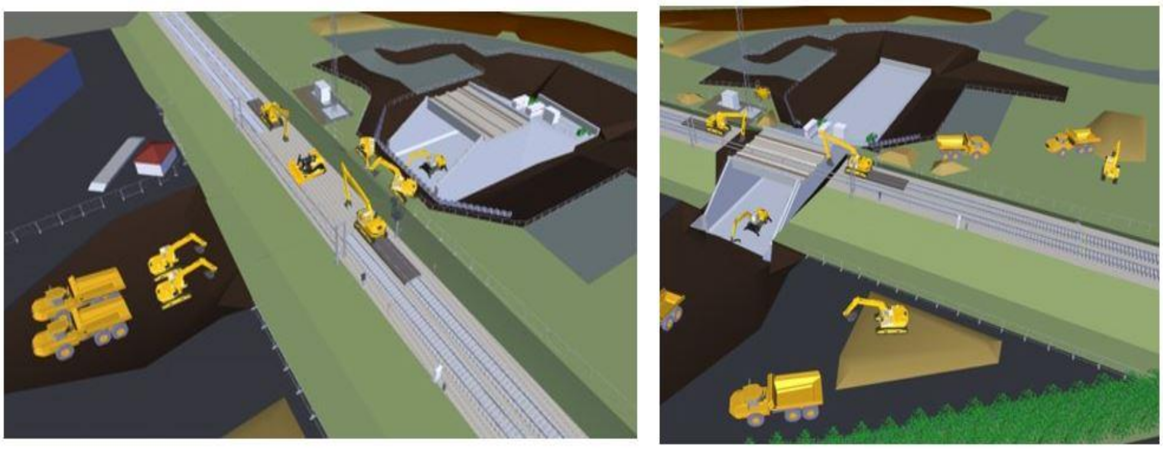


Figure 10 Images showing 4d sequence bridge slide (Starkey, 2018)

4.2.4 BIM Uses in Postconstruction Stage

One weakness that needs to be considered in the project is the handing over of the asset data attributes for the highways maintainer to import and adopt into their databases. As discussed earlier, the contractor and its BIM team had very little knowledge of the processes required for a smooth data handover. The maintainer helped this learning curve by embedding a handover manager into the contractor's team. Whilst this was a great help, many struggles gathering the data from site engineers became a significant downfall that would persist for 18 months after the highway opened to traffic.

Integrating existing data with new data posed a significant challenge in implementing these highway schemes. However, this hurdle was effectively overcome through the use of specialised software. Safe Software emerged as the cornerstone of Data Integration Platform (refer to Figure 11), enabling seamless integration of the two datasets.

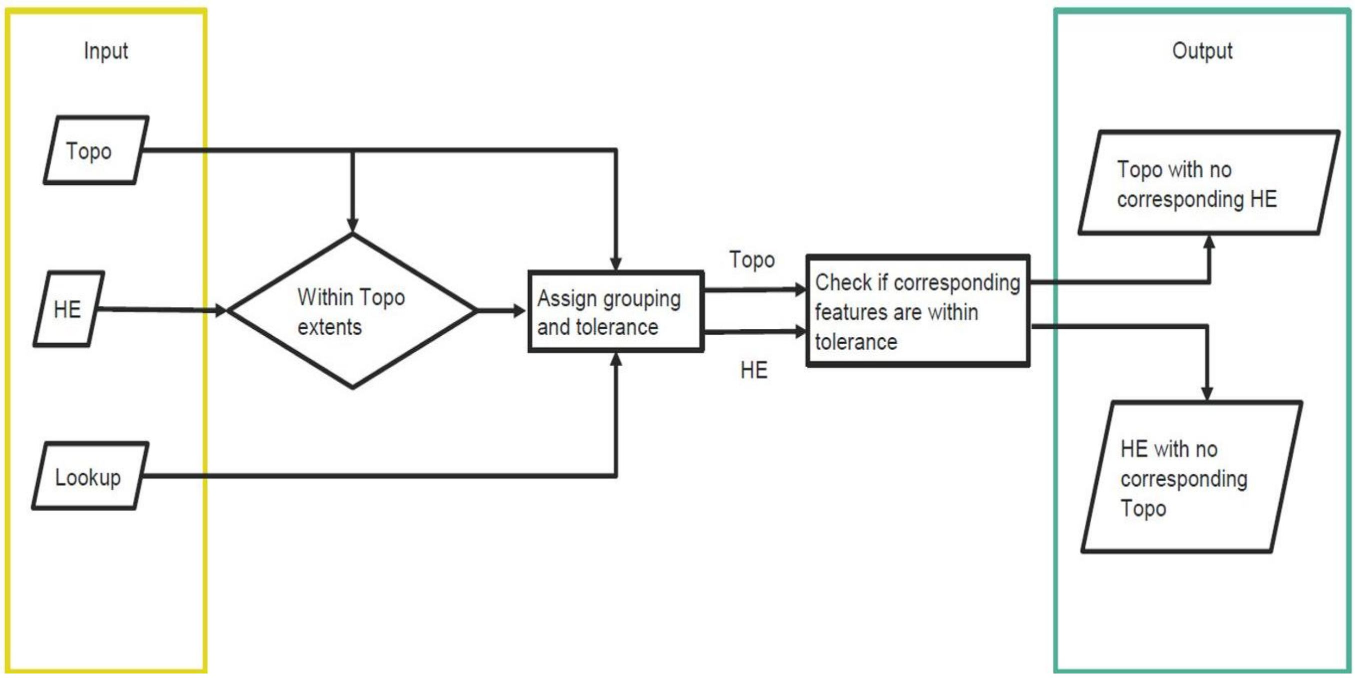


Figure 11 Image showing a flowchart for merged data (DottedEyes, 2016).

However, there was a firm interest in adopting other BIM uses during operation and maintenance after the completion of the project, such as road management and geospatial issue tracking. The BIM team needed to develop an understanding of the existing asset databases, the Highways Agency's proposals for its Integrated Asset Management Information System (IAM-IS) and the information that the maintenance service providers need to extract from the data to use for maintenance needs.

After the oversight of missing the handover of asset data, which typically occurs within three months, in the case of A160, this realisation struck a whopping 18 months later. The maintenance team then acknowledged that the version of the ADMM agreed upon with the contractor was incompatible with the new database. Consequently, the data had to be reprocessed to meet the necessary version specifications, extending the completion time, as noted by Interviewee 6.

4.3 Case Study 2: M1 J28-35a Scheme

4.3.1 Background for M1 J28-35a Scheme

M1 J28-35a Smart Motorway improved a 52km section of the M1 Motorway by making it a "Smart Motorway" Figure 12. The project increased the capacity of the M1 between Junctions 28 and 35a by making the existing hard shoulder suitable for use as a running lane and introducing Smart Motorway technology where overhead signs and signals will control traffic. Additionally, the project included undertaking local Pinch Point schemes and asset renewals to improve the condition of the network and leave it maintenance-free for five years after opening.

Figure 12 Images showing the M1 Smart Motorway Project (Starkey, 2021)

This scheme was not part of the BIM ‘Early Adopters’, and whilst some design elements were completed in 3D, it was not a contracted project that would use the BIM process and the PAS 1192 suite of standards; the contract was signed pre-2014 and well before the 2016 Government Mandate. Also, the handover of asset data was not in the original deliverables for the project (Costain, 2015b).

4.3.2 BIM Uses in Postconstruction Stage

Upon completion of the M1 scheme, it was decided that leveraging the expertise of the BIM team responsible for the A160 scheme's asset data handover would improve the process for the M1 project as well. This decision was rooted in the timing of both schemes and the efficiency gained from aligning methodologies. The complexity of the data handover was further compounded by the geographical distribution of the M1 scheme. While most of the project fell under HE's Area 12 jurisdiction, which utilised the IAM-IS main database similar to that of the A160 project, junctions 28 to 30 were to be handed over to Area 7. This transition presented a challenge as Area 7 relied on a different main database named 'CONFIRM,' necessitating a reorganisation of spreadsheet field headings to accommodate its unique format.

Again, this project suffered the same issues as the A160: the data was not collected at the correct time, and the engineer responsible for that series of work had already left and gone on to other projects. Also, the as-built drawings were not completed, allowing for a lack of spatial information on the completed assets.

Using the knowledge gained from A160, the BIM team looked at using specialist software; Figure 13 shows some outputs from this software. To help automate the gathering of data from the 2D CAD drawings of each asset type, several steps were required that would allow the team to improve the quality of the data and then ensure that the data was in the correct order required by whichever database the team had to hand over to.

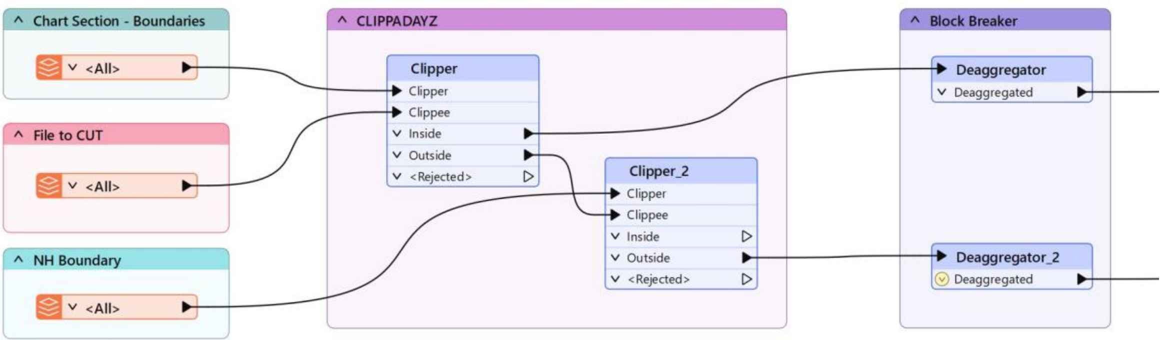
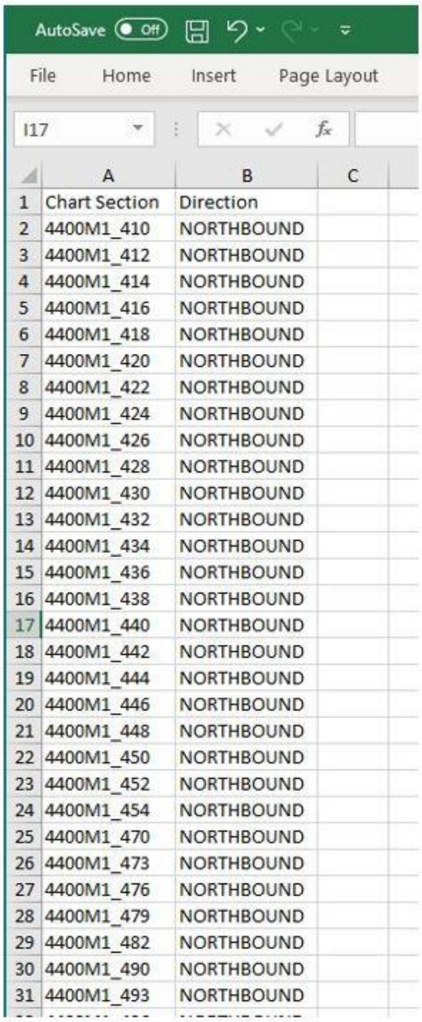


Figure 13 FME specialist software (Starkey, 2019).

Several drawings needed to be produced to allow the software to be successful; the 'Chart Section' set of drawings identifies where the assets start and finish within the highways chainage system; note that this differs from the construction chainage on which the project is constructed. A 2D CAD drawing of the asset type is required for both point and linear assets. The ADMM class is a 4-letter code, a lookup Excel file listing the attributes for a particular asset class and a 'Chart Section' directional lookup highlighting the required section name, shown in Figure14.

	A	B
1	fme_feature_type	source
2	RRVR	Entity_handle
3	RRVR	Type
4	RRVR	Asset ID
5	RRVR	Source ID
6	RRVR	Shape
7	RRVR	Beam/Concrete Profile
8	RRVR	Manufacturer
9	RRVR	Design / Drawing Number
10	RRVR	Owner
11	RRVR	Hazard (reason for VRS)
12	RRVR	Connected Parapet
13	RRVR	Current Maintenance Contract
14	RRVR	Currently Maintained By
15	RRVR	Condition Rating (Manual)
16	RRVR	Ground Type
17	RRVR	Departure - DAS ID
18	RRVR	Expected service life
19	RRVR	Post Type
20	RRVR	Post Frequency
21	RRVR	Foundation
22	RRVR	Start X (Easting)
23	RRVR	Start Y (Northing)
24	RRVR	End X (Easting)
25	RRVR	End Y (Northing)
26	RRVR	Installation Date
27	RRVR	TD19 Compliant?
28	RRVR	If not Compliant
29	RRVR	Was RRRAP used?
30	RRVR	If RRAP not applicable
31	RRVR	Containment Levels - SL 50MPH+
32	RRVR	Containment Levels - SL <50MPH



	A	B	C
1	Chart Section	Direction	
2	4400M1_410	NORTHBOUND	
3	4400M1_412	NORTHBOUND	
4	4400M1_414	NORTHBOUND	
5	4400M1_416	NORTHBOUND	
6	4400M1_418	NORTHBOUND	
7	4400M1_420	NORTHBOUND	
8	4400M1_422	NORTHBOUND	
9	4400M1_424	NORTHBOUND	
10	4400M1_426	NORTHBOUND	
11	4400M1_428	NORTHBOUND	
12	4400M1_430	NORTHBOUND	
13	4400M1_432	NORTHBOUND	
14	4400M1_434	NORTHBOUND	
15	4400M1_436	NORTHBOUND	
16	4400M1_438	NORTHBOUND	
17	4400M1_440	NORTHBOUND	
18	4400M1_442	NORTHBOUND	
19	4400M1_444	NORTHBOUND	
20	4400M1_446	NORTHBOUND	
21	4400M1_448	NORTHBOUND	
22	4400M1_450	NORTHBOUND	
23	4400M1_452	NORTHBOUND	
24	4400M1_454	NORTHBOUND	
25	4400M1_470	NORTHBOUND	
26	4400M1_473	NORTHBOUND	
27	4400M1_476	NORTHBOUND	
28	4400M1_479	NORTHBOUND	
29	4400M1_482	NORTHBOUND	
30	4400M1_490	NORTHBOUND	
31	4400M1_493	NORTHBOUND	

Figure 14 FME Lookup Tables, (Starkey, 2019).

Due to the involvement of the A160 BIM team, the M1 asset data for junctions 28 to 35a were accepted by the HE area maintenance teams into their operations; this was still a slow process that took some 12 months, that said it was still faster than what occurred on the A160 therefore it was seen as a success by HE and the contractor who said "The entire BIM approach has been built using the Golden Thread within Government Soft Landings, meaning involving the Maintaining Agent Contractor and Asset Information owners from the outset and are continuously developing solutions with future operational and maintenance requirements built in. An example of this is how having engaged and are working closely with the Asset Management Office (AMO) to define asset requirements now correctly and in future systems (Highways England, 2015).

4.4 Case Study 1: M1 J23a-25 Scheme

4.4.1 Background for M1 J23a-25 Scheme

For the estimated 100,000 daily users of the M1 between Junction 23a and Junction 25 Figure 15, it is impossible to imagine life without it. Smart motorways have rewoven the fabric of everyday lives, which is ideal timing to raise the 'Customer Service' bar (Highways England, 2019). The project is a 7.1-mile-long scheme located in the East Midlands and supports economic growth both locally and nationally by reducing congestion and providing route capacity enhancements without compromising safety. The scheme will also help access East Midlands

Airport and the A50 growth corridor, including the East Midlands Gateway Rail Freight Interchange (Highways England, 2019)

Figure 15 Image showing M1J25 (Starkey, 2021).

This SMP project shares similarities with the scheme for junctions 28 to 35a. While the contractor had a well-established BIM element, the same cannot be said for the scheme designers directly contracted through Highways England, as it was not a 'Design & Build' project. This difference in approach somewhat complicated matters, as the designers hesitated to invest time in producing a federated model typically expected for a project of this scale.

4.4.2 BIM Uses in the Construction Stage

The contractor's contract had BIM as a requirement, but it lacked detail and clarity. What was required was a comprehensive EIR (Employers Information Requirements), but this was non-existent for a significant part of the scheme (Interviewee No1,2021). Still, this did not derail the contractor's BIM team, who now knew what was required with working knowledge of previous projects; due to the designer's reluctance and capabilities on the modelling front, the contractor engaged with another designer to produce a ‘Rapid Engineering Model’ (REM) for the use of visualisation within the site office. This was transposed onto 64-inch screens in the office, allowing engineers to integrate the scheme's design. The facility was called the ‘Production Hub’, where all team members could view all project data, allowing for planning future works, monitoring and control, and planning, Figure 16 shows this in operation.

Figure 16 Image showing BIM & Engineering staff using the 'Production Hub' (Starkey, 2021)

The ‘Production Hub’ has now been developed more and is now called the ‘Smart Delivery Platform’ (SDP) and is now required on all Costain highways projects.

4.4.3 BIM Uses in Postconstruction Stage

The contractors, now with over three years of knowledge in the handover of asset data, the BIM team immediately engaged with the project management team to better understand what is required for asset data handover and how long it takes. The management agreed that the BIM team should be responsible for gathering the data; this allowed the team to plan for asset data even before design elements were not complete on site. Using lessons learnt from the previous schemes and the knowledge gained by working with different HE area maintenance teams, the handover was started three months before the motorway was open to all traffic.

Again using the FME workbench to help deliver the asset data, the BIM team had to collaborate with different area maintainers to the previous case studies; the new ASC (Asset Support Contractor) team, formally Area 7, also used a database called ‘CONFIRM’ as mentioned in the previous case study, this has a different layout to the IAM-IS database, which contradicts the order of the field headings in the required spreadsheet output in the ADMM, therefore understanding what this meant to the handover process of assets needed to be investigated, using many workshops and meetings to agree on the way forward. The agreement with the area team was that what was best would be to issue the data in line with the ADMM, and the developers of CONFIRM would use a transitioning piece of software to alter the order of the data as it is imported into the database. Also, the construction BIM team started the handover before the as-built drawings were produced, allowing more time to collate the asset attribute data. Still, they were held up by confirmation of the actual site location of the built assets.

After compiling the asset data using the 'For Construction' issued drawings and processing it through the FME workbench, the team sought assurance that the assets were installed according to the construction specifications. Experience has shown that discrepancies between planned and actual placements are not uncommon. Typically, these are addressed by annotating as-built changes on drawings, which are then incorporated into updated construction documentation. However, time limitations and designer availability hindered immediate updates to these drawings and models. Consequently, alternative solutions need to be explored.

Firstly, there was the option of not updating the data; the ADMM allows a tolerance of plus or minus 3m, and whilst this seems a lot in some cases, the asset identified, say a lamp post, would not have another one within three meters of itself, therefore this could be ignored but still complies.

Secondly, use the surveying team to survey each asset type; this would cost extra time and money, and traffic management has to be in place to allow safe access for the surveyor. In some areas of the scheme, traffic management had been removed, the only option was to carry out the surveys at night, closing off specific motorway lanes to allow access.

Considering the options with the senior management, the team chose the second option, which was to ensure the client could not reject the data due to it not being validated. Once the surveys were produced, a check identified the difference between the construction and the actual Figure 17 image, identified the validation.

Figure 17 Image showing Validation built assets against construction issue (Starkey, 2020)

4.5 Analysis

The three case studies above have used BIM slightly differently according to their contract date, and how the client engaged in the design, one being a design and build contract. The other two are more of a traditional route where designers and contractors report separately to the client. Understanding this concerning the cultural and managerial aspects of the projects is essential. Hence, a comparative analysis was conducted in these case studies to examine the implementation of BIM on highways, how BIM is used post-construction, during and during handover, and the associated technologies, roles, responsibilities, and managerial issues of the projects. Moreover, there are differences between how BIM has been used for handover, with some cases not using the advantage of having a PIM (Project Information Model) with its asset data available for the asset maintainers. The tables below show how each case study (i) did it, (ii) Strategies used, (iii) Current and Potential areas for BIM implementation, and (iv) Potential areas for Improvement.

Table 1 How did they do it-A160

A160	**Description**
Problems	Knowledge of BIM and personnel that had appropriate training.
	Lack of knowledge by Contractor of Handover of asset attribute information.
	Information is missing due to resources moving away from the project after construction.
	Lack of Knowledge of HE Chart and Node referencing system.
	Handover (Asset Data) took too long (12 months).
Barriers	Changing the scope of asset data requirements.
	HE databases are not accepting the agreed version of asset data.
	Engineers and subcontractors are not providing coherent information.
Successes	Employment of a seconded Handover Manager.
	Trailing of Software for data amalgamation.
	Drone technology is used to clarify the assets in place.

Table 2 How did they do it - M1J28-35a

M1J28-35a	**Description**
Problems	No BIM team was employed due to contract requirements.
	Surveys had to be carried out to gather asset location information.
	Information is missing due to resources moving away from the project after construction.
	Handover (Asset Data) took too long (9 months).
Barriers	2 Area Teams to Handover to requiring different asset attribute output.
	HE databases are not accepting the agreed version of asset data.
	Engineers and subcontractors are not providing coherent information.
Successes	Employment of a Handover Manager
	Software for data amalgamation was purchased.

Table 3 How did they do it - M1J23a-25

M1J23a-25	Description
Problems	Due to contractual arrangements, the designers did not produce a PIM.
	Surveys had to be carried out to gather asset location information.
	Information is missing due to resources moving away from the project after construction.
Barriers	Using a Drone was restricted due to airport proximity.
	HE databases are not accepting the agreed version of asset data.
	Engineers and subcontractors are not providing coherent information.
Successes	Updating amalgamation software with added automation.
	The BIM Team had a process in place after learning about previous projects.
	Asset Attribute handover was within the required time (3 Months).

Table 4 BIM Strategies of Case Studies

Adopted BIM and associated technologies	A160	M1 J28-35a	M1 J23a-25
BIM Metada naming convention	Yes	Yes	Yes
Use of a CDE (Common Data Environment)	Yes	Yes	Yes
Design by 3D	Yes	Yes	_
Design clash analysis	Yes	_	_
4D sequencing	Yes	_	Yes
5D cost analysis	Yes	_	Yes
Construction safety analysis	Yes	Yes	Yes
BIM-integrated site setting out or surveying	Yes	_	Yes
Tracking onsite construction progress	Yes	Yes	Yes
Production of PIM (Project Information Model)	Yes	_	Yes
Asset Attribute Data loaded into the model	_	_	_
The capture of Asset Information in real-time	_	_	_
Production of AIM (Asset Information Model)	_	_	_
Laser/Drone scanning for Asset Validation	Yes	_	Yes

List from EIR (Employers Information Requirements) at the time of projects

Table 5 Potential areas for improvement are based on achievements in HE projects.

Areas of Improvement	Description
Contracts	Clarification of contracts that BIM is required and at what level.
	Clear detail in EIRs regarding what is required in a PIM or AIM.
	Better clarity from HE Maintainers on source databases and who updates them.
	Plain English is used, but there are still too many ambiguous sentences.
Designers	To deliver what was written in the BEP.
	More open to sharing native documents.
	Attach asset data to models at stage 3 or early stage 5.
	Model existing and not just new design.
	Understand the asset data handover better (ADMM).
Contractors	Allow more time in programmes for the Handover period.
	Handover Managers to be employed from the start of a project.
	Capture asset information in real-time and not wait until the end.
	The use of a Drone or another similar tech to carry out surveys.
	Automation of the redlining process.
General	Better knowledge of BIM throughout the workforce
	More digital training for new tech
	Data and Information management still have processing issues.

4.5.1 Influential Aspects

The case studies reveal diverse impacts of utilising Building Information Modelling (BIM). While incorporating BIM has notably enhanced the infrastructure sector, it has also wielded considerable influence over existing practices, contractual policies, and business models (Al-Ashmori et al., 2020). From 2014 to the present, these case studies encapsulate a pivotal period from pre-mandated BIM adoption by the government to the current landscape. The integration and application of BIM within highway projects have progressed steadily, albeit cautiously. Particularly, the early adopter schemes outlined in these case studies have played a crucial role in illustrating BIM's efficacy within the industry.

Highways England, the client on these projects, needed to acquire BIM knowledge to enhance productivity and reduce labour costs encountered in the country. Therefore, the client initiated the partnering procurement system and absorbed most of the costs concerning the development and exploration of BIM and its uses in the early adopter projects. Consequently, reworks or errors on site were significantly reduced. The virtual and precise information from BIM helped improve the project's productivity. Additionally, the web-based interface on the BIM model and the work progress also contributed to the need for public engagement with consultees. BIM is a digital approach within the construction sector that allows collaboration between project stakeholders in designing, creating and maintaining any given asset throughout the project lifecycle, using digital tools and software to manage information from concept to delivery (Highways England. 2015).

The case studies have shown that (1) BIM has been adopted at varying levels, very much dependent on the contract type and who works for whom, especially on the design side and when the initial contract was signed; (2) the initial development of BIM in Highways can be referred to by the existing BIM experience from the early adopter schemes; and (3) the comparative analysis of BIM in Highways highlights the support of new BIM uses especially in asset data. Whilst there has been a move forward with BIM in Highways, as seen with the above case studies, the element of how this will aid handover has not been fully realised yet and needs further research by all involved to enable a more digital way of gathering assets data from assets that are newly placed on site and to aid the development of a better way of redlining and as-built drawings have been produced.

4.6 Summary

The case studies show that the projects had the opportunity to use BIM similarly, as well as associated technologies, key persons' roles, and responsibilities. One of the probable reasons for this could be traced to the intended BIM agenda in the UK and by Highways England's standardised formats as promoted in the BIM community globally. Moreover, the projects used similar software to develop the BIM models. This would motivate the BIM key individuals to adhere to the same norms and principles established by the software vendor and the contractor's BIM team, particularly during the abovementioned asset-gathering process.

4.6.1 Construction Record Processes

Figure 18, depicted below, elucidates the information flow utilised in the case studies, adhering to the established protocol outlined in the Construction Record Procedure (Costain, 2021). The journey from the Construction Issue drawing to the finalised Status As-Built, now called CR (Construction Record), has long been a staple process, albeit one fraught with numerous challenges. This is precisely where the integration of innovative technologies can usher in substantial time efficiencies for the entire project. Timely completion of the official handover within three months of ALR (All Lanes Running) hinges on successfully executing this process.

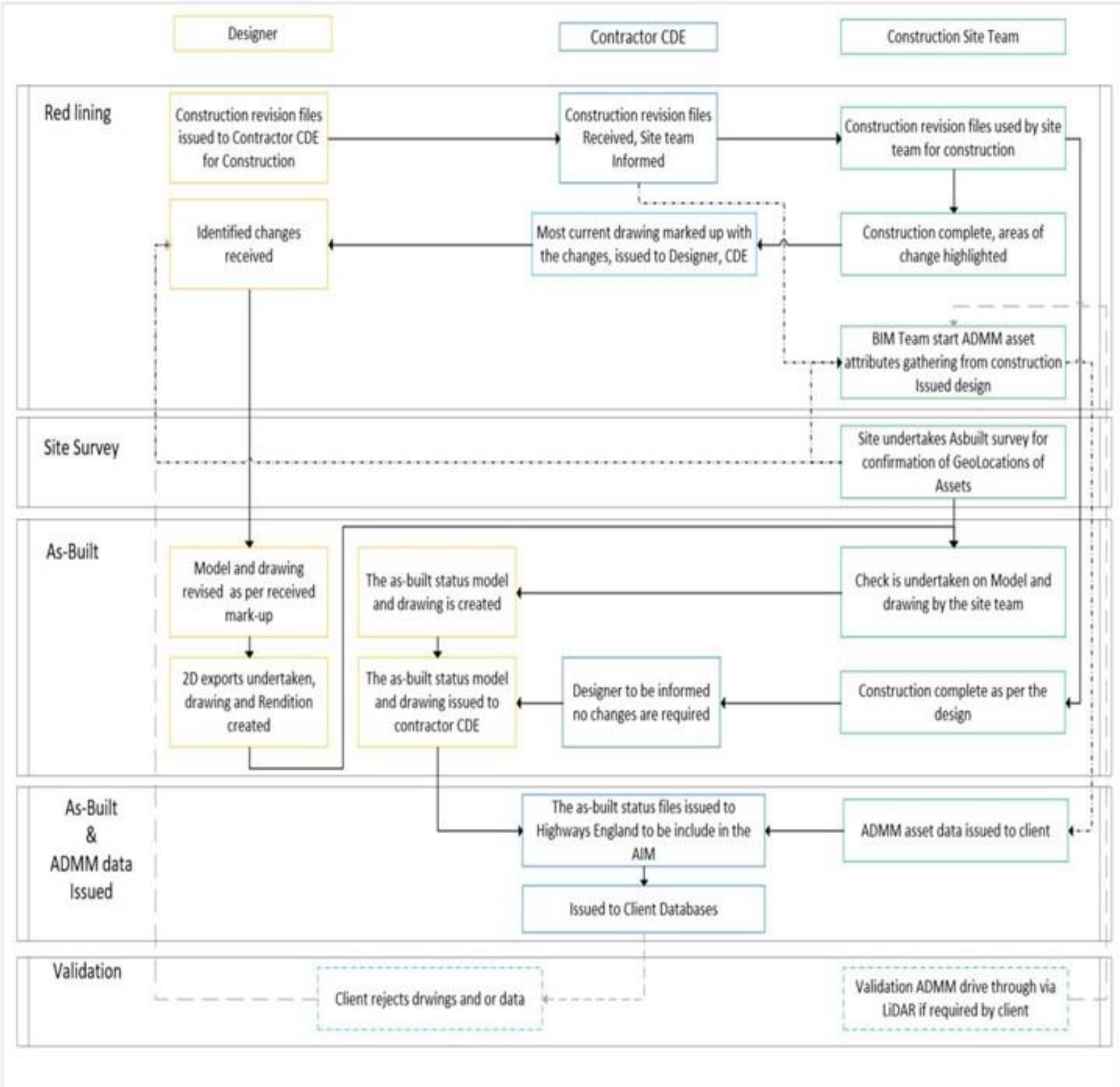


Figure 18 Image showing the process from construction issue to Validation (Starkey, 2022)

4.6.2 Redlining

This process allows the engineers to mark up and note what has changed on 'Construction Issue' drawings; it is now done by digital software such as a PDF writer or CDEs with a built-in 'Markup' function embedded within them, allowing full auditability of the process. In some cases, this is also done via a survey by a site surveyor; however, it is generally carried out after TM (Traffic Management) has been removed, therefore it has to be done at night, making it an H&S issue for the surveyor. Convention documents on how to mark-up drawings have been agreed on in many projects, lessons learned should be carried out as soon as possible making sure data and knowledge are not lost. Figure 19 shows how digital mark-ups should be performed.

- The following convention is to be is to be used when annotating drawings.
  - Red – for changes or deletions (e.g., change of dimension, reposition of a manhole)
  - Green – additions (e.g., additional road markings, fencing, signing)
  - Blue – notes to the construction record team for clarity. These are supporting notes that are not to be transcribed into the construction record drawing.
- Clouds shall be used in the preparation of redline drawings.
- The revision box should be updated to state Construction Record and should be signed and dated in accordance with the Construction Record Workflow Process.

Figure 19 Image showing how engineers should markup drawings (Starkey, 2021)

The images below Figures 20 & 21 show good and bad mark-ups; the blue boxes should have northings and eastings stated; this is also the requirement in the ADMM and is a piece of mandatory asset information (ADMM, 2021)

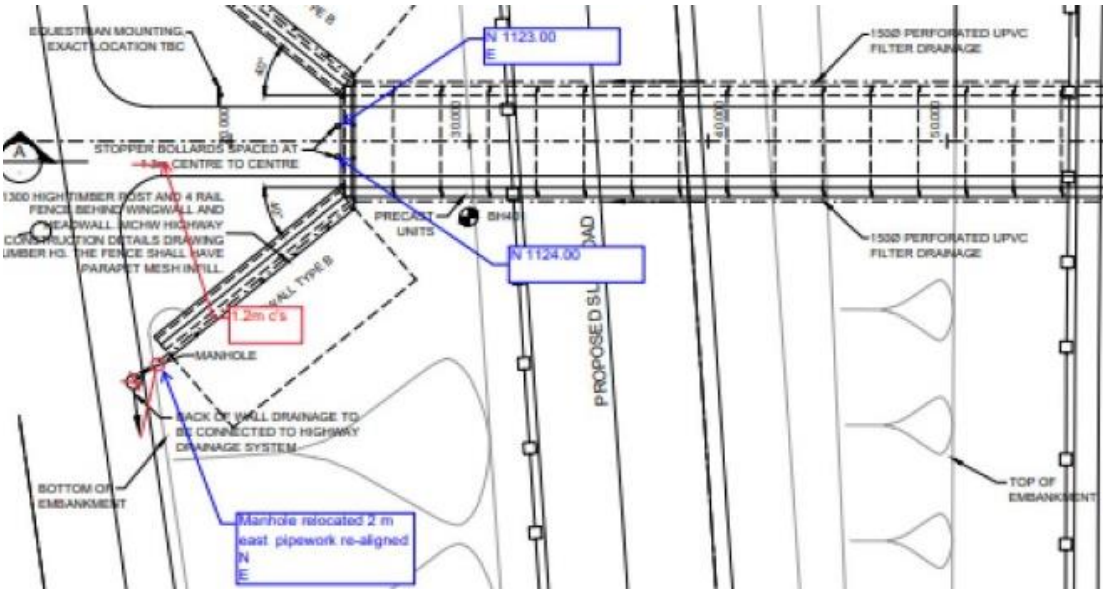


Figure 20 Bad markup incomplete data (Starkey, 2021)

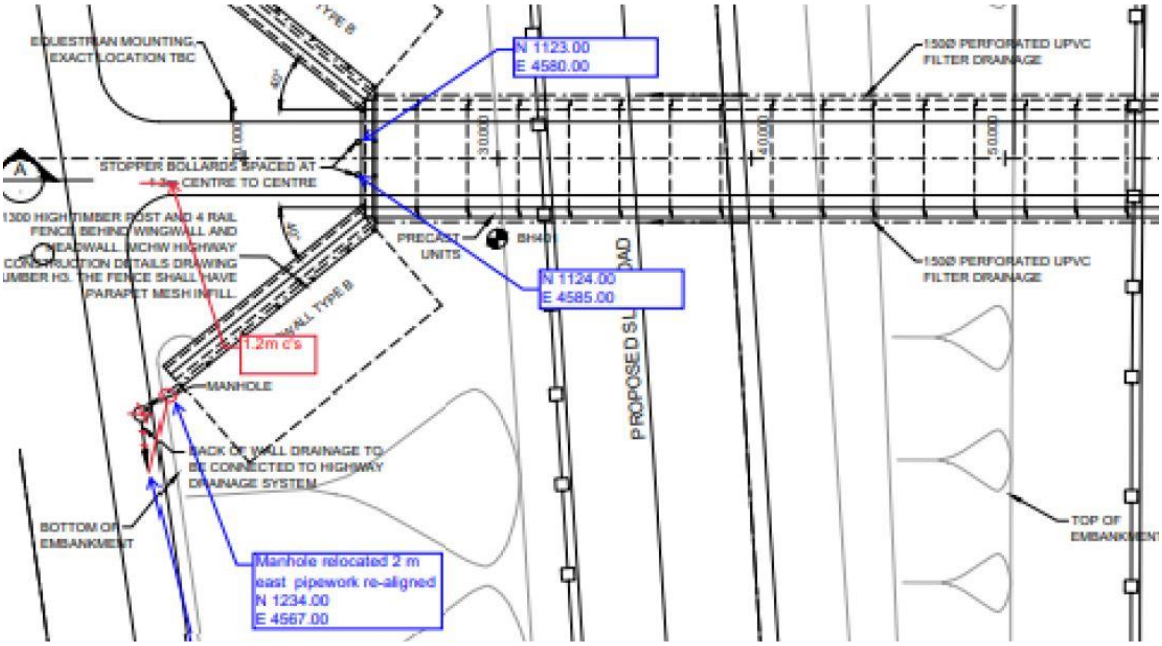


Figure 21 Good mark-up with complete data (Starkey, 2021)

4.6.2 For 'Construction Issue' Altered to As-Built

For this study, the term 'As-built' is still the common term for this Status of drawing; the new BIM Standards now refer to CR 'Construction Record'. Once the designers receive the 'Redlining' document from the contractor, they update the drawing and set of drawings that complete the series. As these projects are now following BIM level 2 requirements, the model for that volume (series) is updated, and the 2D xrefs that are produced from the models are output into a PDF set of drawings.

As-built drawings vividly capture the intricate tapestry of construction processes, often spanning hundreds of steps when crafted with care. Despite their undeniable importance, As-builts can, unfortunately, fall by the wayside amidst the tasks and paperwork accompanying each project. However, their significance cannot be overstated, particularly in ensuring the seamless maintenance of a structure post-construction. The pivotal role of as-built drawings is sometimes overlooked in project scheduling, relegated to a vague time frame or relegated to the eleventh hour. This neglect risks jeopardising the accuracy and completeness of the final product, as changes and adjustments made throughout the project's lifecycle may go undocumented. Digital Builder (2021) noted that this oversight could compromise the project's integrity and hinder efforts to deliver a precise result.

As-builts must contain a wide range of information and papers to be as transparent and helpful as feasible. Among other things, this data consists of:

- Recording changes to scale or using the same scale as the original
- Using clear labels and descriptors
- Changes in sizing, materials, and location
- Noting unexpected obstructions encountered
- Dates when alterations were made
- Changes made as a result of the final inspection
- Attaching all related shop drawings and appendices

4.6.3 On-Site Surveys to Confirm Geo-Location of Assets

Some assets require further on-site surveys; these geo-locations x(Easting) and y(Northing) are critical to all assets and, for some reason, often missed from information on drawings or schedules, as shown in Figure 23. This is also because highways designers and contractors use a ‘Construction Chainage’ whilst maintenance providers use a ‘Chart & Node’ system that is used throughout the SRN (Strategic Road Network). A lot of the X & Y coordinates are produced from the construction chainage and, therefore, been incorrect for asset location information that also needs to be generated in British National Grid (BNG), where construction uses 'Local Grid' very different from BNG, all this is stated in HE's ADMM. The images below Figure 22 are an amalgamation of the existing construction drawing and a new survey that was exported into CAD and validated with a site surveyor.

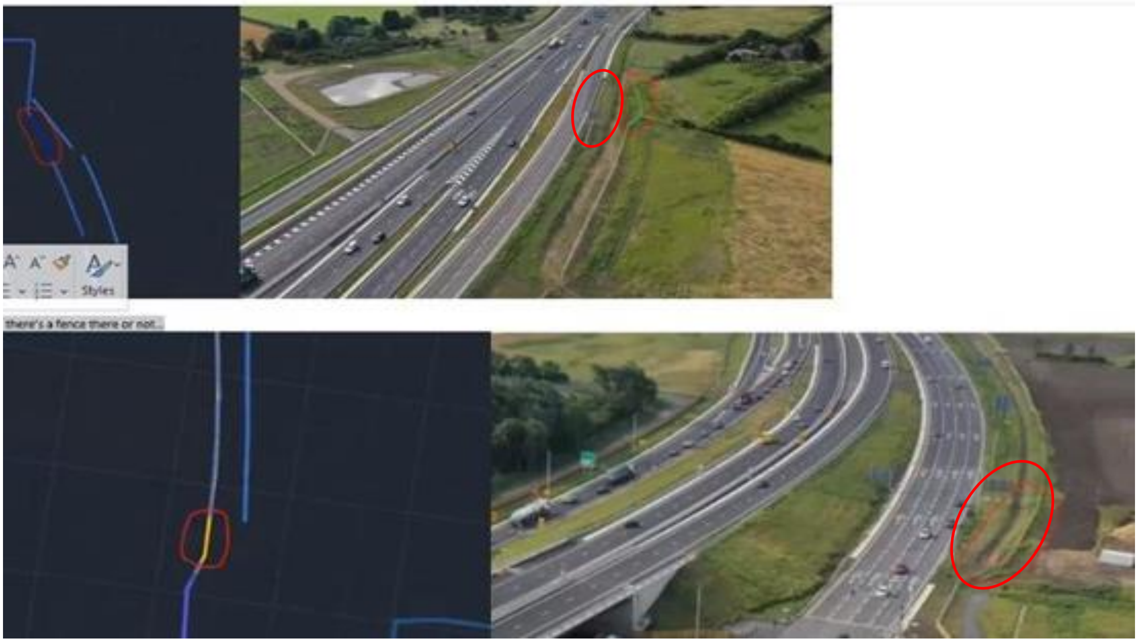


Figure 22 Images showing surveys exported to CAD checked against site images (Starkey, 2021).

4.6.4 Asset data issued to maintainer's databases

Asset data is routinely disseminated to area maintainers through predefined deliverables, as the Asset Data Management Manual (ADMM) outlines. These manual mandates updates every six months to accommodate the inclusion of new assets and attributes. These deliverables typically consist of a singular spreadsheet per asset type, a 2D CAD drawing for each asset category, and a set of Shapefiles compatible with geospatial software Figure 23. However, these practices inadvertently introduce additional time requirements, especially given the prolonged duration of most highway projects spanning several years. Consequently, the ADMM undergoes revisions more frequently, sometimes exceeding four updates, thereby injecting uncertainty into the workflow.

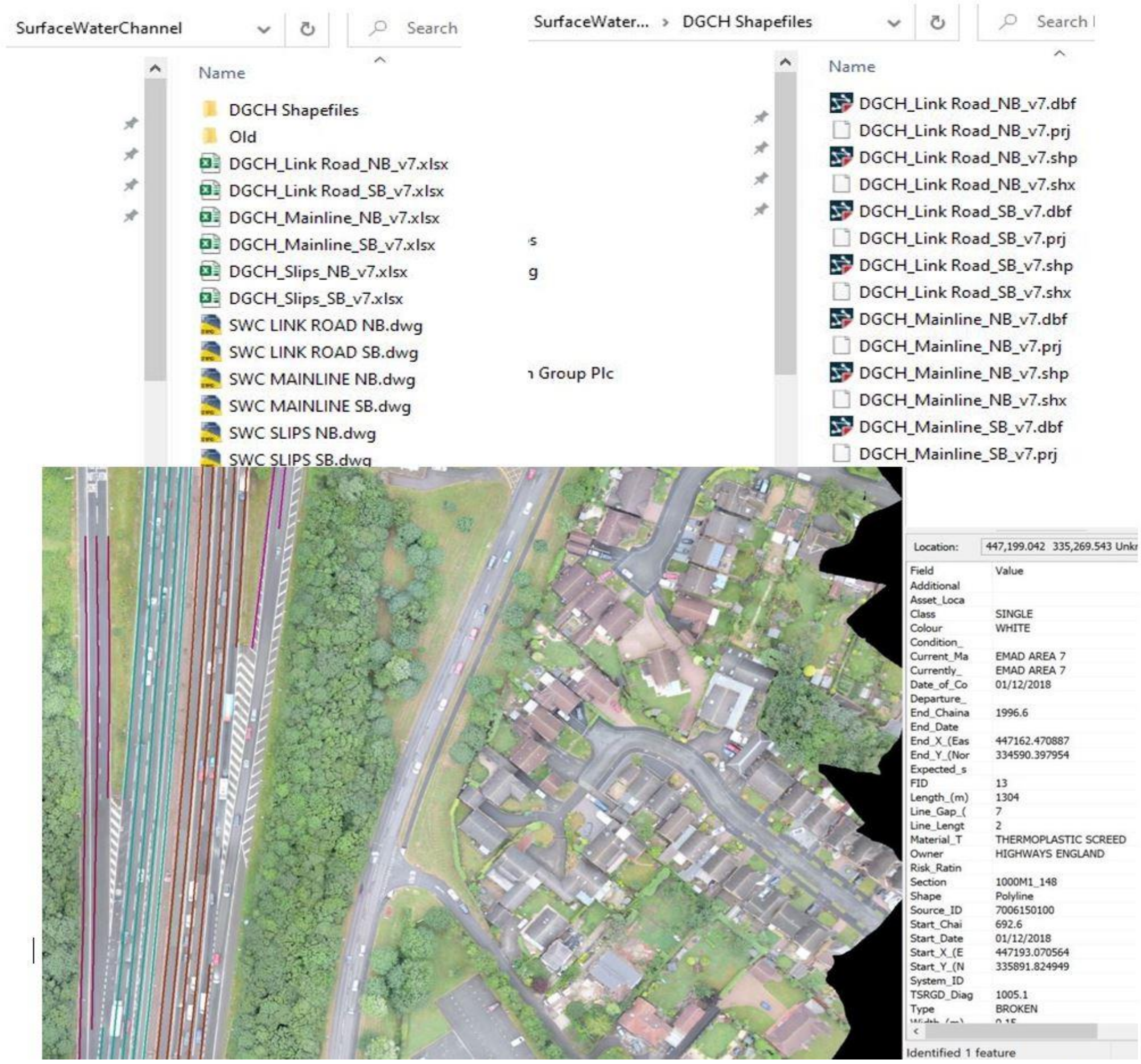


Figure 23 Image of typical asset type file formats and output from GIS GIS-based system that allows the asset data to be interrogated (Starkey, 2021).

4.6.5 Validation of Assets

This is carried out by third parties and is done only when the road is fully open and all TM removed; subcontracting a third party to undertake Lidar & Imagery surveys, which would extract the required inventory data following the ADMM version agreed upon and process this to the ESRI format compatible with Confirm (Barns, 2018). The survey would utilise a vehicle with mounted sensors, lasers and 360 cameras, providing raw datasets that position and describe assets to a higher degree of accuracy and completeness. The survey would be conducted by making several driven passes along the scheme at traffic speed at a predetermined time when traffic volumes are reduced Figure 24. This technique does not require traffic management measures, significantly improves safety for operatives and customers, and does not affect road operations. However, there is a line of site issues and any assets that fall within these areas are missed, meaning a site survey would still be required to complete the validation (He et al., 2017).

Figure 24 Image showing driven LiDAR for asset validation (Starkey, 2019)

4.6.6 Time Scale

The timeline allocated for HE Major Projects is set at three months post-construction phase. While initially appearing reasonable, experiences suggest otherwise, as highlighted in the case study. With the introduction of IAN182 and, more recently, GG182, the emphasis is on early initiation and meticulous resource planning. The importance of this was underscored in the recent endeavour, the A19 Testos project, having to provide asset data to maintainers at least one month before the deadline is imperative. This allows ample time for database owners to import and thoroughly verify the data's compliance. Consequently, the available time frame becomes even more restricted. In light of these insights, it is essential to heed the discussions from the handover meetings regarding time management. It's worth noting that CONFIRM stands as the ASC's preferred central database solution.

- “CF confirmed that the Area team has batched together many schemes for upload, and currently, the timescale he understands is that it takes a few weeks to receive info from HE and then approximately one month from receipt to upload into CONFIRM” (Highways England YNE Region, 2020).

- “Ideally, once data is uploaded to CONFIRM, handover can be completed and signed off. However, the databases sometimes cause some issues. CF to provide further clarification as to when the data is required for CONFIRM uploads” (Highways England YNE Region, 2020).

The programming of this work is crucial; therefore it is now included in the project's overall program and is constantly coordinated by the project BIM Coordinator and Handover Manager. Figure 25 below shows an example of data processing programming now included in the overall construction programs.

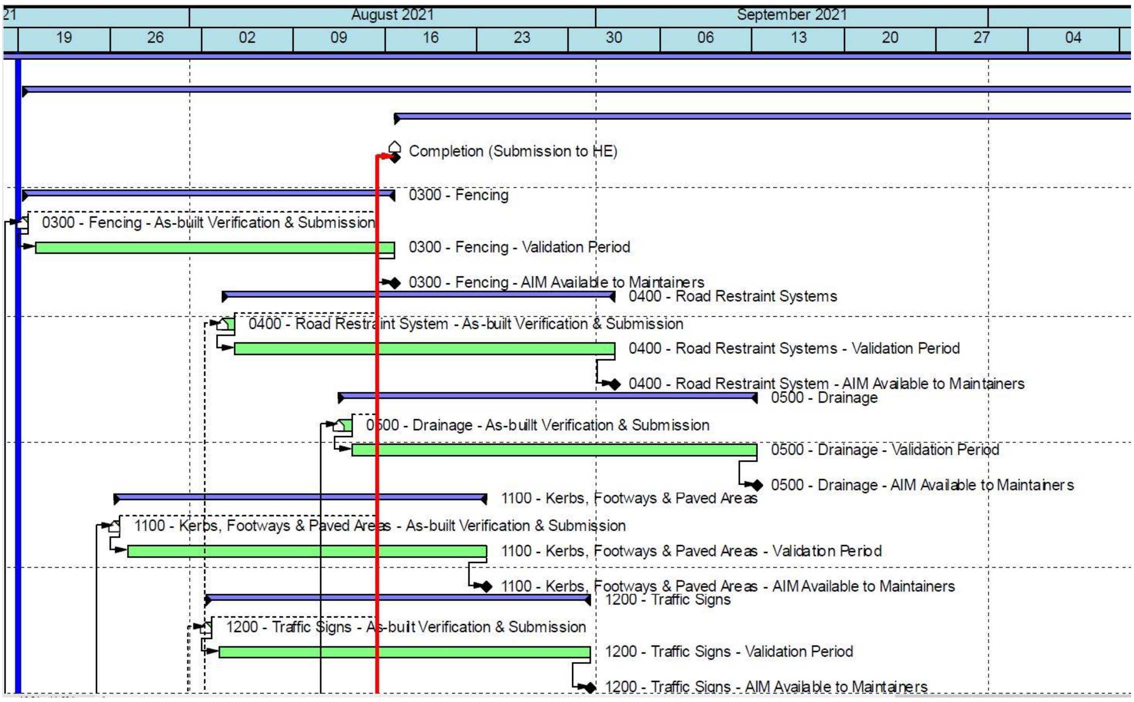


Figure 25 Shows asset processing as part of the overall program of works (Starkey, 2020).

4.7 Qualitative Data Collection

A timetable for semi-structured interviews with highways sector professionals covering BIM, Design and Asset Managers and other specialists was created. Although the questions were presented to the interviewees by category, it did not require them to stick rigidly to them; the interview schedule was used for queries on the themes represented by the primary objectives of this research: ‘To analyse the state of practice for asset information and the potential of BIM implementation’, ‘To investigate the strategies for capturing real-time asset information to facilitate life cycle asset management, ‘To investigate and validate the effective strategy and protocol for capturing highway asset information’, ‘To develop the BIM-based framework and associated protocol for real-time collection, validation, and handover of attribute data for Highways England major schemes’.

Participants were engaged in discussions regarding their involvement in meetings and workshops with Highways England concerning BIM processes and updates on the Asset Data Management Manual (ADMM). Similarly, inquiries were made about any engagements with Highways England regarding updates to the Infrastructure Asset Management-Information System (IAM-IS) or any other operational databases. During the interview sessions, participants were prompted to reflect on the challenges of collaborating with clients and contractors during the project handover phase. Specifically, they were asked whether the implementation of BIM had facilitated any aspects of asset attribute management during the handover to Highways England's area maintenance teams. These discussions naturally segued into inquiries about the factors influencing the handover process of their projects and the methods employed to capture and validate newly constructed assets. Participants were also prompted to share insights into how asset locations were captured and provide their perspectives on the optimal approach to collecting asset data for major highway schemes.

4.7.1 Contributing Factors – Client changing scope

Change orders are one of the major sources of cost growth and disruptions to field productivity on building construction projects. The most frequent types of change met in constructing infrastructure projects are changes to the original scope of work or those that arise from unexpected conditions in the field (Mahat & Adnan, 2018). This is especially true if the client and the maintenance team change the standards agreed upon in the contract or the way they want the data handed over to them.

Over the case studies, this happened many times, not helping the contracting team, which was already learning to gather and collate asset attribute information.

“Change in database format (e.g., HAPMS/IAMIS) within the life of scheme”
“Changes in the number of attributes caused challenges collating the information.”
“Uncertainty of ADMM version to be used, both contractually and operationally”
“Change in ADMM version during scheme duration” (Interview Participant JB,2021).

The ADMM operates on a biannual update schedule, where HE systematically augments assets within the IAM-IS framework. Within four weeks of contract finalisation by all parties, Project BEPs are issued and consented to. This pivotal phase determines the ADMM version to be utilised, varying from version 3 to version 7 in the case studies. This early determination facilitates the establishment of databases and data acquisition sources, enabling contracting teams—employing specialised software—to seamlessly transform data into client-specific formats, as highlighted in the case studies.

4.7.2 Contributing Factors – Lessons Not Learnt

Because HE has different maintainers for different areas, lessons are not picked up as quickly as they should have been; another issue is that HE is not prescriptive enough regarding handover. There is no specific handover process for a Contractor to pick up and work with. The emphasis is on them to make contact with the future asset owners to organise handover. This can lead to missing things or not being of the appropriate quality. “There is no reason there cannot be a standard handover document to work to. The H&S files are standard and can then be adapted for each project. All HE databases are the same throughout the country, therefore they will commonly have the same requirements and specifications” (Interview Participant, ER, 2021).

Also, HE has not consulted the wider maintenance teams on the content of the ADMM or what has been included in the data dictionary, as this holds critical information that the maintainers require to operate their maintenance schedules. “As the service provider, it would be good to be involved in helping create an informed ADMM that is realistic and envelopes the need to capture asset data that is of use and pertinent to the client and service provider. There are no other key people; it just lands on the team without prior notice, and need to be involved” (Interview Participant, MW, 2021). This is designed to overcome one of the critical difficulties surrounding project lessons learnt. They are not realised until they have been successfully implemented on future projects (Fuller et al., 2010).

4.7.3 Contributing Factors – Knowledge Gap

The ‘Knowledge Gap’ for this research is based on the case studies projects above and the evidence received from other literature; however, this issue goes much deeper in the wider BIM fields of the construction industry. Generally, there is a disconnect between those who are BIM practitioners and those who are not also construction team members who have had first-hand experience of how BIM can help with the overall process and those who have had no contact or visual benefits with how it helps apart from hearing the terms needing to be BIM compliant.

The gap is not just isolated to certain areas of the industry; it crosses the entire construction process, from clients to contractors to end-user maintainers. Not enough people appear to be currently educated in the BIM process. “It’s disturbing that there is such a disconnect between the needs and requirements of customers, investors and the professionals who can deliver services” (Alexander, 2017, p1). The big issue is education; a lack of understanding of the benefits BIM brings means people see it as a cost, not an asset. What needs to be realised is that BIM is an enabler for greater efficiency right across the value chain, not to mention the economic benefits it brings (CIOB, 2017).

The knowledge gap is also prevalent in the project's handover stage and asset data exchange to the maintainers. “Contractors and designers do not typically understand the issues with maintaining assets or asset data, as a consequence they can be reluctant to provide the amount of information required by Service Providers” (Interview Participant ER, 2021). Asset data is alien to contractors and designers; they have no experience with what maintainers need. Contractors traditionally see the handover period as not important, and it is not easy to obtain engagement early in the project (Interview Participant ER,2021). The ‘Knowledge Gap’ has narrowed over the last few years, and projects have come down. In some circumstances, as stated in the above case studies, the contractor has become an educator for some elements of asset handover.

4.7.4 Contributing Factors – Meetings

Meetings in the infrastructure sector are a major source of collaboration and are, in some cases, the only source of gathering important knowledge for up-and-coming projects. For the asset data stage of handover and how the client wants and needs its information, there has been some discontinuity in how some requirements have been agreed upon without the collaboration of the area team specialist. As the ADMM is the primary document used for asset attribution, there has been very little collaboration with the ASCs; when asked in an interview, one replied, “Disappointing none. As the service provider, it would be good to be involved in helping create an informed ADMM that is realistic and envelopes the need to capture asset data that is of use and pertinent to the client and service provider. There are no other key people as well; it just lands on the team without prior notice, and the maintenance teams involved is needed” (Interview Participant MW, 2021).

Meetings for the primary database (IAM-IS) that the client has developed, and which dominates the ADMM did take place regularly. (Interview Participant ER, 2021) “Regular liaison meetings were held with the Service Provider’s Asset Data leads to discuss the various HE databases and the specific requirements for each. HE was in attendance, but the Service Providers were instrumental in providing the guidance and parameters for the various databases”. However, the guidance was not frequently fully taken on board, “Unfortunately, this fell upon mainly deaf ears. “Moving on to the new AD (Asset Delivery) contract and having to migrate to

CONFIRM country on one system and then taken off, IAMIS is clunky but has some good bolt-ons like MapCapture" (Interview Participant MW, 2021).

Due to their experience gained in the case studies, the contractors are now in a position where they can pass on the knowledge themselves: "Contractor meetings are now held to teach the designers and new maintenance providers how to complete asset data handover and the different loaders for each database but using the same ADMM attributes" (Participant BE, 2021).

4.7.5 Contributing Factors – Databases

HE continues to oversee numerous operational databases, all gradually integrating into the IAM-IS system. While progress is underway, several databases still stand apart. Typically, Scheme delivery partners are not required to engage directly with the asset data management systems. Instead, they are expected to furnish data suitable for updates, with the Structures Management Information System (SMIS) being the sole exception, where designer input is necessary.

Based upon the requirements of IAN 182: Enabling Handover, scheme delivery partners shall, from the outset, establish with the regional HE teams a list of key systems and contacts to support the exchange of asset data, supported by a single point of contact for all correspondence (Highways England ADMM, 2018).

4.7.6 Contributing Factors – Process Challenges and Time Constraints

Generally, it takes three months from ALR and the handover of asset attribute data for HE area maintenance teams to receive the database information. This can be negotiated if there are early warnings in place with, HE that, due to scope changes, the deadline cannot be made.

“Timescales are the biggest influence; how long it takes for the data to be mounted into HE’s databases is key. The A160 timescales were particularly tight, in fact, pretty impossible, as when work was being signed off, on-site data was expected to be mounted in the relevant database” (Interview Participant MW, 2021).

As noted in the case studies, the process is still very manual, and the databases are very rigid in how they will accept information. “Because of the way the HE databases are set up, the current methods are the only way to get information into the databases. They do not allow for any different methods. Databases will only accept certain formats, therefore the data, however, captured at the end, needs to be able to be output to the traditional formats“ (Interview Participant ER, 2021).

Consent to Implement (CTI) is the pivotal sign-off, marking the pathway to resume operations at full capacity. It represents a fundamental set of prerequisites, essential even before finalising the as-built documentation. The stringent nature of CTI demands adherence to the ADMM data, posing a significant challenge to the team. Nevertheless, it is a critical milestone in ensuring the seamless progression towards the goal.

Capturing the as-built data and populating the ADMM attributes as per as-built is challenging; creating information from surveys prior to as-built drawing updates due to time constraints. Accessing certain attribute information can be time-consuming, as can looking up multiple installation sheets for specific information. The time frame for completion is crucially important; the area teams need the information for when the motorway opens back up to 70mph and all lanes running, therefore on day one, the rest of the handover documentation, i.e. the H&S file, including As-builts, certificate etc is handed over three months later (Interview Participant BE, 2021).

4.7.7 Contributing Factors–Lack of Planning and Resources for Handover

Looking over the case studies and handing them over to different HE area teams, it became clear that better planning and more resources were required. On the SMP M1 junctions 23a to 25 project, the team did not want to make the same planning and handover mistakes on the A160 scheme.

“Previous scheme lessons learnt regarding asset management are typically left last to complete rather than made a daily task/business as usual. Thus, increasing costs to track and manage data as the project nears the handover stage, due to hiring a third-party company specialising in asset management/data gathering” (Interview Participant DT, 2021).

“Earlier engagement can help a successful handover. Also, engagement with the right personnel who will be taking the assets back over is essential. This should start at the design stage with the same personnel. Contractors and designers do not typically understand the issues with maintaining assets or asset data, therefore they can be reluctant to provide the amount of information required by Service Providers” (Interview Participant ER, 2021).

Effective communication and proactive planning with the service provider emerge as pivotal factors, as evidenced by the case studies. Their expertise allows them to offer invaluable insights into the data prerequisites for contractors, along with assistance and direction to ensure that the requisite data is furnished in optimal formats for various HE databases.

“Unfortunately, this is historic. Contractors see the handover as being the last piece of the jigsaw in relation to major projects. Then, the process can become somewhat rushed, and the data requirements of the service provider who is managing HE’s databases on their behalf are often not understood” (Interview Participant MW, 2021).

4.8 Conclusion

With varying degrees of success, BIM has been used in all the case studies above to deliver a more reliable process, especially on early adopter schemes (A160). However, work remains before the BIM can fully mature in the highways sector, especially for the handover of asset data attributes and how it is captured and validated for Highways England.

Although these case studies have not considered all the challenges mentioned in the literature, this research still has significant implications for BIM implementation for infrastructure development. Consideration how the Contributing Factors to problems highlighted in interviews can be improved to ensure that BIM continues to grow as a process and contributes to the real-time collection and validation of asset information.

Chapter Five Data Collection

5.1 Introduction

Chapter 3 guards the reader through the philosophical underpinnings that shaped the research approach. Elucidating the rationale behind the chosen philosophical viewpoint, offering validation for its selection. Additionally, and clearly outlining the methodological techniques employed in this study, underscoring their relevance and justification within the research framework. Central to this chapter are the insights gleaned from semi-structured interviews with esteemed professionals from the industry. Dissecting the interview data, presenting a thorough analysis alongside the techniques instrumental in its interpretation. This rigorous examination lays the foundation for the development of a robust BIM-based protocol and a decision support framework. These innovations are tailored for real-time data collection, validation, and seamless handover of attribute data, specifically engineered to meet the demands of key Highways England developments.

5.2 Qualitative data collection using semi-structured interviews

Qualitative research uses various techniques when studying individuals in their workplaces, including interviews, audio-visuals, documents, and observations (Creswell, 2014). Observation techniques allow for first-hand experiences with information being recorded but are challenging to record accurately. Even though documents and audio-visual may offer the view of first-hand accounts, difficulties in explaining the account may interfere with understanding a problem. Conducting interviews allows the researcher to control the information, but it can be challenging to retrieve sensitive information. Also added is the difficulty of recording and transcribing any further information. Semi-structured interviews are less formal than structured interviews since they ask the same questions in the same order without flexibility (Flannery et al., 2019). The most common and commonly utilised data collection procedures in research are qualitative semi-structured interviews. They are useful because they allow researchers to investigate subjective perspectives and compile detailed reports of people's experiences. An interview schedule is typically employed, allowing the researcher to address a specific topic while allowing the respondent to speak in their own words and explore issues and themes that are significant and relevant to them (Evans & Lewis, 2017).

Interview participants were carefully selected based on established criteria, specifically targeting individuals with substantial experience in infrastructure, particularly in the highways sector. The selection process prioritised candidates with a rich background in the industry, identified through the researcher's extensive network of contacts and their involvement in pertinent case studies. Employing a non-probability sampling method proved advantageous for this study, ensuring the inclusion of participants who could contribute valuable insights. This approach facilitated high-quality discussions, conveniently accommodating all participants' schedules (Flannery et al., 2019). Following Galvin's (2015) recommendation, ten individuals were interviewed, aligning with common practice in qualitative research, where interviewee numbers typically range between 8 and 17 to ensure comprehensive coverage of relevant knowledge domains. Table 8 provides an overview of the interviewed participants, detailing their backgrounds and expertise pertinent to the inquiry. Throughout the interviews, participants offered invaluable perspectives on current practices and effective strategies for real-time asset information capture. Each session, lasting between 45 minutes and an hour and was recorded.

Table 6 Interviewees

Interview	Job Role	Experience (years)
1	BIM Manager	11
2	BIM Coordinator	7
3	BIM Manager	9
4	Data Manager	20
5	Snr Agent	25
6	Data Analysis	26
7	Quality Manager	15
8	Data Manager	9
9	Data Analysis	21
10	Data Analysis	17

A timetable for semi-structured interviews with highways sector workers covering BIM/Designers/Asset Managers and other specialists was created. The interview questionnaire aimed to understand the realistic attitudes and behaviours and operative opinions on improvement asset data collection. Although the questions were presented to the interviewees by category, it did not require them to stick rigidly to them; the interview schedule used questions on the themes represented by the primary objectives of this research: *'To analyse the state of practice for asset information and the potential of BIM implementation', 'To investigate the strategies for capturing real-time asset information to facilitate life cycle asset management',* ‘To investigate and validate the effective strategy and protocol for capturing highway asset information’ and ‘To develop the BIM-based framework and associated protocol for real-time collection, validation, and handover of attribute data for Highways England major schemes’.

Participants were kindly requested to share their insights on the meetings and workshops they had attended with Highways England, focusing on discussions around BIM processes and ADMM updates. Similarly, when soughing information on any engagements with Highways England about updates on IAM-IS or other operational databases. During the interviews, attention was directed towards understanding the challenges encountered during collaboration with clients and contractors, particularly during the project's critical 'handover' phase. Additionally, participants were invited to reflect on whether the implementation of BIM had facilitated the transfer of assets to Highways England's area maintenance teams. This line of inquiry led to discussions on the factors influencing project handover decisions and the strategies employed for capturing and validating newly constructed assets. Finally, participants were invited to share their perspectives on asset location capture methods and provide insights on the most effective approaches for gathering asset data in major highway schemes.

The topic was discussed informally with two experienced asset engineers from another industry. This was done in part as a practice run for the questions on the interview agenda. Based on feedback from these discussions, the final interview questions and the sequence of questions were adjusted for clarity.

5.3 Qualitative data analysis and findings from industry interviews

The interview data were analysed using MAXQDA, a programme created for computer-assisted qualitative and mixed methods data, text, and multimedia analysis in academic research. The program was used to import the transcribed interviews and the audio recordings. The responses to each interview question were organised into ten distinct documents and loaded into specialist software. Thematic and quantitative content analysis approaches were used to evaluate and interpret the interview data, as outlined in the 'Research Design and Methodology' chapter. The thematic analysis consisted of first reading all the answers to each question. Then, several codes for the data using the ‘Open Coding’ process, an acceptable method to report qualitative data from interviews, are shown in Figure 26 (Weston et al., 2001).

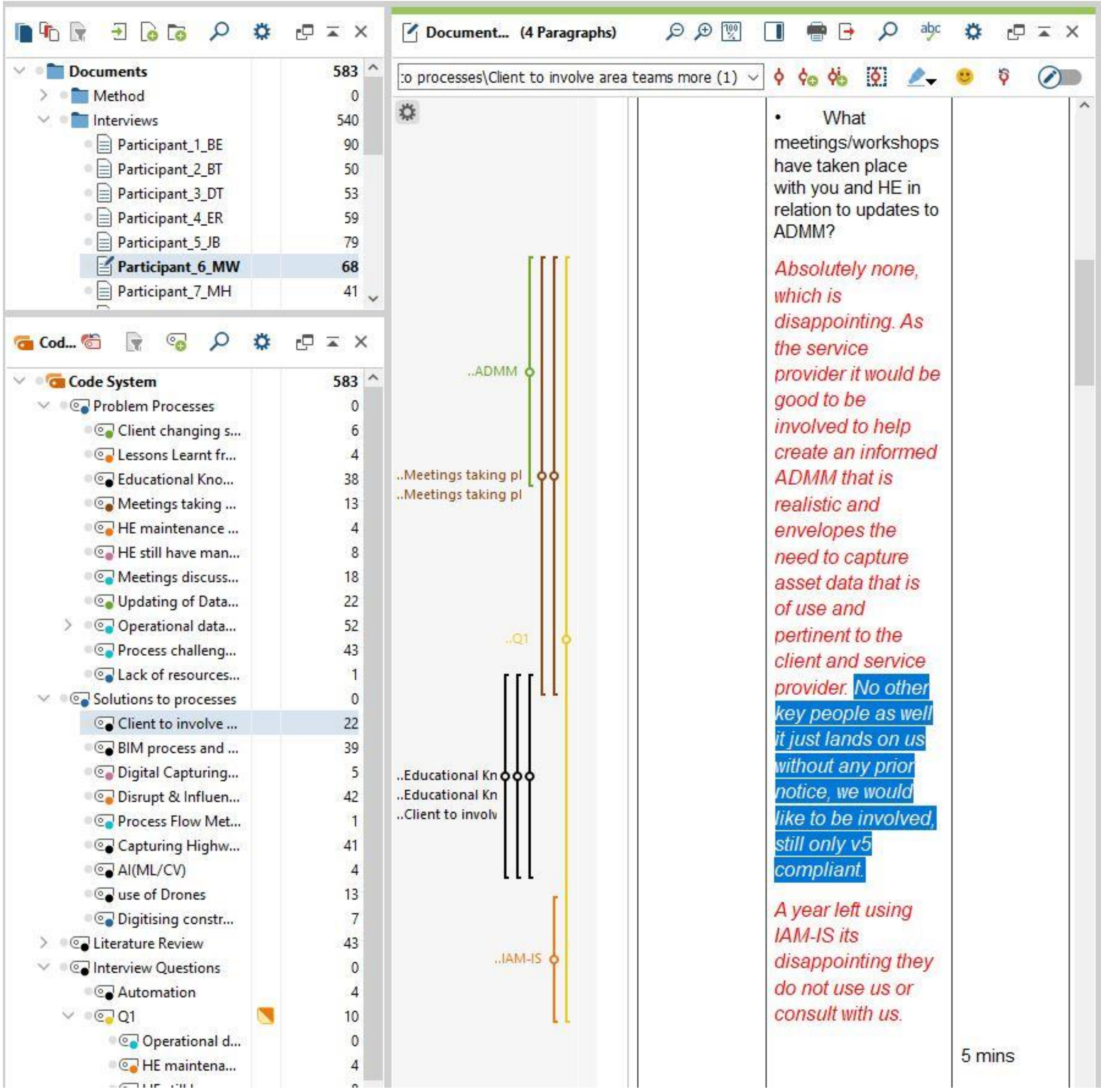


Figure 26 MAXQD showing coding from interview questions (Starkey, 2021)

Each response was then reread, and codes were assigned to each answer. In many instances, additional codes were generated based on individual responses. When the data appeared inconsistent, the audio recordings were reviewed again to ensure correct transcription. Braun and Clark (2006) propose an iterative technique for coding interview data.

Upon concluding the coding process for each question, all codes and corresponding quotations were clearly sorted into pertinent themes. These themes underwent thorough scrutiny to guarantee uniform data classification. Braun and Clark (2006) advocate for an iterative approach to categorising and thematically organising related codes, which was duly adopted in this study.

After reviewing the transcripts multiple times post-interview transcription and highlighting key discussion points. Following the guidelines laid out by Braun and Clarke (2006) for transcription refinement across six stages, this process aimed to effectively capture both overt and subtle remarks. Employing a content-driven thematic analysis, the data underwent careful scrutiny, with codes and keywords meticulously identified and subsequently organised into data coding segments, as outlined in Table 8.

Table 7 Examples of the coding segment

Quotation	Interview	Factor
'[...] Absolutely none, which is disappointing. As the service provider, it would be good to be involved […].'	6	Meetings with HE in relation to ADMM
'[...] There is not a specific handover process for a Contractor to pick up and work with. The emphasis is on them to make contact with the future asset owners to organise handover […].'	4	What has Influenced Handover
'[...] Adopting BIM/Digital Engineering does have a beneficial impact due to equipping the project teams with the correct tools where data management is concerned […]	3	How has the BIM process helped with Asset Attribute Handover

After examining the data segments proposed by Braun and Clark (2006), the information was classified, as presented in Table 9, with references and associated literature indicated. Following the exploratory mixed approach, these factors served as the foundation for the questionnaire.

Table 8 Contributing Factor referenced back to Literature

		Interviews											
No	Contributing factor for rtAIM	1	2	3	4	5	6	7	8	9	10	Source of literature	
Objective 1 To analyse the state of practice for asset information and the potential of BIM implementation.													
CF1	Client changing scope while project is under construction	✓	□	✓	□	✓	□	□	□	□	□	(Hwang et al., 2013)	Problems
CF2	Lessons NOT learnt from previous projects with HE	✓	✓	□	□	□	□	✓	□	□	□	(Fuller et al., 2010)	
CF3	Knowledge Gap	✓	✓	□	✓	✓	✓	□	✓	✓	✓	(Alexander, 2017	
CF4	Meetings taking place due to contractors' lack of knowledge	✓	✓	✓	□	✓	✓	✓	✓	□	✓	(Tommelein et al., 2000)	
CF5	HE maintenance area teams have different main databases, IAMIS/CONFIRM	✓	□	□	□	✓	□	□	✓	□	□	(Hood and Wilson, 2001)	
CF6	HE still have many databases that need to be populated	✓	□	□	□	✓	✓	□	✓	□	□	(Aziz et al., 2017)	
CF7	Lack of meetings discussing databases	✓	✓	□	✓	✓	□	✓	✓	□	✓	(Agrawal, 2008)	
CF8	Updating of Databases-who does this	✓	✓	✓	✓	✓	✓	□	□	✓	□	(Michele and Daniela, 2011)	
CF9	Operational Databases	✓	✓	□	✓	✓	✓	□	□	□	□	(Han et al., 2012)	
Objective 2 To investigate strategies for capturing real-time asset information to facilitate life cycle asset management													
CF10	Process challenges and time constraints	✓	✓	□	✓	✓	✓	✓	✓	✓	□	(April et al., 2019)	
CF11	Lack of resources and planning for the Handover stage	□			✓		□	□	□	✓		(Wang and Zhang, 2021)	

CF12	Client to involve area teams more		✓	✓	✓	✓	✓	✓	✓	✓	✓	(Patacas et al, 2020)	Improvements & Solutions
CF13	BIM process and its metadata	✓	□	✓	✓	✓	✓	□	✓	✓	✓	(Munir et al., 2019)	
Objective 3 To investigate and validate the effective strategy and protocol for capturing highway asset information													
CF14	Digital Capturing of asset information	✓	□	✓	□	✓	□	✓	□	□		(Bates, 2007)	
CF15	Disrupt & Influenced Handover	✓	✓	✓	□	✓	✓	✓	✓	✓	✓	(Sarden and Engstrom, 2010)	
CF16	Process flow Methods	□	□	□	✓	□	✓	□	✓	□	□	(Halttula et al., 2020)	
Objective 4 To develop the BIM-based framework and associated protocol for real-time collection, validation, and handover of attribute data for Highways England's major schemes													
CF17	Capturing Highway Assets	✓		✓	✓	✓	✓	□	✓	✓	✓	(Haalaa et al., 2008)	
CF18	AI(ML/CV)-machine learning in construction	✓	✓		□	□	□	□	□	□	✓	(Xu et al., 2021)	
CF19	Use of drones in construction	✓	✓	✓	□	□	□	✓	✓	□	✓	(Li and Liu, 2018)	
CF20	Digitising construction documents	✓	✓		□	✓	✓	□	□	□	✓	(Wong et al., 2018)	

Note CF = Contributing factor

5.4 Research Reliability

The reliability of research hinges on the consistency of data collection processes when replicated (Saunders et al., 2009). Braun and Clark (2006) assert that quantifying the quality of research proves challenging due to the interpretive nature of qualitative studies, wherein knowledge is constructed and contextualised rather than uncovered. They highlight the divergence among qualitative researchers regarding the relevance of replication, though efforts have been made to enhance the quality and rigour of qualitative inquiry. Saini and Shlonsky (2012, p. 115) acknowledge the lack of consensus among researchers on this matter.

Nevertheless, they propose three key steps to ensure reliability in qualitative research:

- Quotes and examples are used to support themes.
- Themes and quotes consistency
- The study process's transparency

As shown in the images above, demonstrating a link between the results and the data is critical in increasing the reliability of qualitative research, which necessitates describing the analysis process in as much detail as possible when reporting the results, i.e. audit of the decision trail (Saunders et al., 2009). Throughout this study, quotes and examples are used to support the themes that emerge from the interview data and responses to the open-ended questions in the survey. The interview data represent the study's qualitative approach, whilst the quantitative method is represented by the survey results. This means a mixed-method technique was used in this study. The mixed-method approach will enable the survey results to complement and uphold the findings from the interviews conducted in creating the proposed framework Braun and Clark (2006). This thesis will plainly and accurately describe the methods and processes used throughout this research.

5.5 Quantitative Introduction

The preceding paragraphs have provided awareness into the data collection and analysis techniques employed for the Internet questionnaire, crucial for validating the research process. Transitioning forward, this section delves into the quantitative methodologies utilised within this mixed-method investigation. Assessing the feedback from subject matter experts regarding the construction industry survey and thoroughly examine the survey data results.

5.6 Quantitative Data Collection Procedures

A support framework is built on several connected concepts underpinned by phenomenon and framework-specific philosophies (Jabareen, 2009). The support framework proposed in this research aims to enable the capture of assets in real-time; this research has been developed based on the results of interviews with the ten SMEs (Subject Matter Experts). Over 40 emails were sent to construction professionals in the UK who work on highway projects requesting their participation in the survey. Respondents were urged to distribute the survey link to individuals inside their firm who could contribute to the study; thirty replies were received from the SME community.

The survey consisted of questions/statements presented in four sections based on the Aims of the research; a copy of the questionnaire is presented in Appendix 1. The survey was split into five sections, and the last section collected demographical information about the respondents. The first four sections of the survey were presented to the respondents with four research aims with accompanying questions formed from the thematic analysis from the semi-structured interviews. The respondents were then asked to rate each statement to elicit their level of agreement or disagreement based on Likert data. Each statement in the survey provided options ranging from ‘Strongly Agree’, ‘Agree’, ‘Neither agree nor Disagree’, ‘Disagree’, and ‘Strongly Disagree’. As a result, it is possible to determine the overall significance of each measure by adding up participants' responses to all of the measures.

5.7 The following statistical tools will be used to present the data:

Cronbach’s Alpha:

Internal consistency refers to the idea of matching responses to a question with every response within the questionnaire in order to ensure consistency. Cronbach's Alpha is the most often used metric for determining the internal consistency of Likert data (Saunders et al., 2009).

Central Tendency:

Likert items are classified as 'Ordinal' data, and descriptive statistics are recommended for assessing them; however, according to (Norman, 2010), Likert data has been presented as continuous data in scientific publications for several years and may be examined using procedures appropriate for continuous data to obtain a robust comprehension of the data. To display the major patterns of the data, descriptive statistics such as bar charts, mode (i.e. the value that happens most frequently), median (the middle value of the data after the data is ranked), and mean (average rating using the numerical scale) will be utilised.

Data Dispersion:

Data dispersion illustrates the variability within a dataset, offering valuable insights into its central tendencies. Through metrics like the interquartile range (IQR) and standard deviation, gaining a nuanced understanding of how data points are spread across each Likert item. The interquartile range (IQR) delineates the spread between the upper and lower quartiles, encapsulating the middle 50% of the data. Widely acknowledged as a reliable measure of dispersion, it furnishes a concise summary of data variability. Complementing the IQR, the standard deviation further enriches the comprehension by showcasing the diversity of responses. Assessing the distance of data points from the mean affords a deeper insight into the distribution pattern, facilitating more robust interpretations (Saunders et al., 2009).

Respondent Experience:

It may be assumed that respondents with more than fifteen years of experience in the construction sector have a more in-depth understanding of how construction projects are carried out. To better understand the data, their ratings are computed separately, and their responses are presented independently to show how more seasoned construction professionals perceived the suggested support framework.

Table 9 Demographics of correspondence in the questionnaire

How long have you worked in the industry (Years)?	Number of Correspondents in the age group	% of Age group
0 to 5	6	20%
6 to 10	12	40%

11 to 15	6	20%
16 to 20	2	7%
over 20	4	13%
Total	30	

Job Role	Number of correspondents in the role	% of the group questioned
BIM Apprentice	1	3%
BIM Technician	6	20%
BIM Co-ordinator	14	47%
BIM Manager	6	20%
Snr BIM Manager	1	3%
Asset Analysis	2	7%
Total	30	

5.8 Cronbach's Alpha for Internal Consistency

Cronbach's alpha is an appropriate and widely used metric for determining data internal consistency (Field, 2013). When the questions/items measure a linked concept, Cronbach's alpha is recommended. In the context of this study, all assertions are offered to validate the support architecture proposed in this study, which attempts to enable real-time asset acquisition. Cronbach's alpha, as determined for the Likert items in the statistical software 'SPSS' is displayed in Figure 33. According to Gliem and Gliem (2003), an alpha value greater than 0.7 suggests that the data has a good internal consistency. The alpha for the 30 replies across the 3 sections of the questionnaire was section one $\alpha = 0.705$, section two $\alpha = 0.712$ and section three $\alpha = 0.714$, which reaches the threshold of 0.7 for the data to be deemed internally consistent.

Table 10/11/12 Showing SPSS analysis

Table 10 SPSS analysis of the state of practice for asset information and the potential of BIM implementation

Case Processing Summary			
		N	%
Cases	Valid	30	100.0
	Excluded[a]	0	.0
	Total	30	100.0
a. Listwise deletion based on all variables in the procedure.			

Reliability Statistics	
Cronbach's Alpha	N of Items
.705	7

Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
An educational knowledge gap still exist in relation to BIM and its implementation	26.83	7.247	.434	.673
BIM implementation will help with Handover and Asset Capture	26.83	7.385	.232	.716
Highways England maintenance area teams still have different main databases.	27.07	6.409	.539	.640
Highways England still have many databases that need to be populated	26.97	6.723	.505	.652
There is not enough meetings with HE/Contractor and Area teams discussing databases	27.30	5.941	.523	.641
Are lessons learnt from previous projects in regards to Handover of Asset Attributes	27.17	6.971	.325	.696
ADMM changes too often, thus leading to scope change	27.23	6.461	.400	.678

Table 11 SPSS analysis of the strategies for capturing real-time asset information to facilitate life cycle asset management.

Case Processing Summary			
		N	%
Cases	Valid	30	100.0
	Excluded[a]	0	.0
	Total	30	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics	
Cronbach's Alpha	N of Items
.712	3

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
As it stands, the processing requirements for capturing asset information pose challenges and time constraints	8.93	1.306	.478	.683
The client (HE) must include area teams more when discussing ADMM and asset attribute requirements	8.83	1.109	.545	.605
BIM processes and their metadata requirements can help deliver handover asset attribute data more efficiently	8.83	1.178	.573	.570

Table 12 SPSS analysis of the investigation and validation the effective strategy and protocol for capturing highway asset information.

Case Processing Summary			
		N	%
Cases	Valid	30	100.0
	Excluded[a]	0	.0
	Total	30	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics	
Cronbach's Alpha	N of Items
.714	5

Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
BIM processes can help with the capturing of asset information	18.10	3.472	.566	.635
BIM processes can influence the handing over of asset attribute information	17.93	3.857	.328	.718
BIM can replace traditional methods of capturing asset information	18.43	3.357	.353	.729
Digitising traditional construction documents for filed use will help with automation of data	17.97	3.206	.646	.598
There is always a lack of resources and planning at the handover stage	17.97	3.275	.531	.641

5.9 Central Tendency

The position of mean, median, and mode within the spectrum of central tendency measures is contingent upon the shape of the distribution. All three measures coincide in a normal distribution, represented in Image 27a. However, in skewed distributions such as those depicted in Figures 27b and 27c, the mean is drawn towards the tail due to the influence of extreme observations. Meanwhile, the mode, representing the most frequent score, naturally aligns with the peak or hump of the skewed distribution. As for the median, it positions itself between the mean and mode within a skewed distribution (Manikandan, 2011).

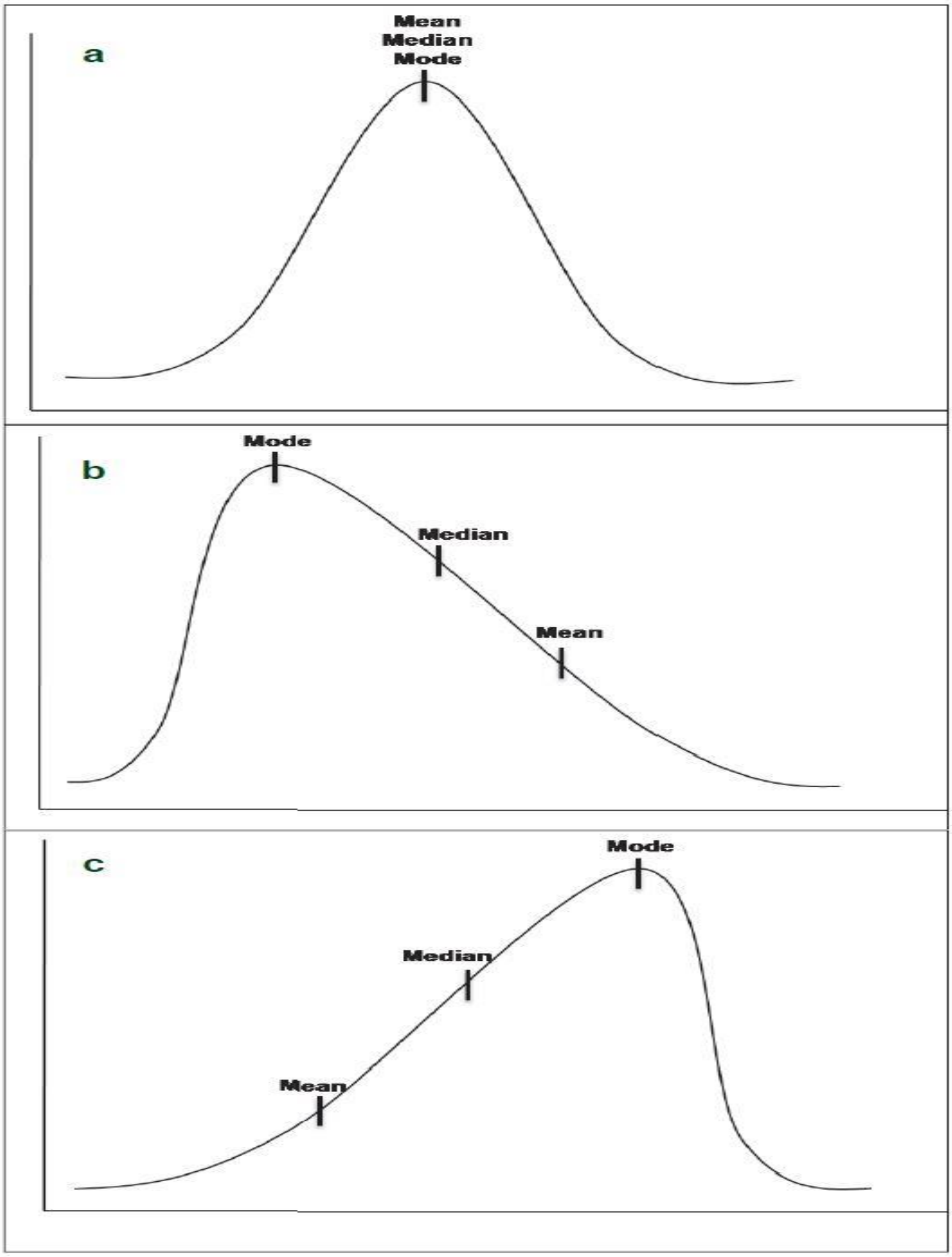


Figure 27 Central Tendency (*Manikandan, 2011)*

Chapter Six Prototyping of Proof of Concept

6.1 Introduction

This chapter describes the procedures and outcomes of a proof of concept. The data analysis and the techniques used to interpret the data are given, leading towards creating a BIM-based protocol and decision support framework for real-time collection, validation, and handover of attribute data for the National Highways programme.

6.2 Why is this required

Highways England's Asset Information Improvement Plan (AIIP) has been developed to enable the creation of a complete and highly accurate set of asset information on the Strategic Road Network (SRN) (IBI, 2015). Relevant stakeholders will be able to access and use this asset information to support operational and business decisions.

In order to effectively reach this goal, Highways England needs to enhance its asset data infrastructure consistently. This involves integrating newly acquired and validated asset data to enhance and sustain its asset inventory. Crucially, this process necessitates rigorous assurance of the quality of source data and thorough validation to align with internal asset data standards. By doing this, Highways England can enrich its existing knowledge base and seamlessly integrate the updated data into its databases, thereby replacing and augmenting the current asset information (IBI, 2015).

As part of the delivery of major projects and renewal/improvement schemes, asset data is often collected manually at the end of the project and handed over to operations.

This is time-consuming and involves surveyors having to go out on-site with TM (traffic Management) in place on busy live carriageways. This PoC (Proof of Concept) aims to enable a framework to be delivered to Highways England and set a protocol to collect this data as it is constructed on-site, stopping the need for post-construction surveys and sending surveyors and engineers out in live traffic.

6.3 AI

In commercial IT, the terms artificial intelligence, machine learning, and deep learning are frequently used, especially when businesses attempt to advertise their goods. However, there are large differences between the two, and they are not interchangeable. Artificial intelligence (AI) describes how machines mimic human intelligence. Its definition constantly evolves as new technologies are developed to better emulate people and as the potential and boundaries of AI are re-examined. These techniques include machine learning, deep learning, and neural networks, which are all subsets of deep learning.

Since the 1950s, artificial intelligence has existed. In essence, it represents the fight to create machines that can contend with the intelligence that allowed humans to be the dominant lifeform on the planet. But defining intelligence has proven to be challenging because the perception of what constitutes intelligence evolves throughout time. Robotics, self-driving cars, and natural language comprehension are just a few of the applications that potentially benefit from the ability of contemporary AI systems to learn from previous data. Although while AI has occasionally demonstrated superhuman ability in these areas, there is still a long way to go before AI can actually match human intelligence (Patersson D, 2023).

One ground-breaking AI technique that is pioneered to mirror human intelligence is Machine Learning (ML), a subtype of AI. Prior to the advent of machine learning, the approach involved painstakingly instructing computers on how to make each decision. This process prioritized transparency, ensuring that every decision-making step was explicitly defined. Despite its meticulousness, this method had limitations when confronted with numerous complex scenarios. However, with the emergence of Machine Learning, a paradigm shift occurred. Instead of relying solely on predefined rules, ML empowers machines to learn autonomously by analysing vast troves of data and discerning patterns within them. This marks a departure from traditional methodologies, where the onus was on explicit programming. The role of big data in catalysing the rise of machine learning is a subject of debate. Nevertheless, it's undeniable that the proliferation of data and advancements in data gathering played a pivotal role in enabling machine learning to flourish. Many machine learning algorithms operate on statistical principles, leveraging expansive datasets to refine their understanding and decision-making capabilities.

6.4 Data for Machine Learning

Image annotation is used to generate training data for supervised AI models. How users label photographs indicates how the AI will act after seeing and learning from those images. As a result, improper annotation commonly appears in training, causing models to make incorrect predictions. Annotated data is especially important when applying AI to a new domain to tackle a specific problem. Pre-trained models are available for basic tasks like image classification and segmentation (He 2018), and these can be customised to particular use cases with the use of Transfer Learning with little to no data.

However, generating a substantial volume of annotated data, segmented into training, validation, and test sets, proves to be a time-intensive endeavour in the training process of a complete model. Conversely, unsupervised algorithms offer a direct pathway for training on raw data without the need for labelled inputs. The quality of the outcomes hinges upon the quality of the input data. Furthermore, the accuracy of the labelled data used to train learning algorithms is pivotal for the development of computer vision models capable of consistently detecting, recognising, and categorising objects. The intricacies of image annotation often go underestimated, yet erroneous annotations can pose significant challenges (Bandyopadhyay, 2023).

Photographs in a dataset are tagged using image labelling to train machine learning models. After the hand annotation is complete, a machine learning or deep learning model processes the labelled images to duplicate the annotations without human intervention. Because picture annotation defines the criteria that the model seeks to meet, any inaccuracies in the labels are reproduced as well. As a result, effective image annotation is one of the most important professions in computer vision since it serves as a foundation for training neural networks.

6.5 Library of Images for Machine Learning

Image labelling serves the vital purpose of pinpointing and categorising specific elements within an image. Put simply, it involves highlighting particular details or objects within an image to guide computer vision algorithms. These labels play a crucial role in teaching algorithms to recognise distinct objects accurately. For example, in a set of high-resolution photographs depicting a road network, labelling each sink gully enables a model to comprehend the concept of a roadway gully (Kudan, 2022).

For computer vision models, image annotation produces datasets with various objects divided into training sets for initial model training and test/validation sets for model performance assessment. Data scientists use the dataset to train and assess their models. At that point, the model can automatically identify unlabelled data. By choosing the appropriate picture labelling method, allowing the production of a high-quality dataset that will aid a model in better learning how to recognise things. Machine learning engineers constantly modify and enhance the dynamic process of labelling photos.

Using imagery from the drone output images needs to be carefully organised and named; at least 150 images are required, and these are later separated with at least 10% separated for ‘testing’ see later in ‘Training Model’. Out of the 1200 images from the drone data, only 156 had the asset type shown within them; in this case, the asset type was ‘Surface Water Channel.’ each of these images needs to be uniquely referenced: SurfaceWaterChannel_001, SurfaceWaterChannel_002, SurfaceWaterChannel_003 to _XXX. Also, each image must be labelled to identify the pixels within the image that the computer needs to be trained. This is saved as a *.json and xml files using software called *Labellme.* Others are available; this is required for all images, shown in Figures 28 & 29.

Figure 28 shows Labelling software identifying assets within the image (Starkey, 2022).

```
<annotation>
      <folder>DGCH_SurfaceWaterChannel</folder>
      <filename>SurfaceWaterChannel_001.JPG</filename>
      <path>C:\Users\grastar\Desktop\PhD-Present\Machine
Learning\DGCH_SurfaceWaterChannel\SurfaceWaterChannel_
001.JPG</path>
      <source>
            <database>Unknown</database>
      </source>
      <size>
            <width>927</width>
            <height>830</height>
            <depth>3</depth>
      </size>
      <segmented>0</segmented>
      <object>
            <name>DGCH_SurfaceWaterChannel</name>
            <pose>Unspecified</pose>
            <truncated>0</truncated>
            <difficult>0</difficult>
            <bndbox>
                  <xmin>276</xmin>
                  <ymin>19</ymin>
                  <xmax>399</xmax>
                  <ymax>80</ymax>
            </bndbox>
        ...
```


Figure 29 shows a JSON file created from software with coordinates of polygons (Starkey, 2022).

6.6 The Machine Learning process

In the execution of significant projects and enhancement initiatives, asset data acquisition typically entails a laborious manual process at project culmination, followed by its transfer to operational teams. This practice demands considerable time and effort, requiring surveyors to navigate on-site with traffic management protocols in effect, especially on bustling thoroughfares. This Proof of Concept (PoC) aims to introduce a framework to Highways England that streamlines this process. By implementing this protocol, the aim is to collect data concurrently with on-site construction activities. This approach eliminates the necessity for post-construction surveys and alleviates the risk associated with deploying surveyors or engineers amidst live traffic conditions.

To capture assets, the focus was on using machine learning to detect objects within the imagery provided. This was to overcome the shortcomings of traditional computer vision techniques for object recognition, which required the detection of standard and predictable objects.

The methodology proposed for detecting assets as captured through spatial images outlines several aspects with regard to the transformation of input data, the use of machine learning and neural networks for object detection, and the subsequent method of generating shapefiles using the attributes of the detected objects.

Once the drone image is processed into Raster data, it can be directly manipulated by applying a trained model and different masks and segments. This would use the R-CNN model, which is trained to recognise assets and then output raster data that can be accessed to create shapefiles.

Utilising a technique known as Faster R-CNN (Region-based Convolutional Neural Network), which does two things. Two networks—the backbone network and the region proposal network—make up the first stage. These networks execute once for each image to provide a list of suggestions. These proposals are regions in the feature map which contain the object. Next, the network predicts each proposed region's bounding boxes and object classes. Each region can vary in size, while fully connected network layers commonly require fixed-size vectors to make the prediction (Patterson, 2023).

Mask R-CNN elevates the process by incorporating a Feature Pyramid Network (FPN) into its framework. FPN captures objects across various scales, enhancing the feature extraction mechanism initially introduced by Faster R-CNN. By integrating a second pyramid, FPN enables the transmission of high-level features from the upper to lower layers. This architecture facilitates comprehensive feature access across all levels, enabling a more robust representation of objects within the scene Figure 30.

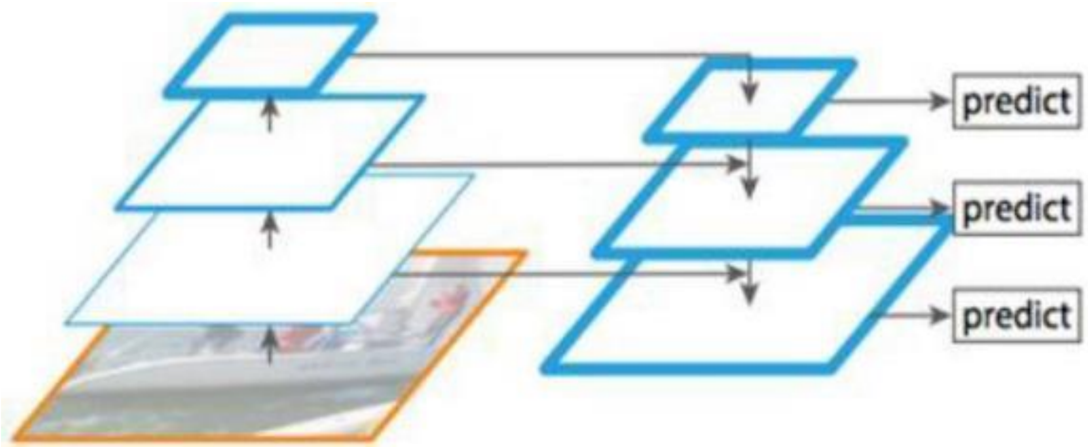


Figure 30 shows the Feature Pyramid Network (FPN) (He et al., 2018)

6.6.1 RPN

Faster R-CNN uses a Regional Proposal Network (RPN), a lightweight neural network that scans an image using a window to generate proposals that pass through to the remaining network.

Regions scanned by RPN are called anchors, which are boxes distributed over the image area. RPN can produce as many as 200 thousand anchors to cover the image as much as possible. The RPN generates two outputs per anchor: the class and a bounding box. An Anchor class is split into one of two classes: foreground and background. Bounding Box Refinement takes the foreground anchor as foreground anchors may not be positioned perfectly over the object. It applies a percentage change of location to fit the object better. Anchors are scored and reduced to provide the best regions of interest (ROIs) for the next stage Figure 31.

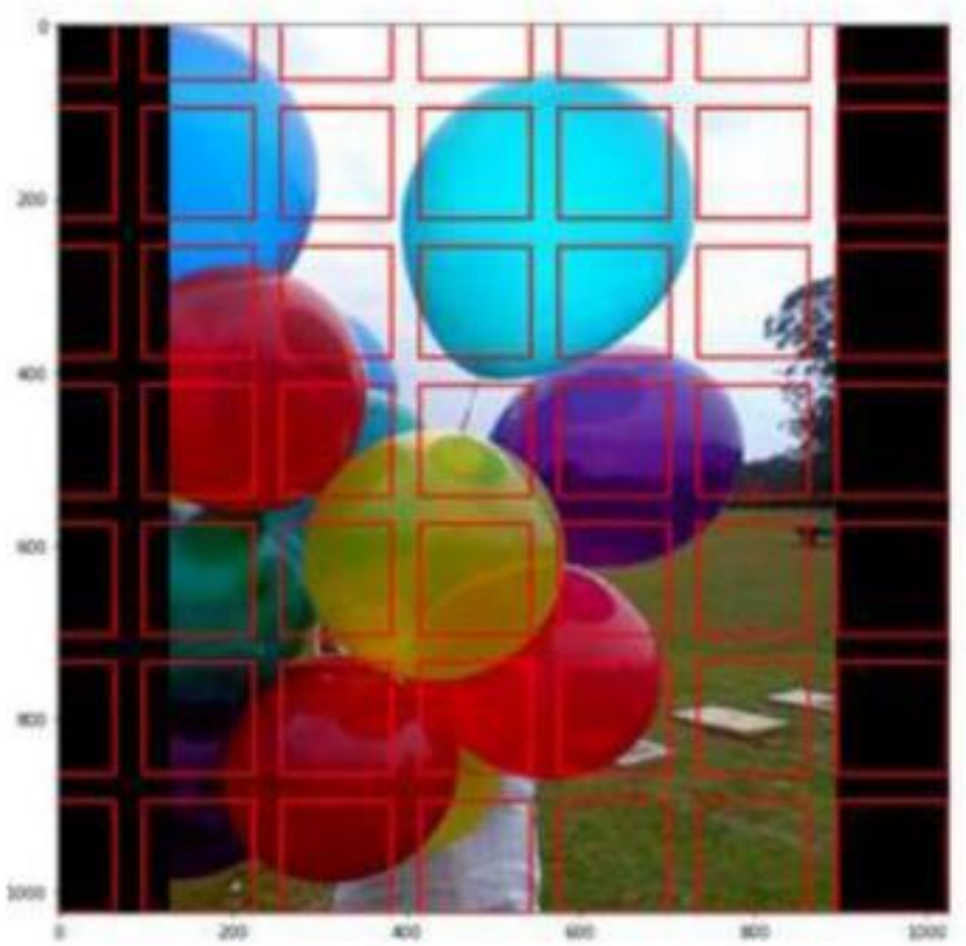


Figure 31 shows Regions scanned by RPN are called anchors (He et al., 2018)

6.6.2 ROI Classifier & Bounding Box Regressor

Processing Input Regions of Interest (ROIs) from the Region Proposal Network (RPN) involves two key steps: classification and bounding box refinement. Unlike the RPN, which simply categorises ROIs as foreground or background, this phase identifies the specific object class for each ROI. Once classified, the bounding box undergoes further refinement to encompass the object precisely. Next, utilising Region of Interest Align (ROIAlign) to extract a compact feature map from the RPN. ROIAlign employs bilinear interpolation to accurately compute the feature values at four regularly sampled locations within each bin Figure 32. These values are then aggregated using maximum or average pooling to represent the input data optimally. This process ensures that the extracted features align seamlessly with the ROIs, enhancing the overall accuracy of the subsequent stages in the pipeline.

Figure 32 how each ROI is classified and its bounding box (He et al., 2018).

6.6.3 Implementing instant segmentation

The process of identifying, categorising, and segmenting each distinct object in a picture is known as instance segmentation. Combining semantic segmentation and object identification (finding all instances of a category in an image) allows instance segmentation to distinguish distinct instances of any given segment class from the basic segmentation task (Bandyopadhyay, 2023).

In contrast to semantic segmentation and object detection networks, instance segmentation offers a more nuanced approach, as highlighted by Lewis (2018). Unlike semantic segmentation, which provides category labels for each pixel, and object detection, which merely identifies objects with bounding boxes, instance segmentation delves deeper. It generates segment maps for each category and each instance within that category, assigning pixel-level category labels. As noted by Kudan (2022), this intricate process leads to a richer output format, facilitating more profound insights into images.

Instance segmentation is implemented in the library used within this project using the Mask R-CNN model trained on the coco dataset. A convolutional network takes positive regions the ROI classifier selects and generates masks for them. These masks are called soft masks as shown in Figure 33, which are represented by float numbers and, therefore, hold more information than binary masks.

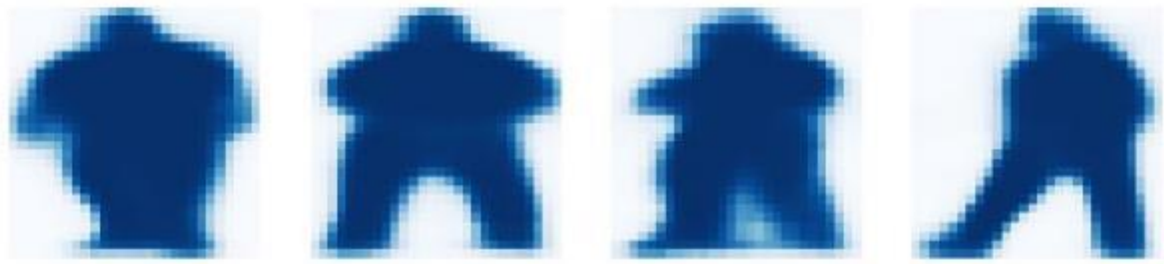


Figure 33 shows soft masks (He et al., 2018).

Therefore, the mask represents more than just whether a pixel belongs to an object or not. This gives the object a boundary, which is more useful to the process of identifying the object and ensures the pixels at the edge are included in the detection (Miso, 2022) Figure 34.

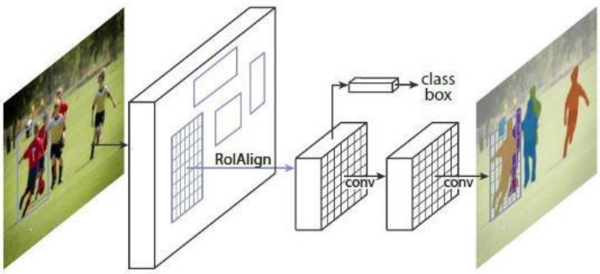
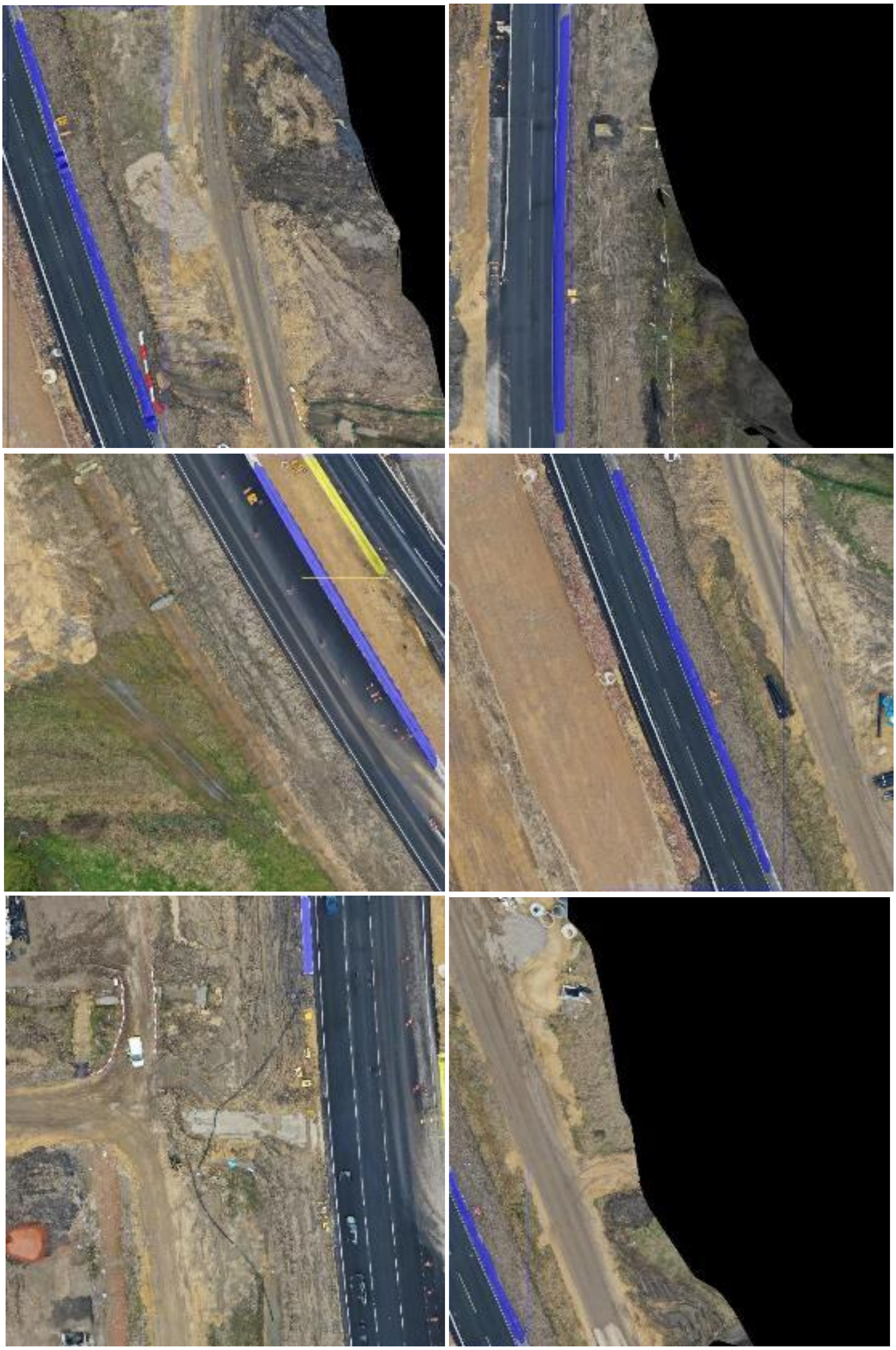


Figure 34 The resulting backbone of the mask R-CNN solution (He et al., 2018)

6.7 Output from Instant Segmentation

Fifty images were processed using the concept discussed in the previous chapters. The images show the results, highlighting the bounding box and coloured pixels where the process has recognised the trained images. 46 out of 50 images were segmented correctly; a selection is shown below Figure 35.



Incorrectly Split Object

2 out of 50 test images produced multiple mask objects instead of a singular object

Incorrect Segmentation

2 out of 50 test images did not generate full masks for the detected object

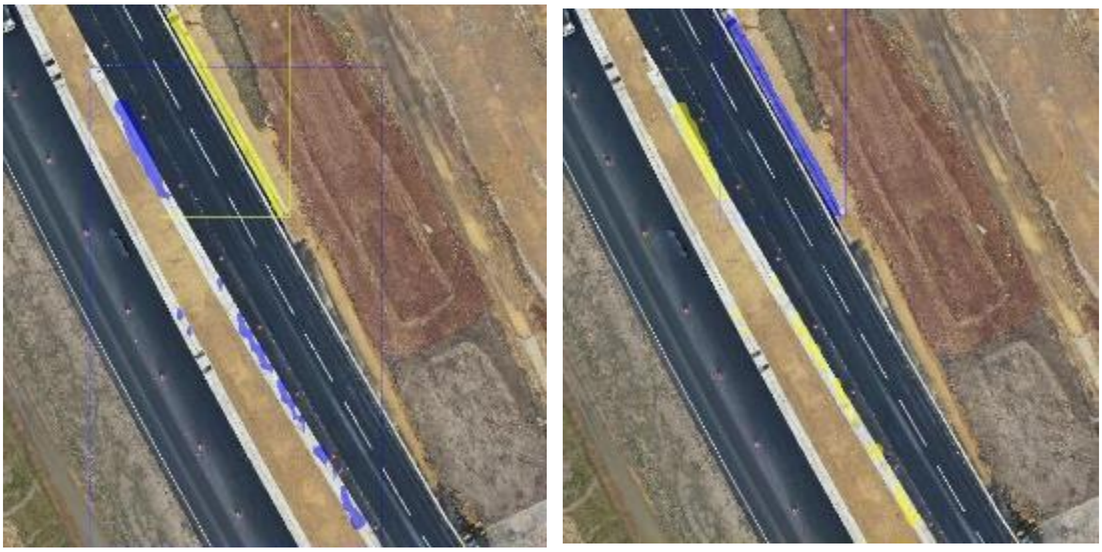


Figure 35 shows the resulting mask of images (Starkey, 2022)

6.8 Final Output

Once the assets and objects within the imagery have been rendered into masks, the mask needed to be translated into a polygon shapefile with real-world coordinates. The mask outputs contained an (X, Y) attribute on each point within its perimeter, then using this attribute and the WLD file provided with the image to select each point on the perimeter and manipulate its point reference from the X, Y image using the ESRI shapefile algorithm to create a polygon with real-world coordinates.

Once the polygon formation is complete, the next step involves the creation of a connecting line. Initially, having determined whether the polygon comprises multiple points or originates from a single point by analysing the image from the top. In the case of multiple points, the line commences from the centroid of these points. Conversely, if the polygon begins from a singular point, that point serves as the starting position. Subsequently, the process entails traversing to the subsequent point and identifying another point along the polygon's edge that shares the same horizontal plane. This is achieved by comparing the Y values of their X and Y attributes. The midpoint between these points is then connected in a straight line to the previously established point Figure 36. This iterative procedure is repeated for all polygon sections, culminating in generating a final line. This line is then outputted in the form of a shapefile.

Figure 36 shows lines that are required for databases (Starkey, 2022).

The original investigation before this project focused on the applicability of machine learning to detect assets when observing locations from a drone image. As described in this document, the Mask R-CNN network architecture adds superb usability for accurate instance segmentation.

While the model is pre-trained, it may encounter anomalies as it attempts to identify assets it has not been exposed to. However, this risk can be mitigated through additional training and exposure to a broader array of objects. With time, its accuracy will steadily improve. The option to load more images into the test directory is provided to facilitate this process. Subsequently, the model will undergo further training using this additional information.

Care needs to be taken when labelling the images, as moving past the perimeter of the asset that has been detected will cause confusion, therefore it is much better to be slightly on the inside line of the perimeter. Reducing the number of node points on the polygon when labelling also helps keep the searchable area within its correct parameters. In general, although the multicoloured images are a distraction, they can still be used as they are the required centre line of the asset. Also, having too many labelled assets all next to each other can cause some issues; however, in general, and for this PoC, the repeatability was sufficient, and as stated, the more images in the test area, the better the results.

Machine Learning Output

Figure 37 shows the final outputs into the geospatial software (Starkey, 2022).

6.9 Protocol Flow Chart

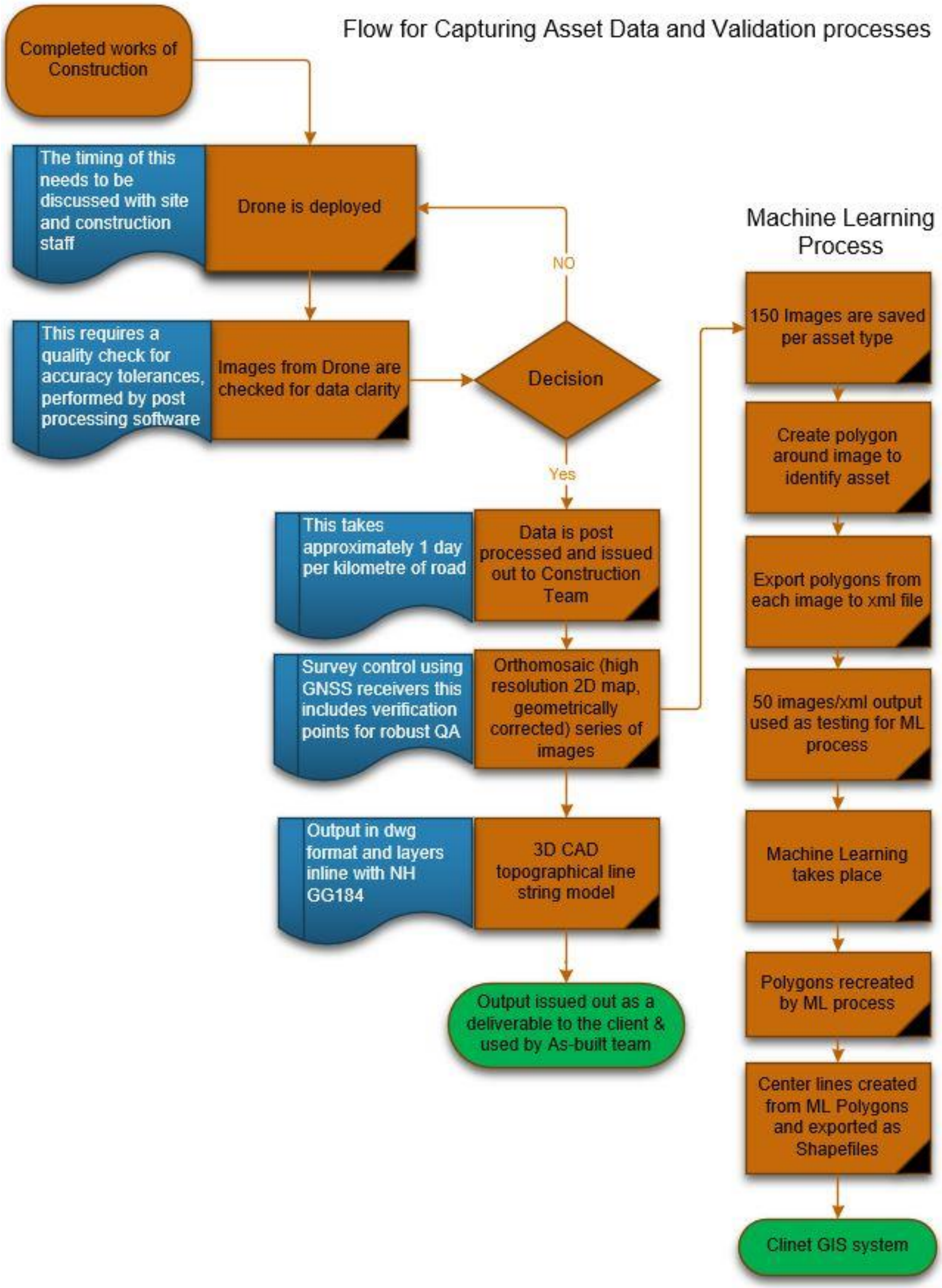


Figure 38 Drone Protocol for Asset Capturing and Machine Learning (Starkey, 2024).

The above protocol flowchart highlights what actions should be taken and what should be avoided. The brown boxes indicate actions, and the blue boxes indicate what should be avoided. The green tablets are the final output uses.

6.10 Summary

This chapter explores the process involved in constructing a proof of concept to implement the framework for real-time asset acquisition. These pages look into the selection of hardware and software components essential for crafting the software prototype. Through analysis and strategic decision-making, showcasing how these components synergise to lay the foundation for the framework. The software prototype is a tangible manifestation of the research, demonstrating the feasibility of efficiently integrating specific framework components to extract items from drone imagery. Moreover, providing a concise overview of the iterative journey undertaken in developing the functioning prototype, shedding light on the challenges overcome and the milestones achieved. The rigorous testing regimen within controlled environments validates the framework's efficacy as outlined in Chapter 6, underscoring its potential real-world applicability. In the subsequent chapter, distilling the insights from this research endeavour, offering a succinct synthesis of the findings.

Chapter Seven Findings and Discussion

7.1 Introduction

This chapter discusses the findings from the case studies, interviews, and surveys to develop a BIM-based protocol and decision support framework for real-time collection, validation, and handover of attribute data for National Highways major schemes. This framework incorporates the achievement of Objectives 1-4 of this research as follows:

1. To analyse the state of practice for asset information and the potential of BIM implementation.
2. To investigate the strategies for capturing real-time asset information to facilitate life cycle asset management.
3. To investigate and validate the effective strategy and protocol for capturing highway asset information.
4. To develop the BIM-based framework and associated protocol for real-time collection, validation, and handover of attribute data for National Highways major schemes.

7.2 Findings from Case Studies

The case studies reveal a missed opportunity where projects could have fully leveraged Building Information Modelling (BIM) but fell short. One plausible explanation lies in the alignment with the UK's BIM agenda and the standardised formats advocated by Highways England, which enjoy broad support within the BIM community. Moreover, using similar software to create BIM models across projects likely influenced key personnel to adhere to rules and guidelines set by both the software vendor and the contractor's BIM team. This influence was particularly evident in asset tagging and data collection processes.

There are differences in how BIM has been used for handover, with some cases not taking advantage of having a PIM (Project Information Model) with its asset data available for the asset maintainers. The main findings in Tables 2 to 6 in Chapter 4, which analyses the state of practice for asset information and the potential of BIM implementation.

Policies that consider BIM and Asset Management as a single entity must be developed to fully realise BIM's potential for asset management. Because of this, National Highways must offer a standard framework for the growth of the two practices. The benefits of using an integrated strategy are negated when asset management and BIM are addressed separately. The key to achieving this is ensuring that an information management process is in place to make data from the common data environment easily accessible for the management of assets.

7.2.1 How it is currently done

The capture of asset information for dissemination into National Highways databases for handover is now semi-automated using software that allows for the joining up of geospatial graphical information and data text files like Excel or CSV.

The as-built drawings of the scheme are produced from a set of markups (redlining) from the construction team; once the designer or contractor has created these, they become the construction record drawings. The model files, usually 2D and in dwg format, are then used to represent the graphical output for the asset databases. However, these need to be synced with the Excel spreadsheets for each asset type; each asset type has its own attribute set, detailed in the ADMM, as shown in Figure 39.

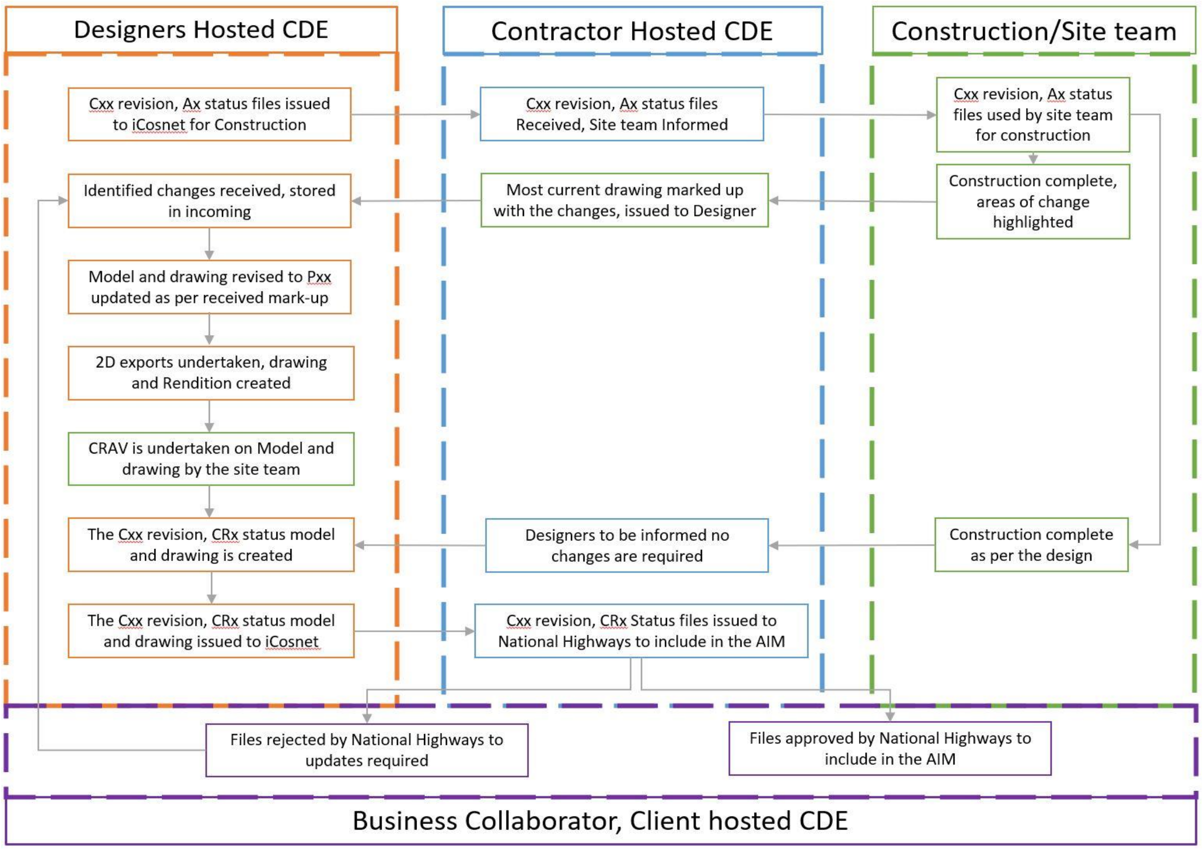


Figure 39 shows the current as-built process (Starkey, 2024).

The current process still requires extensive manual effort to move data from cells in Excel spreadsheets and produce CAD drawings of each asset type; these have to be merged for import into the client's geospatial software.

7.2.2 The Challenges and Areas Requiring Attention

While acknowledging that these case studies have not comprehensively addressed all challenges outlined in existing literature, it is important to underscore the substantial implications this research holds for BIM implementation in infrastructure development. Table 13 effectively illustrates the research's examination of Contributing Factors to the issues identified in interviews, showcasing potential improvements crucial for the continued advancement of BIM as a process. This advancement is pivotal in facilitating real-time data collection and validation of asset information.

Eleven BIM and asset data professionals were interviewed in this study phase. The professionals were asked about issues relating to their role in a construction project, their views and experiences about BIM and asset capture, the importance of knowing the location of assets on the construction site, and their opinions regarding the proposed method of capturing assets in real-time. The data revealed that the interview analyses created a framework for capturing assets in real-time; therefore, the objective of "To investigate the strategies for capturing real-time asset information to facilitate life cycle asset management" outlined in the Introduction Chapter was achieved.

7.2.3 How BIM could help

BIM: According to RICs (2020), the use of BIM in the construction sector has grown over the past ten years. Over the past ten years, many commercially available BIM tools have exploded. According to recent studies, BIM can address various construction-related problems, including design, visualisation, cost planning, coordination, and schedule management. According to data, BIM has quickly become the industry standard for facilitating communication between the numerous AEC sector partners during the facility's planning, construction, and maintenance. Evidence suggests BIM will significantly impact future facility design, construction, and maintenance.

In each case study, a comprehensive BIM model was meticulously crafted to propel the design phase forward, generating seamlessly integrated drawings. This strategic approach empowered the project team to proactively mitigate potential conflicts during construction and conduct thorough simulations, pre-emptively detecting errors or issues before commencing on-site work. An eminent advantage stemming from creating a detailed 3D BIM model was the entire team's enhanced comprehension of the design. This facilitated the identification of potential hazards and swift correction of any missteps encountered during the design phase, thereby fostering a more streamlined and error-free project execution.

However, using the PIM did not translate into an Asset Information Model (AIM). At the same time, asset tagging was available; the designers typically did not include this option early enough to attach attribution to each object that had been modelled. This was because the contracts only required the output of construction drawings and not an asset-rich data model. Consequently, this process has been missed in many schemes, making the handover of captured asset data not embrace the BIM processes; in many cases, the maintainer will not accept a 3D model that does not represent the maintenance network.

7.3 Capture Asset Information

While the importance of capturing accurate data is becoming clear, acquired data must be kept, upgraded, and available at the handover stage. According to many research reports, the costs of inefficiencies caused by insufficient interoperability between outdated software systems and poor data and information transfer from the design and construction stage into maintenance amounts to millions of pounds (Highways, 2017). This highlights the need for client organisations to spell out their information needs and develop an integration strategy to ensure data adds value to their daily operations. Consequently, clients often maintain and operate assets without sufficient knowledge and understanding of the built assets. Traditional approaches to data handover present many difficulties, including failed opportunities to optimise asset performance and life spans.

Highway asset inventory data collection frequently entails significant but unidentified costs. Highways England and regional organisations have used various techniques to gather information about the highway inventory, including field surveys, photo and video logs, integrated mapping systems, satellite imagery, plane and drone aerial photography, and mobile LiDAR. The equipment needed, the time needed to collect the data, and the cost and reduced data for each method vary; each method has advantages and disadvantages.

Ensuring asset information is captured promptly is paramount for project success. As highlighted in earlier chapters, delaying this process until the project's end creates unnecessary pressure on handover personnel. By deciding to collect data early, it can alleviate this strain and ensure a thorough and diligent approach. Once the decision is made to initiate data collection early, it is crucial to establish a clear plan of action. This includes determining what information to capture and the level of detail required. For instance, any completed structures, roads, or other assets should be surveyed without delay. Furthermore, adherence to industry standards is essential. In the case of highways, compliance with GG184 for CAD layer naming is imperative. Additionally, incorporating a standardised naming convention for surveyed items (such as fences, kerb edges, or gullies) enhances clarity and facilitates efficient asset capture.

Several studies have supported the usage of drone technology in the construction industry for real-time data collection. Some academics have used drones with BIM and other visualisation tools to make surveying-related decisions (Banach et al., 2019; Turnbull, 2018; Barnes, 2018; Hubert, 2022). This combination has been utilised in studies to visually portray the position of construction assets within a site in a virtual environment for capture purposes. However, it was discovered that these studies took a very technology-focused approach to developing demonstration software and did not fully address it from a more lifecycle viewpoint of activities for capturing on-site assets previously placed during construction.

7.3.1 Strategy and Measure for Capturing Real-time Asset Information

For a strategy to be effective, it must be noted that an organisation's current processes must be understood and added to, as organisations require time to adjust to newly implemented strategies, and cultural change must be appreciated. Ideally, the following list needs to be defined before the project's construction phase to allow sufficient time to successfully adopt the new workflow framework strategy to assist with decision-making:

1. Project geographical locations such as airports and overhead powerlines.
2. Project type, in this case, highways
3. Organisational competencies and capabilities.

Including these minimum points is crucial for tailoring the workflow strategy to accommodate diverse project factors, such as varying locations. Each project presents unique challenges, including compliance with flying regulations that may impact the utilisation of drones. Regarding BIM, these outlined points establish a baseline BIM level to strive for, facilitating the adoption of appropriate standards and processes like GG104 (Safety Risk Management). Moreover, they ensure sufficient time to utilise BIM libraries, mitigating the risk of duplicated information. This proactive approach allows for the establishment and integration of the BIM protocol well before the construction phase, streamlining processes and enhancing project efficiency.

The following stages are designed to improve asset data collection on a construction site by guiding what can be done with the gathered data from Drones and how BIM can manipulate this to produce the necessary improvements.

First Stage of Workflow: This phase is designed to initially set up BIM and UAV capability on the project. It allows for the necessary data to be gathered and checked for accuracy, data validity, and effectiveness for the BIM model and development for the second stage, ensuring optimum H&S safety improvements are achieved.

Preparation:

1. Establish BIM capability through the Construction Project Team.
2. Adopt and implement the necessary BIM standards, such as ISO19650 and any General Governance (GG) documents, to ensure the requirements are achieved.
3. Ensure that drone pilots are qualified, whether it is an internal or external capability, and that CAA approval is granted.
4. Agree on data format output and coordinate systems to be used.

Operation:

1. Proceed with the survey and collect necessary data from the planned route
2. Flight path mapped, tracked, and stored data through Drone mapping software.
3. Data analysed and checked to ensure validity for compiling and processing

Data Processing:

1. BIM authoring tools such as Navisworks, Revit and CAD capability adopted for appending and importing drone survey data as point cloud *.las format and orthomosaics for the post-production of a site survey.

2. The AIM can be produced consisting of drone survey and project model data as an overlay

Application:

1. Data from output to a geospatial platform allows visualisation of industry-standard 3D and 2D geospatial data and to capture high-resolution point clouds and orthomosaics.

2. Create a progressive as built to continually update and maintain an exact digital map of the project that shows the ongoing state of the site at any given time (past, present and future)

3. Remove the need to be physically present to contribute to solving site problems by bringing the site to engineers and open collaboration with remote subject matter experts

PREPARATION

- •BIM capability
- •Employ BIM standards to achieve the BIM level required
- •Internal/external CAA approved

OPERATION

- •Data gathering
- •Flight path mapped
- •Data complied for downloading through CDE

FLIGHT PLANNING

- •Determine UAV capability
- •Plan safe/vantage point
- •Site analysis
- •Plan route
- •Weather check

APPLICATION

- •Platform allows you to visualise industry-standard point clouds and orthomosaics.
- •An exact digital map of the project that shows the ongoing state of the site at any given time
- • Remove the need to be physically present to contribute to solving site problems by bringing the site to you and open collaboration with remote subject matter experts

Figure 40 Stage One - Framework Implementation Strategy Highways England. (2021) adapted by (Starkey, 2024)

See Appendix C for full flowchart

Second Stage of Workflow:

This stage represents a significant advancement from the initial phase, dedicated to ensuring continual enhancements and diligent monitoring of the volumes allocated to the BIM model and fulfilling the As-built requirements essential for handover within the project timeline. This refined workflow is designed to promote the most effective utilisation of BIM and UAV technologies, heightening the construction team's understanding of the outputs available for the as-built survey, which can serve diverse project needs.

Planning:

1. BIM (3D and 2D) model can now be split into volumes or areas as per the maintainer's handover requirements, resulting in the model being more manageable per area of the project or construction site
2. The BIM model volumes can now be linked to the project programme for the handover of each asset type. This essentially will represent separate stages during the construction phase that are scheduled to be finish
3. Drone technology to be adopted at agreed times to suit the project programme and allow monitoring of specific areas that correspond to the BIM model volumes.

Data Processing:

1. Pointcloud and Orthomosaic survey gathered during the drone survey for the assigned task that falls under certain asset types, e.g. kerbs surface water gullies can be traced over using semi-automated software.
2. Photogrammetry is to be geotagged to model and track progress for each asset type area.
3. Record and register to be created or updated and linked to the BIM model for each asset type.

Data Delivery:

1. The resultant 3D topographical survey for the as-built site can be delivered to the highway maintainer.

2. The orthomosaic images can be used for the AI process to collect asset-type images used in the machine learning process; these will be delivered as GeoTIFFs (geospatial images).

The following workflow is what the process is after the delivery of the data:

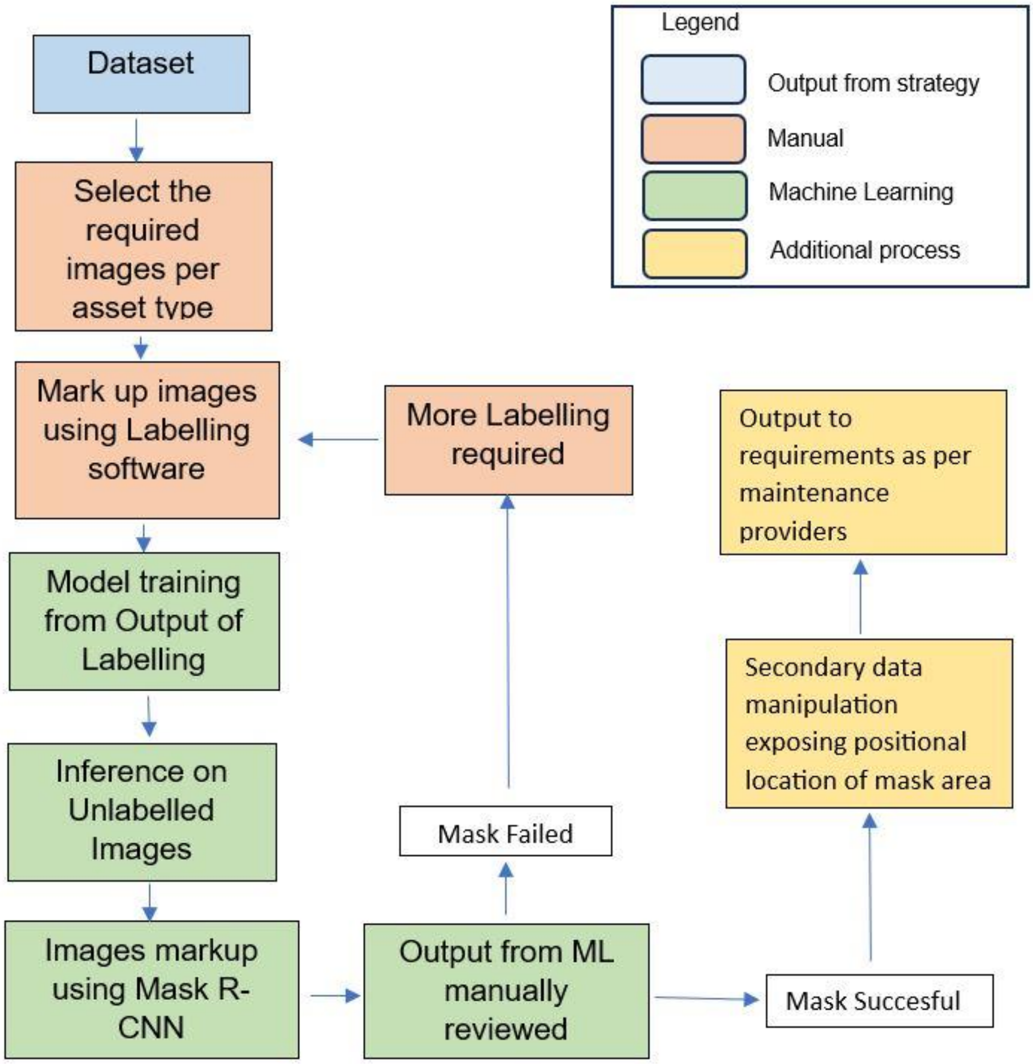


Figure 41 Stage Two – Post-Strategy Process (Starkey, 2024)

7.4 Industrial Contribution

This research showed that construction industry professionals could capture asset locations and collections of attributes in real-time. They have several reasons for knowing the location of assets and validating them as soon as possible to aid the as-built process. However, this research has shown that no known method is currently widespread in the construction industry to facilitate the real-time collection of assets. This research presents a protocol and decision support framework for real-time collection, validation and handover of attribute data for National Highways major schemes.

The framework underwent clear development and validation, drawing insights from industry experts to ensure its robustness. It outlines various scenarios where the suggested protocol and framework can be effectively applied. The PoC leveraged cutting-edge machine learning algorithms and the most advanced AI solutions available at the time, offering a glimpse into the potential of asset capture techniques. The research revealed a palpable enthusiasm among industry professionals for adopting the proposed framework to capture assets in real-time and for multifaceted applications.

Chapter Eight Conclusion

8.1 Introduction

This chapter provides a thorough overview of the study, outlining its goals, methodology for gathering and analysing data, and research design. This is followed by the study's essential findings, which are provided by the study's aim and objectives, as stated previously in the first chapter. The study's implications for concept and application and its constraints are discussed before concluding the chapter with proposals for further research.

8.2 Overview of the study

The National Highways Asset Information Improvement Plan (AIIP) aims to establish a comprehensive and precise repository of asset information across the Strategic Road Network (SRN). This initiative, outlined by Highways England (2017), is pivotal in providing accessible and reliable data to pertinent stakeholders for informed operational and strategic decisions. Highways England's commitment to continuously enhance its asset data is central to the success of this endeavour. This involves integrating newly acquired and verified asset information into its inventory while ensuring quality and alignment with internal standards. Through rigorous validation processes, Highways England ensures that incoming data meets its criteria and enriches its existing knowledge base. Consequently, this facilitates seamless database integration, thus replacing and updating outdated asset records.

To optimise the utilisation of data gathered during the execution of significant projects and enhancement initiatives, it is essential to address a recurring issue: data often gets collected and then shelved without further use by operations. To rectify this inefficiency and ensure that National Highways leverages only pertinent asset data that is easily accessible and maintained, it is imperative to establish and enforce specifications and standards for new data collection practices. This approach guarantees that the collected data aligns with operational requirements and seamlessly integrates into the company's Asset Data Management Manual (ADMM) and maintenance databases.

Various data gathering and analysis approaches were employed to meet the study's aim. The study integrated qualitative and quantitative approaches at intensive and extensive stages, respectively, adhering to the principles of the critical realism philosophy. At the early stage of the study, data was collected through a systematic literature review, and 10 Semi-structured interviews of subject matter experts in this field were conducted to understand their views and experiences on capturing, the location of assets and their thoughts about the proposed method of capturing assets in the future. The suggested approach for real-time asset capture could be employed under a framework developed following thematic and content analysis of the interview responses. A survey asking professionals in the construction industry for their opinions on the suggested framework was used to validate the conceptual framework. The framework and the conclusions derived from the qualitative interview data were validated by the study's quantitative results. Demonstrator software was created and assessed using a prototyping methodology to implement the framework in an emulated construction environment.

After combining factors emerging from literature and semi-structured interviews, 20 unique factors were established overall, 10 classed as ‘Problems’ covering objectives 1 and 2. In comparison, nine factors were established for ‘Improvement and Solutions’ covering objectives 3 and 4; Table 9 in Chapter 5 shows this with the referencing back to the literature. A questionnaire was created using the identified factors, and pilot-tested before being given to professionals in the UK construction sector. Through this process, 30 responses were received, with all 30 used for further analysis, including Cronbach’s Alpha, central tendency, and data dispersion analysis. These statistical analyses helped establish the critical success factors for developing a BIM-based protocol and decision support framework for real-time collection, validation and handover of attribute data for National Highways major schemes.

8.3 Key Findings of the study

The study's findings are examined something very carefully to ensure they align with its overarching goal and objectives. Firstly, the analysis delves into the current state of asset information practices and explores the potential benefits of implementing Building Information Modelling (BIM). These findings from comprehensive case studies serve as a foundation for in-depth discussions during the semi-structured interviews. The subsequent segment encapsulates critical success factors identified to probe into strategies for effectively capturing real-time asset information, facilitating streamlined life cycle asset management practices. Continuing in this vein, the third part integrates insights gleaned from both questionnaire responses and rigorous statistical analysis. This synthesis aims to validate an optimal strategy and protocol for capturing highway asset information efficiently. Concluding the narrative, the final two sections encapsulate insights derived from the study's objectives. These conclusions offer strategic direction for developing a BIM-based architecture and accompanying protocol. The ultimate aim is to enable the seamless collection, validation, and timely handover of attribute data for National Highways major schemes.

8.4 Contribution to Knowledge

This section presents the primary contributions of this research to academic study and BIM practices in the infrastructure sector.

8.4.1 Academic Contribution

Research has indicated that BIM can help the contractor optimise the project's budget and timeline while facilitating a smooth handover of buildings to building owners for upkeep and operations. More drone imagery can also be used to collect the necessary data for asset attribution during stage 6, or the construction period, of road projects and to ensure worker safety on the job site. The method's findings have revealed that drones can capture images for site inspections and topographical surveys. In conjunction with intelligent apps, they can analyse data in real-time to offer solutions and support faster, more accurate decisions. Surveying drones boast quick data-collection times, excellent positional accuracy and safe operator experience.

This research showed widespread agreement within the construction community that a framework for developing a BIM-based protocol and decision support framework for real-time collection, validation and handover of attribute data for National Highways major schemes. Literature has shown that drones, including site safety, are used for numerous purposes on a construction site. Literature has also shown that BIM is used in several ways in the construction industry, including site monitoring of completed works. However, a theoretical argument for using drones and imagery to capture assets in real-time for attribute handover was not found in the literature review. The protocol developed in this research can be used to conduct future research in determining the use of drones and BIM for capturing asset data, as described in Section 7.7 of this thesis. The results also presented several situations beyond capturing that industry professionals said the framework could be employed.

8.4.2 Research Methodology Limitations

The thesis acknowledges certain limitations arising from methodological choices made during its execution. One such decision involved adopting a qualitative paradigm for the study. While qualitative investigations offer valuable contextual insights, their generalizability to broader settings can be uncertain, potentially leading to unintended consequences. The utilisation of semi-structured interviews with industry experts was instrumental in developing a framework for monitoring the safety of construction workers. However, it is important to recognise the inherent limitations of this form of data collection, including the potential for interviewer or subject bias. Furthermore, the applicability of the developed framework may vary significantly in different geographical contexts, each with its unique legal, cultural, and hierarchical characteristics within the construction industry. Therefore, extrapolating its effectiveness to other nations with distinct regulatory frameworks warrants careful consideration.

8.4.3 Research Limitations Due to Technology Choices

The proposed protocol and framework for real-time asset capture were presented using drone photography. Other technologies, like Lidar (both road and airborne) and satellite and outdoor GPS, promise to collect the position of assets in a physical environment. This study considered various technologies but concentrated on Drone Imagery; for this study, the availability of Drones on building sites was employed. However, it must be remembered that additional options in the AI domain are constantly emerging, and ChatGPT and LLMs (Large Language Models) now permits pictures to be incorporated into the system. The data collected during the framework's implementation can be utilised for various reasons, as proposed by the participants.

The PoC created to implement the framework had limited functionality, and only one asset type was evaluated on a live highways project. The technology stack used for creating the prototype was not robust or easy to replicate on another computer.

A software prototype was created to show how useful drone imagery is for real-time asset capture during highway construction projects. Machine learning, algorithms, and the commercially available "Miso field solution" were used to develop the software prototype. The solution was created using the BIM platform "FME". The prototype was used to evaluate the use of geospatial imagery from a drone to capture the location of assets that have been newly constructed. These images were labelled to enable the ML algorithms to train a model allowing a mask to automatically identify new unlabelled images over the image. The results were colour-coded within the bounding boxes to show if they were captured correctly or not see pictures in 6.7 in chapter 6. The final output was to create a set of polylines from the captured data that could be sent directly to operational databases; this platform was enclosed in the FME workbenches. The resultant output of shapefile, the preferred file format for the client, was imported into the database. The only missing attribution was the attribute that would link the line to a row in a spreadsheet that held the rest of the asset attributions. This was discussed, and it was agreed that this could be added during the processing of the polylines and shapefiles in the FME workflow.

The objective of developing a software prototype demonstrator for implementing the framework has been successfully achieved. As proposed in the framework, the prototype effectively showcased how drone photogrammetry, powered by Machine Learning, a subset of Artificial Intelligence and Building Information Modelling (BIM) processes, can capture assets in real-time. Hence, the objective of the research to "Investigate and validate the effective strategy and protocol for capturing highway asset information" was accomplished.

8.5 Future Research

This study developed a BIM-based protocol and decision support framework for real-time attribute data collection, validation, and handover for major National Highways schemes. The framework was tested using a software prototype that only looked at a single linear asset. More research is needed before the proposed framework can be implemented in a real-world situation on a construction site for many assets, both linear and point asset types. Commercial software allowing the integration of imagery and the geospatial location of the said asset type to make it easier for construction companies to implement the proposed framework currently does not exist on the market. The actual costs for implementing the proposed approach are still unknown; however, using a drone on-site will cut the cost even further.

Additional research is imperative to establish an optimal pricing strategy and conduct a thorough cost-benefit analysis for construction companies considering the adoption of the proposed framework. Moreover, further investigation is warranted to identify the most effective technologies for real-time asset tracking in the dynamic setting of a construction site. As highlighted by participants, the envisioned method of asset capture using drones and Building Information Modelling (BIM) may extend to various other applications. Thus, there exists a promising opportunity to explore these alternative uses in greater detail.

References

Agrawal, R., Ailamaki, A., Bernstein, P.A., Brewer, E.A., Carey, M.J., Chaudhuri, S., Doan, A., Florescu, D., Franklin, M.J., Garcia-Molina, H. and Gehrke, J., 2009. The claremont report on database research. *Communications of the ACM*, *52*(6), pp.56-65.

Ajayi, S., 2017. *Design, procurement and construction strategies for minimizing waste in construction projects* (Doctoral dissertation).

Ajayi, S. O. and Oyedele, L. O. (2017) Policy imperatives for diverting construction waste from landfill: Experts' recommendations for UK policy expansion. *Journal of Cleaner Production*, 147, pp. 57-65. <doi: 10.1016/j.jclepro.2017.01.075>.

Al-Ashmori, Y. Y., Othman, I., Rahmawati, Y., Amran, Y. H. M., Sabah, S. H. A., Rafindadi, A. D. u. and Mikić, M. (2020) BIM benefits and its influence on the BIM implementation in Malaysia. *Ain Shams Engineering Journal*, 11(4), pp. 1013-1019. <doi: 10.1016/j.asej.2020.02.002>.

Alexandra, N. (2017) *It's time to plug the BIM knowledge gap*. [Online].].

Allen, R. (2019) Five Lessons for Applying Machine Learning. *Research-Technology Management*, 62(3), pp. 38-44. <doi: 10.1080/08956308.2019.1587330>.

Al-Ruzouq, R. and Abu Dabous, S. (2017) Archaeological Site Information Modelling and Management Based on Close-Range Photogrammetry and GIS. *Conservation and Management of Archaeological Sites*, 19(3), pp. 156-172. <doi: 10.1080/13505033.2017.1343061>.

April, S., Oliver, A. L. and Kalish, Y. (2019) Organizational creativity-innovation process and breakthrough under time constraints: Mid-point transformation. *Creativity and Innovation Management*, 28(3), pp. 318-328. <doi: 10.1111/caim.12326>.

Arroyo Ohori, K., Diakité, A., Krijnen, T., Ledoux, H. and Stoter, J. (2018) Processing BIM and GIS Models in Practice: Experiences and Recommendations from a GeoBIM Project in The Netherlands. *ISPRS International Journal of Geo-Information*, 7(8). <doi: 10.3390/ijgi7080311>.

Azhar, S. (2011) Building Information Modelling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadership and Management in Engineering*, 111(3).

Aziz, Z., Riaz, Z and Arsalan, M (2017) Leveraging BIM and big data to deliver well maintained highways. <doi: 10.1108/F-02-2016-0021>.

Aziz, Z. and Bayar, S. (2018) Optimising handover of as-built data from highways england major schemes to maintenance service providers.

Baduge, S.K., Thilakarathna, S., Perera, J.S., Arashpour, M., Sharafi, P., Teodosio, B., Shringi, A. and Mendis, P., 2022. Artificial intelligence and smart vision for building and construction 4.0: Machine and deep learning methods and applications. *Automation in Construction*, *141*, p.104440.

Baker, S. E. (2012) How many qualitative interviews is enough? *NCRM*.

Banach, D. M., Brooks, C. N. and Dobson, R. J. (2019) *Utilizing Drones to Assess Transportation Infrastructure*: R&D Magazine. [Online].].

Bandolier (2007) *Research methods*. [Online].].

Bansal, M., Goyal, A. and Choudhary, A., 2022. A comparative analysis of K-nearest neighbor, genetic, support vector machine, decision tree, and long short term memory algorithms in machine learning. *Decision Analytics Journal*, *3*.

Barns, J. (2018) *Drones Photogrammetry vs Terrestrial LiDAR - What Kind of Accuracy Do You Need?* [Online].].

Bates, J. (2007) Joint Asset Visibility: Why So Hard? Capturing Information. *Army Logistician*.

Baxter, P. and Jack, S. (2008) Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers.

Begić, H. and Galić, M., 2021. A Systematic Review of Construction 4.0 in the Context of the BIM 4.0 Premise. *Buildings*, *11*(8), p.337

Blakstad, H (2009). Population Sampling Techniques. Explorable.com: https://explorable.com/population-sampling

Blackstone, A. (2018) Principles of Sociological Inquiry.

Bolpagni, M. (2018) *How BIM is transforming the way we build future roads*. [Online].].

Bolton A, E. M., Schooling J et al. (2018). *The Gemini Principles*.

Boulenouar, J. and Schweitzer, R. (2015) Infrastructure asset management for rural water supply. *Building blocks for sustainability series* [Online].

Boyd, M. (2016) *Investigation into Maturity Management: A Progression Model for Building Information Modelling*. MUL.

Braun, V. C., V. (2006) Using thematic analysis in psychology. *Qualitative Research in Psychology*.

Braun, V. C., V. (2012) Thematic Analysis. *American Psychological Association*.

Brundage, M. (2014) Limitations and risks of machine ethics. *Journal of Experimental & Theoretical Artificial Intelligence*, 26(3), pp. 355-372. <doi: 10.1080/0952813x.2014.895108>.

Bryman, A. (2012) *Social Research Methods* Oxford University Press.

Bsharat, E. A. A. A. I. A. I. T. R. K. (2021) Understanding quantitative and qualitative research methods: A theoretical perspective for young researchers. *International Journal of Research*, 08(02). <doi: 10.2501/ijmr-201-5-070>.

BSi-BuildingSMART (2010). *Constructing the business case. Building Information Modelling*.

Butkovic, B. (2019) *A Framework for Developing 4d LOD on Construction Projects*. University of Wolverhampton.

CabinetOffice (2011). *Government Construction Strategy*: p. 14.

Cai, H., Hu, Z., Huang, G., Zhu, D. and Su, X. (2018) Integration of GPS, Monocular Vision, and High Definition (HD) Map for Accurate Vehicle Localization. *Sensors (Basel)*, 18(10) Sep 28. <doi: 10.3390/s18103270>.

Cai, H., Yuan, C., McClure, T. and Dunston, P. (2015). *A Synthesis Study on Collecting, Managing, and Sharing Road Construction Asset Data*.

Cambridge (2019) *Cambridge-university-policy-on-ethics-research.* [Online].].

Casella, E., Drechsel, J., Winter, C., Benninghoff, M. and Rovere, A. (2020) Accuracy of sand beach topography surveying by drones and photogrammetry. *Geo-Marine Letters*, 40(2), pp. 255-268. <doi: 10.1007/s00367-020-00638-8>.

cdbb (2019) *About the Centre for Digital Built Britain — Centre for Digital Built Britain*.

[Online].].
Chong, H. Y., Lopez, R., Wang, J., Wang, X. and Zhao, Z. (2016) Comparative Analysis on the Adoption and Use of BIM in Road Infrastructure Projects. *Journal of Management in Engineering*, 32(6). <doi: 10.1061/(asce)me.1943-5479.0000460>.
Clark, M. T. a. A., H.S., (2019) A framework for cost estimation using BIM object parameters. *In Proceedings, Annual Conference.*,(June), pp. 12-15.
Clarke, V. and Braun, V. (2016) Thematic analysis. *The Journal of Positive Psychology*, 12(3), pp. 297-298. <doi: 10.1080/17439760.2016.1262613>.
Costain (2015). *HE BIM Case Study Proposal A160*.
Costain (2015). *M1J28-35A*.
Costain (2016). *Seminar Outlines Benefits OfBIM For Highways Sector*.
Costain (2016). *Smartphone Innovation For Highways*.
Costain (2021). *A19 Testo's Asset Information Model Production program*.
Costin, A., Adibfar, A., Hu, H. and Chen, S. S. (2018) Building Information Modelling (BIM) for transportation infrastructure – Literature review, applications, challenges, and recommendations. *Automation in Construction*, 94, pp. 257-281. <doi: 10.1016/j.autcon.2018.07.001>.
Creswell, J. (2007) *Qualitative Inquiry & Research Design: Choosing Among Five Approaches*. SAGE.
Creswell, J. (2014) *Research Design: Qualitative, Quantitative and Mixed Method Approaches*. Fourth ed.: SAGE.
Crossrail (2014). *The Business Case for Mobility*.
Crossrail (2014). *Central Section Delivery Mobility Plan*.
Daly, T., Carluccio, S., Bhanderi, D., Patterson, D., Power, C. and Codd, J., 2020. Use of Geotechnical Asset Data Within Highways England: The Journey so Far and the Future. In *Information Technology in Geo-Engineering: Proceedings of the 3rd International Conference (ICITG), Guimarães, Portugal 3* (pp. 797-812). Springer International Publishing.
Damoah, Isaac & Ayakwah, Anthony & Twum, Paul. (2021). Assessing public sector road construction projects' critical success factors in a developing economy: Definitive stakeholders' perspective. Journal of Project Management. 10.5267/j.jpm.2021.7.003
Darlin, D. (2017). *Why GPS Units Beat Smartphones in the Car*: The New York Times.
Denzin, N. K. (2009) The elephant in the living room: or extending the conversation about the politics of evidence. *Qualitative Research*, 9(2), pp. 139-160. <doi: 10.1177/1468794108098034>.
DfT (2016). *BIM guidance for infrastructure bodies*: DfT.
Dotted Eyes,(2016). Data Validation.
Dornan, D. L. (2002) Asset management: remedy for addressing the fiscal challenges facing highway infrastructure. *IJOTM*.
Driscoll, D. L. A.-Y., A; Salib, P; Rupert, D.J. (2007) Merging Qualitative and Quantitative Data in Mixed Methods Research: How To and Why Not. *Ecological and Environmental Anthropology*, 3(1).
Eadie, R., Millar, P. and Harte, N. (2013) A comparison between CESMM3 and MCHW as

methods of measurement for civil engineering work. *International Journal of Procurement Management*, 6(5). <doi: 10.1504/ijpm.2013.056170>.

Eastman and al, e. (2008) *A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers, and Contractors*. Wiley.

Egan, J. (1998). *Rethinking Construction*.

Eisenhardt, K. M. (1999) Building Theories from Case Study Research. *Academy of Management* 14(4).

Emma, R. (2021). *Interview Participant 4*.

Esmaeili, H., Thwaites, H. and Woods, P. C. (2017). Workflows and Challenges Involved in Creation of Realistic Immersive Virtual Museum, Heritage, and Tourism Experiences: A Comprehensive Reference for 3D Asset Capturing. Paper presented at the *2017 13th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS)*

Esmaili, D. and El-Diraby, T. E. (2017) Organizational competency in urban water infrastructure asset management. *Canadian Journal of Civil Engineering*, 44(12), pp. 1056-1070. <doi: 10.1139/cjce-2017-0011>.

Evans, C. and Lewis, J. (2018) *Analysing Semi-Structured Interviews Using Thematic Analysis: Exploring Voluntary Civic Participation Among Adults*.

Fellows R , L. A. (2015) *Research Methods for Construction-p48.* Fourth ed.

Fellows R , L. A. (2015) *Research Methods for Construction-p198.* Fourth ed.

Findley, D. J., Cunningham, C. M. and Hummer, J. E. (2011) Comparison of mobile and manual data collection for roadway components. *Transportation Research Part C: Emerging Technologies*, 19(3), pp. 521-540. <doi: 10.1016/j.trc.2010.08.002>.

Fitz, D. V. (2016) *Investigation into Building Information Modelling Data Management: Quality of Non-Geometric Data Veracity at Project Hand-Over*. Middlesex University.

Flannery, J., Ajayi, S. O. and Oyegoke, A. S. (2021) Alcohol and substance misuse in the construction industry. *Int J Occup Saf Ergon*, 27(2) Jun, pp. 472-487. <doi: 10.1080/10803548.2019.1601376>.

Flick, K., Steinke (2004) *What is qualitative research? An introduction to the field. A companion to qualitative research, pp.3-11.*

Floros, G. S., Boyes, G., Owens, D. and Ellul, C. (2019) Developing IFC for Infrastructure Asset Management: A Case Study of Three Highway Entities. *In ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 4.

Foster, B. (2012) Using Real-Time CMMS Asset Data Capture During Construction to Improve Facility Management. *Journal of Building Information Modelling*, Fall 2012.

France-Mensah, J., O'Brien, W. J., Khwaja, N. and Bussell, L. C. (2017) GIS-based visualization of integrated highway maintenance and construction planning: a case study of Fort Worth, Texas.

Fuller, P. A., Dainty, A. R. J. and Thorpe, T. (2011) Improving project learning: a new approach to lessons learnt. *International Journal of Managing Projects in Business*, 4(1), pp. 118-136. <doi: 10.1108/17538371111096926>.

Galvin, R. (2015) How many interviews are enough? Do qualitative interviews in building energy consumption research produce reliable knowledge? *Journal of Building*

Engineering, 1, pp. 2-12. <doi: 10.1016/j.jobe.2014.12.001>.
Gibbons, P. B., A (2017) Developing the road ahead. *IAM*, 09.
Gilbert, T., Barr, S., James, P., Morley, J. and Ji, Q. (2018) Software Systems Approach to Multi-Scale GIS-BIM Utility Infrastructure Network Integration and Resource Flow Simulation. *ISPRS International Journal of Geo-Information*, 7(8). <doi: 10.3390/ijgi7080310>.
Gleeson, B. (2017) *Why Silos Kill The Ability To Communicate A Unified Vision, And 5 Ways To Eliminate Them.* [Online].].
Goldenberg, J., Horowitz, R., Levav, A. and Mazursky, D. (2003) How to find your innovation sweet spot
Golparvar-Fard, M., Balali, V. and de la Garza, J. M. (2015) Segmentation and Recognition of Highway Assets Using Image-Based 3D Point Clouds and Semantic Texton Forests. *Journal of Computing in Civil Engineering*, 29(1). <doi: 10.1061/(asce)cp.1943-5487.0000283>.
Gonfalonieri, A. (2019) *How to Implement Machine Learning For Predictive Maintenance _ Towards Data Science.* [Online].].
Goonetillake, J. (2019) *A Framework for the Integration of Information Requirements Within Infrastructure Digital Construction*. School of Engineering. Cardiff University.
Gov.Uk (2012). *Industrial strategy: government and industry in partnership*.
Gov.Uk (2016). *Challenges in highways asset management*.
Gov.Uk (2017). *BIM Adoption Strategy Statement of Intent*.
Gov.Uk (2017). *Procurement of Highway Infrastructure Asset Condition Surveys*.
Gov.Uk (2018) Industrial Strategy Artificial Intelligence Sector Deal.
Graf, M. (2017) Linking Excel Data to Navisworks Model Objects. *Autodesk*.
Greener (2008) *Business research methods. BookBoon.*
group, A.-V. B. w. (2015) *Building Information Modelling - Belgian Building Information Modelling*. [Online].].
Haala, N., Peter, M., Celalu, A. and Kremer, J. (2008) Mobile Lidar Mapping for Urban Data Capture. *In Proceedings of the 14th International Conference on Virtual Systems and Multimedia, Limassol, Cyprus (Vol. 2025, p. 95100)*.
Halttula, H., Haapasalo, H. and Silvola, R. (2020) Managing data flows in infrastructure projects - the lifecycle process model. *Journal of Information Technology in Construction*, 25, pp. 193-211. <doi: 10.36680/j.itcon.2020.012>.
Han, J., Kamber, M. and Pei, J. (2012) Data Warehousing and Online Analytical Processing. In: *Data Mining*. pp. 125-185.
Hancock, D.R., Algozzine, B. and Lim, J.H., 2021. Doing case study research: A practical guide for beginning researchers.
Hayes, E. (2015) *The Virtual Interactive Relationship between BIM Project Teams:*
Effective Communication to aid Collaboration in the Design Process. Middlesex University.
He, K., Gkioxari, G., Dollar, P. and Girshick, R. (2018) Mask-RCNN.
He, Y., Song, Z. and Liu, Z. (2017) Updating highway asset inventory using airborne LiDAR. *Measurement*, 104, pp. 132-141. <doi: 10.1016/j.measurement.2017.03.026>.
Heaton, J. (2021). *Line of Sight*.
Heaton, J., Parlikad, A. K. and Schooling, J. (2019) A Building Information Modelling

approach to the alignment of organisational objectives to Asset Information Requirements. *Automation in Construction*, 104, pp. 14-26. <doi: 10.1016/j.autcon.2019.03.022>.

Heipke, C., Woodsford, P. A. and Gerke, M. (2008) Updating geospatial databases from images. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Chapter 26.

Hennink, M. M., Kaiser, B. N. and Marconi, V. C. (2017) Code Saturation Versus Meaning Saturation: How Many Interviews Are Enough? *Qual Health Res*, 27(4) Mar, pp. 591-608. <doi: 10.1177/1049732316665344>.

Highways Agency (2014). *BIM Programme BluePrint*.

Highways England. (2012). *IAN_182 14A Enabling Handover into Operations and Maintenance*: p. P.1.

Highways England. (2015). *TTR_HE_ADC-IAM-IS Asset Inventory Amalgamation Report*.

Highways England. (2015). *Highways England A160 News Arcticle*.

Highways England (2016). *Information Management and Technology Strategy*.

Highways England. (2016). *Highways England Assets Written question - 45703 - UK Parliament*.

Highways England. (2016). *IAN_184/16 Highways England Data & CAD Standard. Instructions on naming conventions, file types and data structures for the delivery and transfer of CAD / BIM files to Highways England and its supply chain.*

Highways England. (2017). *SMP / AIG Data Handover Task Brief-41*.

Highways England. (2018). *ADMMv7 Additional Information*.

Highways England. (2018). *ADMMv7 Data Principles and Governance*.

Highways England. (2018). *ADMMv8 Data Principles and Governance*.

Highways England. (2018). *Asset Data Improvement Group*.

Highways England. (2019). *ADMMv9 Data Principles and Governance*.

Highways England. (2019). *Annual report and accounts*.

Highways England. (2019). *Highways England Delivery Plan 2019-2020*.

Highways England. (2020) *About us - Highways England*. [Online].].

Highways England. (2020). *ADMMv12 Part 2 Requirements and Additional Information*.

Highways England. (2020). *HE YNE Handover Meeting Notes*.

Highways England. (2020). *P04 Exchange Information Requirements*.

Highways England. (2021). *A19 - Use of Drones (UAVs) for Mapping and Visual Surveys*

HM Government (2013). *Industrial Strategy: government and industry in partnership, Construction 2025*.

Hood, W. W. and Wilson, C. S. (2001) The scatter of documents over databases in different subject domains: How many databases are needed? *Journal of the American Society for Information Science and Technology*, 52(14), pp. 1242-1254. <doi: 10.1002/asi.1191>.

Hu, Z. (2013) Intelligent Road Sign Inventory (IRSI) with Image Recognition and Attribute Computation from Video Log. *Computer-Aided Civil and Infrastructure Engineering*, 28(2), pp. 130-145. <doi: 10.1111/j.1467-8667.2012.00768.x>.

Hubert, D. (2018) *Drones How To*. [Online].].

Hwang, B.-G., Zhao, X. and Goh, K. J. (2014) Investigating the client-related rework in building projects: The case of Singapore. *International Journal of Project*

Management, 32(4), pp. 698-708. <doi: 10.1016/j.ijproman.2013.08.009>.
IAM (2015) Asset Management – an anatomy. *IAM*.
Interview4 (2021). *Participant 4*.
Jalayer, M., Zhou, H., Gong, J., Hu, S. and Grinter, M. (2014) A Comprehensive assessment of Highway Inventory Data Collection Methods. *Transportation Research Forum*.
Jon, B. (2021). *Interview Participant 6*.
Joshi, A., Kale, S., Chandel, S. and Pal, D.K., 2015. Likert scale: Explored and explained. *British journal of applied science & technology*, *7*(4), pp.396-403.
Kim, G. G. (2007) *Locating and Tracking Assets Using RFID*.
Kim, Y. R., Hummer, J.E., Gabr, M., Johnston, D., Underwood, B.S., Findley, D.J. and Cunningham, C.M. (2009). *Asset Management Inventory and Data Collection*.
Klein, L., Li, N. and Becerik-Gerber, B. (2012) Imaged-based verification of as-built documentation of operational buildings. *Automation in Construction*, 21, pp. 161-171. <doi: 10.1016/j.autcon.2011.05.023>.
Konar, A., 2018. Artificial intelligence and soft computing: behavioral and cognitive modeling of the human brain. CRC press.
KPMG, O. (2017). *Review of Highways England Maintenance and Renewals Delivery*.
Kumar, R. (2010) *Research Methodology A Step-by-Step Guide for Beginners*. Sage.
Kumar, S., 2018. Understanding Different Issues of Unit of Analysis in a Business Research. *Journal of General Management Research*, *5*(2).
Lahlou, S., 2011. How can we capture the subject's perspective? An evidence-based approach for the social scientist. *Social science information*, *50*(3-4), pp.607-655.
Lamont, J. (2015) *Digital asset management: Video advances!* : KMWorld. [Online].].
Latham, S. M. (1994). *Constructing the Team*: p. Forward bullet points.
Lee, D., La, W. G. and Kim, H. (2018) Drone Detection and Identification System using Artificial Intelligence. *ICTC*.
Lewis, T. G. and Denning, P. J. (2018) Learning machine learning. *Communications Of The ACM*, 61(12), pp. 24-27. <doi: 10.1145/3286868>.
Li, Y. and Liu, C. (2018) Applications of multirotor drone technologies in construction management. *International Journal of Construction Management*, 19(5), pp. 401-412. <doi: 10.1080/15623599.2018.1452101>.
Liu, F. (2009) Research methods for construction. Chichester.
Marrelli, A.F., 2005. The performance technologist's toolbox: Literature reviews. *Performance Improvement*, *44*(7), pp.40-44.
Maguire, M. and Delahunt, B. (2017) Doing a Thematic Analysis: A Practical, Step-by-Step Guide for Learning and Teaching Scholars. *All Ireland Journal of Higher Education*, 9(3).
Mahat, N. A. A. and Adnan, H. (2018) The influence of client brief and change order in construction project. *IOP Conference Series: Earth and Environmental Science*. <doi: 10.1088/1755-1315/117/1/012009>.
Marr, B. and Ward, M. (2019) *Artificial Intelligence in Practice: How 50 Successful Companies Used Artificial Intelligence to Solve Problems*. Wiley.
Marsh, D. (2017) *Building Information Modelling (BIM) and The UK Quantity Surveying Organisation: A Framework For Value*. Liverpool John Moores University.
McGrath, J. and George, J. (2018) Balancing the Business Case for BIM in Project Environments. *PM World Journal*, 7(12).

McMahon, P., Zhang, T. and Dwight, R. (2020) Requirements for Big Data Adoption for Railway Asset Management. *IEEE Access*, 8, pp. 15543-15564. <doi: 10.1109/access.2020.2967436>.

Mertens, D. M. (2005) Transformative Paradigm Mixed Methods and Social Justice.

Michele, D. S. and Daniela, L. (2011) Decision-support tools for municipal infrastructure maintenance management. *Procedia Computer Science*, 3, pp. 36-41. <doi: 10.1016/j.procs.2010.12.007>.

Miettinen, R., Kerosuo, H., Metsälä, T. and Paavola, S. (2018) Bridging the life cycle: a case study on facility management infrastructures and uses of BIM. *Journal of Facilities Management*, 16(1), pp. 2-16. <doi: 10.1108/jfm-04-2017-0017>.

Migliaccio, G. C., Bogus, S. M. and Cordova-Alvidrez, A. A. (2014) Continuous Quality Improvement Techniques for Data Collection in Asset Management Systems. *Journal of Construction Engineering and Management*, 140(4). <doi: 10.1061/(asce)co.1943-7862.0000427>.

Miller, S. (2019) Machine Learning, Ethics and Law. *Australasian Journal of Information Systems*, 23(Research on Applied Ethics (Cybersecurity)).

Mirza, S. and Ali, M. S. (2017) Infrastructure crisis — a proposed national infrastructure policy for Canada. *Canadian Journal of Civil Engineering*, 44(7), pp. 539-548. <doi: 10.1139/cjce-2016-0468>.

Moore, J. (2006) The Nature, Importance, and Difficulty of Machine Ethics. *INTELLIGENT SYSTEMS*, July/August.

Morgan, D. (2014). Integrating qualitative and quantitative methods. SAGE Publications, Inc., https://doi.org/10.4135/9781544304533

Mortensen, D. (2022) *How to Do a Thematic Analysis of User Interviews*. [Online].].

Moses, T. G. (2018) *The Development of 5D BIM Framework to Facilitate Costing in Contractor-Led Projects*.

Munir, M., Kiviniemi, A., Finnegan, S. and Jones, S. W. (2019) BIM business value for asset owners through effective asset information management. *Facilities*, 38(3/4), pp. 181-200. <doi: 10.1108/f-03-2019-0036>.

Munir, M., Kiviniemi, A. and Jones, S. W. (2019) Business value of integrated BIM-based asset management. *Engineering, Construction and Architectural Management*, 26(6), pp. 1171-1191. <doi: 10.1108/ecam-03-2018-0105>.

National Audit Office (2014). *Maintaining Strategic Infrastructure: Roads*.

NBS (2019). *National BIM Report, The definitive industry update*.

NBS (2018) What is COBie? | NBS. https://www.thenbs.com:443/knowledge/what-is-cobie,

Neubauer, B. E., Witkop, C. T. and Varpio, L. (2019) How phenomenology can help us learn from the experiences of others. *Perspect Med Educ*, 8(2) Apr, pp. 90-97. <doi: 10.1007/s40037-019-0509-2>.

NGwira, M. M. (2015) *Development of a flexible and adaptable operational property asset management framework for local authorities*.

nima (2022) *UK BIM Alliance*. [Online].].

Nogueira, K., Penatti, O.A. and Dos Santos, J.A.. (2017) Towards better exploiting convolutional neural networks for remote sensing scene classification. Pattern Recognition, 66.

O'Cathain, A., Thomas, K. J., Drabble, S. J., Rudolph, A. and Hewison, J. (2013) What can qualitative research do for randomised controlled trials? A systematic mapping review. *BMJ Open*, 3(6) Jun 20. <doi: 10.1136/bmjopen-2013-002889>.

Omar, H., Mahdjoubi, L. and Kheder, G. (2018) Towards an automated photogrammetry-based approach for monitoring and controlling construction site activities. *Computers in Industry*, 98, pp. 172-182. <doi: 10.1016/j.compind.2018.03.012>.

Omoregie, A. and Turnbull, D. E. (2016) Highway infrastructure and Building Information Modelling in UK. *Proceedings of the Institution of Civil Engineers - Municipal Engineer*, 169(4), pp. 220-232. <doi: 10.1680/jmuen.15.00020>.

ORR (2019). *Review of Highways England's asset management of road technology*.

ORR, H. E. a. (2018). *Review of Highways England's Ability to Improve Efficiency from its Asset Management Capability*.

Oxford (2019) *Where and how to apply for ethical review _ Research Support.* [Online].].

Patacas, J., Dawood, N. and Kassem, M. (2020) BIM for facilities management: A framework and a common data environment using open standards. *Automation in Construction*, 120. <doi: 10.1016/j.autcon.2020.103366>.

Perrons, R. K. and Jensen, J. W. (2015) Data as an asset: What the oil and gas sector can learn from other industries about "Big Data". *Energy Policy*, 81, pp. 117-121. <doi: 10.1016/j.enpol.2015.02.020>.

Prakash, (2018) Urban building extraction using satellite imagery through Machine Learning. *IEEE Symposium Series on Computational Intelligence SSCI 2018*.

pwc (2018) Skies without Limits: Drones impact on the UK economy.

Qu, Y., Qian, X., Song, H., Xing, Y., Li, Z. and Tan, J. (2018) Soil Moisture Investigation Utilizing Machine Learning Approach Based Experimental Data and Landsat5-TM Images: A Case Study in the Mega City Beijing. *Water*, 10(4). <doi: 10.3390/w10040423>.

R., F. and Liu, A. M. (2015) *Research Methods for Construction*. Fourth ed.

RICS (2020). *The future of BIM: Digital transformation in the UK construction and infrastructure sector*.

Robson, C. (2002) Real world research: A resource for social scientists and practitioner-researchers. Wiley-Blackwell.

Rokstad, M. M., Ugarelli, R. M. and Sægrov, S. (2015) Improving data collection strategies and infrastructure asset management tool utilisation through cost benefit considerations. *Urban Water Journal*, 13(7), pp. 710-726. <doi: 10.1080/1573062x.2015.1024692>.

Rowa-Dewar (2011) Combining qualitative and quantitative research within mixed method research designs: a methodological review. *Int J Nurs Stud*, 48(3) Mar, pp. 369-383. <doi: 10.1016/j.ijnurstu.2010.10.005>.

S, M. N. K. (2006) Research dilemmas: Paradigms, methods and methodology.

Sairam, N., Nagarajan, S. and Ornitz, S. (2016) Development of Mobile Mapping System for 3D Road Asset Inventory. *Sensors (Basel)*, 16(3) Mar 12. <doi: 10.3390/s16030367>.

Saldana Ochoa, K. and Guo, Z. (2019) A framework for the management of agricultural resources with automated aerial imagery detection. *Computers and Electronics in Agriculture*, 162, pp. 53-69. <doi: 10.1016/j.compag.2019.03.028>.

Sanjari, M., Bahramnezhad, F., Fomani, F.K., Shoghi, M. and Cheraghi, M.A (2014) Ethical challenges of researchers in qualitative studies: the necessity to develop a specific guideline. *Journal of Medical Ethics and History of Medicine*.

Sankaran, B., Nevett, G., O'Brien, W. J., Goodrum, P. M. and Johnson, J. (2018) Civil Integrated Management: Empirical study of digital practices in highway project delivery and asset management. *Automation in Construction*, 87, pp. 84-95. <doi: 10.1016/j.autcon.2017.12.006>.

Sapsford, R., Jupp, V., 2006. Data Collection and Analysis. SAGE.

Sardén, Y. and Engström, S. (2010) Modern Methods of Construction: A Solution for an Industry Characterized by Uncertainty? *In Annual ARCOM Conference: 06/09/2010-08/09/2010 (pp. 1101-1110). Association of Researchers in Construction Management.*

Saunders (2009) *Research Methods for Business Students. Pearson Education.*

Saunders, M., Lewis, P. and Thornhill, A., 2009. *Research methods for business students*. Pearson education.

Saur, G. and Krüger, W. (2016) Change Detection in Uav Video Mosaics Combining a Feature Based Approach and Extended Image Differencing. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLI-B7, pp. 557-562. <doi: 10.5194/isprsarchives-XLI-B7-557-2016>.

Sayrs, L. (1998) InterViews: An Introduction to Qualitative Research Interviewing Steinar Kvale. Thousand Oaks, CA: Sage, 1996. 326 pp. *The American Journal of Evaluation*, 19(2), pp. 267-270. <doi: 10.1016/s1098-2140(99)80208-2>.

Seong, H., Son, H. and Kim, C. (2018) A Comparative Study of Machine Learning Classification for Color-based Safety Vest Detection on Construction-Site Images. *KSCE Journal of Civil Engineering*, 22(11), pp. 4254-4262. <doi: 10.1007/s12205-017-1730-3>.

Shah, R., McMann, O. and Borthwick, F. (2017) Challenges and prospects of applying asset management principles to highway maintenance: A case study of the UK. *Transportation Research Part A: Policy and Practice*, 97, pp. 231-243. <doi: 10.1016/j.tra.2017.01.011>.

Sharma, G., 2017. Pros and cons of different sampling techniques. International journal of applied research, 3(7), pp.749-752.

Shchutskaya, A. V. and Ivanova, E. E. (2019) *Exports of Russian Cereals: Analysis of the Current State and Development Prospects*. [Online]. 62].

Shou, W., Wang, J., Wang, X. and Chong, H. Y. (2014) A Comparative Review of Building Information Modelling Implementation in Building and Infrastructure Industries. *Archives of Computational Methods in Engineering*, 22(2), pp. 291-308. <doi: 10.1007/s11831-014-9125-9>.

Siegel, J., Erb, D. and Sarma, S. (2018) Algorithms and Architectures: A Case Study in When, Where and How to Connect Vehicles. *IEEE Intelligent Transportation Systems Magazine*, 10(1), pp. 74-87. <doi: 10.1109/mits.2017.2776142>.

Singh, A. K. S., A et al (2017) Vision based rail track extraction and monitoring through drone imagery. *ScienceDirect*.

Smyth (2019) *Research ethics guidebook - Undertaking a research project - ebook companion website.* [Online].].

Son, H., Bosché, F. and Kim, C. (2015) As-built data acquisition and its use in production monitoring and automated layout of civil infrastructure: A survey. *Advanced Engineering Informatics*, 29(2), pp. 172-183. <doi: 10.1016/j.aei.2015.01.009>.

Song, Y., Wang, X., Tan, Y., Wu, P., Sutrisna, M., Cheng, J. and Hampson, K. (2017) Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective. *ISPRS International Journal of Geo-Information*, 6(12). <doi: 10.3390/ijgi6120397>.

Stöcker, C., Ho, S., Nkerabigwi, P., Schmidt, C., Koeva, M., Bennett, R. and Zevenbergen, J. (2019) Unmanned Aerial System Imagery, Land Data and User Needs: A Socio-Technical Assessment in Rwanda. *Remote Sensing*, 11(9). <doi: 10.3390/rs11091035>.

Strauss, A. a. C., J. (1990) Basics of qualitative research. Sage publications. <doi: 10.5072/genderopen-develop-7>.

Sutrisna, M. and Abbott, C. (2002) Presenting Case Studies of Construction Projects to the Construction Industry Audience.

TaskGroup, B. (2016) *What is BIM*. [Online].].

TODAY, B. (2020) Counting the carbon cost. *BIM Today*,(September).

Tolich, M., 2023. Anonymity, confidentiality and de-identified data. In *Encyclopedia of Business and Professional Ethics* (pp. 104-107). Cham: Springer International Publishing.

Tommelein, I. D., Kirkendall, R. L. and Ballard, G. (2000) Contribution of Specialty Contractor Knowledge to Early Design. *In Proc. Eighth Annual Conference of the International Group for Lean Construction.*

Trochim, W. M., Cabrera, D. A., Milstein, B., Gallagher, R. S. and Leischow, S. J. (2006) Practical challenges of systems thinking and modeling in public health. *Am J Public Health*, 96(3) Mar, pp. 538-546. <doi: 10.2105/AJPH.2005.066001>.

Turnbull, D. (2018) *The impact of Building Information Modelling on Health and Safety: An Investigation of Drone Capability to Improve Health and Safety on Construction Sites*. Middlesex University.

UCI (2019) *Privacy and Confidentiality - UCI Office of Research.* [Online].].

UoL (2019). *Research ethics*

Valenzuela, D. and Shrivastava, P. (2002). *Interview as a Method for Qualitative Research*.

Ventresca (2001) Archival Research Methods.

Viguier, R., Lin, C. C., AliAkbarpour, H., Bunyak, F., Pankanti, S., Seetharaman, G. and Palaniappan, K. (2015). Automatic Video Content Summarization Using Geospatial Mosaics of Aerial Imagery. Paper presented at the *2015 IEEE International Symposium on Multimedia (ISM)*

Vollmer, S., Mateen, B.A., Bohner, G., Király, F.J., Ghani, R., Jonsson, P., Cumbers, S., Jonas, A., McAllister, K.S., Myles, P. and Granger, D. (2018) Machine learning and AI research for Patient Benefit: 20 Critical Questions on Transparency, Replicability, Ethics and Effectiveness. *arXiv preprint arXiv:1812.10404.*

Walliman, N. (2010) *Research Methods the basics*. Routledge.

Wang, G. and Zhang, Z. (2021) BIM implementation in handover management for underground rail transit project: A case study approach. *Tunnelling and Underground Space Technology*, 108. <doi: 10.1016/j.tust.2020.103684>.

Ward, B. (2015) *Integrated Asset Management Systems Water Sector*. University of

Exeter.
WBGD (2022) *Building Information Modelling (BIM)*. [Online].].
Wetherbe, J. C. (1991) Executive Information
Requirements: Getting It Right. *MIS Quarterly*.
Wierzbicki, D., Kedzierski, M. and Fryskowska, A., 2015. Assesment of the influence of UAV image quality on the orthophoto production. *The international archives of the photogrammetry, remote sensing and spatial information sciences*, *40*, pp.1-8.
Wiki (2019) *Machine learning - Wikipedia.* [Online].].
Wikipedia (2019) *<Machine ethics - Wikipedia*. [Online].].
Wilkins, B. (2004). *Framework for Highway Asset Management*: County Surveyors' Society.
Wolstenholm, A. (2009). *Never Waste a Good Crisis*.
Wondimu, P. A., Hailemichael, E., Hosseini, A., Lohne, J., Torp, O. and Lædre, O. (2016) Success Factors for Early Contractor Involvement (ECI) in Public Infrastructure Projects. *Energy Procedia*, 96, pp. 845-854. <doi: 10.1016/j.egypro.2016.09.146>.
Wong, J. K. W., Ge, J. and He, S. X. (2018) Digitisation in facilities management: A literature review and future research directions. *Automation in Construction*, 92, pp. 312-326. <doi: 10.1016/j.autcon.2018.04.006>.
Wuest, T., Weimer, D., Irgens, C. and Thoben, K.D., 2016. Machine learning in manufacturing: advantages, challenges, and applications. *Production & Manufacturing Research*, *4*(1).
Xu, Y., Zhou, Y., Sekula, P. and Ding, L. (2021) Machine learning in construction: From shallow to deep learning. *Developments in the Built Environment*, 6. <doi: 10.1016/j.dibe.2021.100045>.
Xu, Z., Li, L., Xiang, Z. and Long, C. (2016) A digital panorama mapping system with soft-IMU technology: experience with a Chinese low-cost mobile mapping system. *Survey Review*, 48(348), pp. 224-232. <doi: 10.1179/1752270615y.0000000028>.
Yang, C. (2013) *Highway Asset Management*. University of Nottingham.
Yen, K. S., Ravani, B. and Lasky, T. A. (2011). *Lidar for Data Efficiancy*.
Yi, E., 2018. Themes don't just emerge: Coding the qualitative data. *Medium data science*.
Yilmaz, K. (2013) Comparison of Quantitative and Qualitative Research Traditions: Epistemological Theoretical and Methodological Differences. *European Journal of Education*, 48(2).
Yin, R. K. (2009) Yin, R.K., 2009. Case study research: Design and methods (Vol. 5). sage.
Zahiroddiny, S. (2016) *Understanding the Impact of Building Information Modelling (BIM) on Construction Projects Communication Patterns*. University of Northumbria at Newcastle.
Zanella, A., Bui, N., Castellani, A., Vangelista, L. and Zorzi, M. (2014) Internet of Things for Smart Cities. *IEEE Internet of Things Journal*, 1(1), pp. 22-32. <doi: 10.1109/jiot.2014.2306328>.
Zhou, H., Jalayer, M., Gong, J., Hu, S. and Grinter, M., 2013. Investigation of methods and approaches for collecting and recording highway inventory data. FHWA-ICT-13-022.

Appendices

Appendix A – Interview Questionnaire

Real-time Asset Information Modelling (rtAIM) protocol for Highways

The survey will take approximately 6 minutes to complete.
Questionnaire to find realistic attitudes and behaviours as well as operative opinions on improvement of asset data collect.

Hello, my name is Graham Starkey and I am engaged with a research study at Leeds Beckett University. I am carrying out some research for my thesis to find out how to develop a BIM-based protocol and decision support framework for real-time collection, validation and handover of attribute data for Highways England major schemes. I am very interested in your opinions and there is no set structure or right/wrong answer so please be honest where you can and anything you say will be anonymous.

Section 1 ...

Research Question 1

To analyse the state of practice for asset information and the potential of BIM implementation

1. An educational knowledge gap still exist in relation to BIM and its implementation

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

2. BIM implementation will help with Handover and Asset Capture

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

3. Highways England maintenance area teams still have different main databases.

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

4. Highways England still have many databases that need to be populated

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

5. There is not enough meetings with HE/Contractor and Area teams discussing databases

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

6. Are lessons learnt from previous projects in regards to Handover of Asset Attributes

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

7. ADMM changes to often, thus leading to scope change

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

Section 2 ...

Research Question 2

To investigate strategies for capturing real-time asset information to facilitate life cycle asset management.

8. As it stands the processing requirements for capturing asset information poses challenges and time constraints

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

9. The client (HE) must include area teams more when discussing ADMM and asset attribute requirements

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

10. BIM processes and it's metadata requirements can help deliver handover asset attribute data more efficiently

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

Section 3 ...

Research Question 3

To investigate and validate the effective strategy and protocol for capturing highway asset information.

11. BIM processes can help with the capturing of asset information

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

12. BIM processes can influence the handing over of asset attribute information

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

13. BIM can replace traditional methods of capturing asset information

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

14. Digitising traditional construction documents for filed use will help with automation of data

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

15. There's always a lack of resources and planning at handover stage

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

Section 4 ...

Research Question 4

To develop the BIM-based framework and associated protocol for real-time collection, validation, and handover of attribute data for Highways England major schemes (Participant_1_BE, Pos. 4)

16. BIM can help with the capturing of asset locations

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

17. The use of AI (Machine Learning) can help with the validation and capture of assets

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

18. The use of Drones can help identifying assets

Five point scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. *

	Option 1	Option 2	Option 3	Option 4	Option 5
Statement 1	○	○	○	○	○

Section 5 ...

Demographic Information

19. Age Range *

◯ 18 to 25

◯ 26 to 35

◯ 36 to 45

◯ 46 to 55

◯ 56 and above

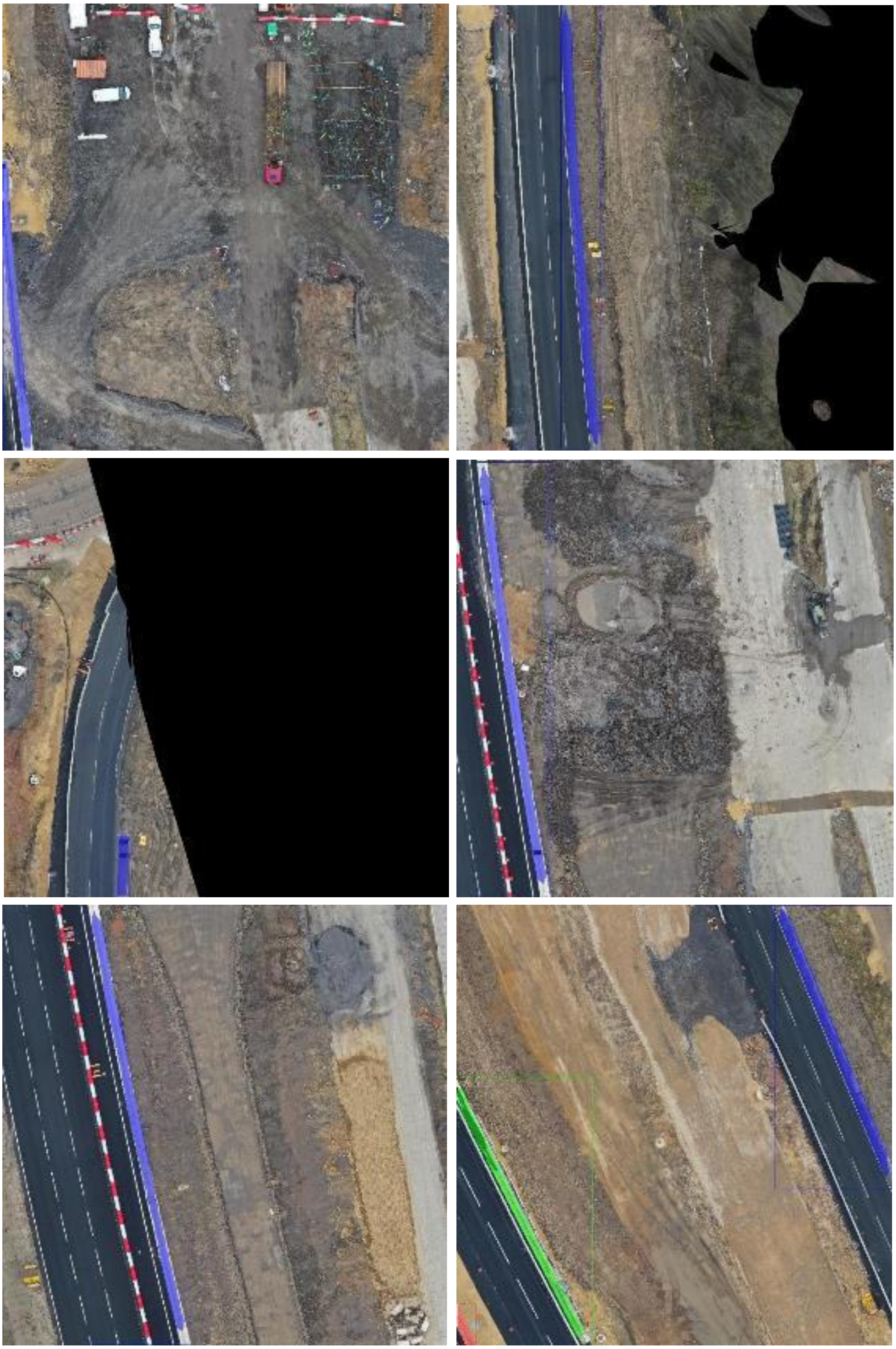
20. Job Role *

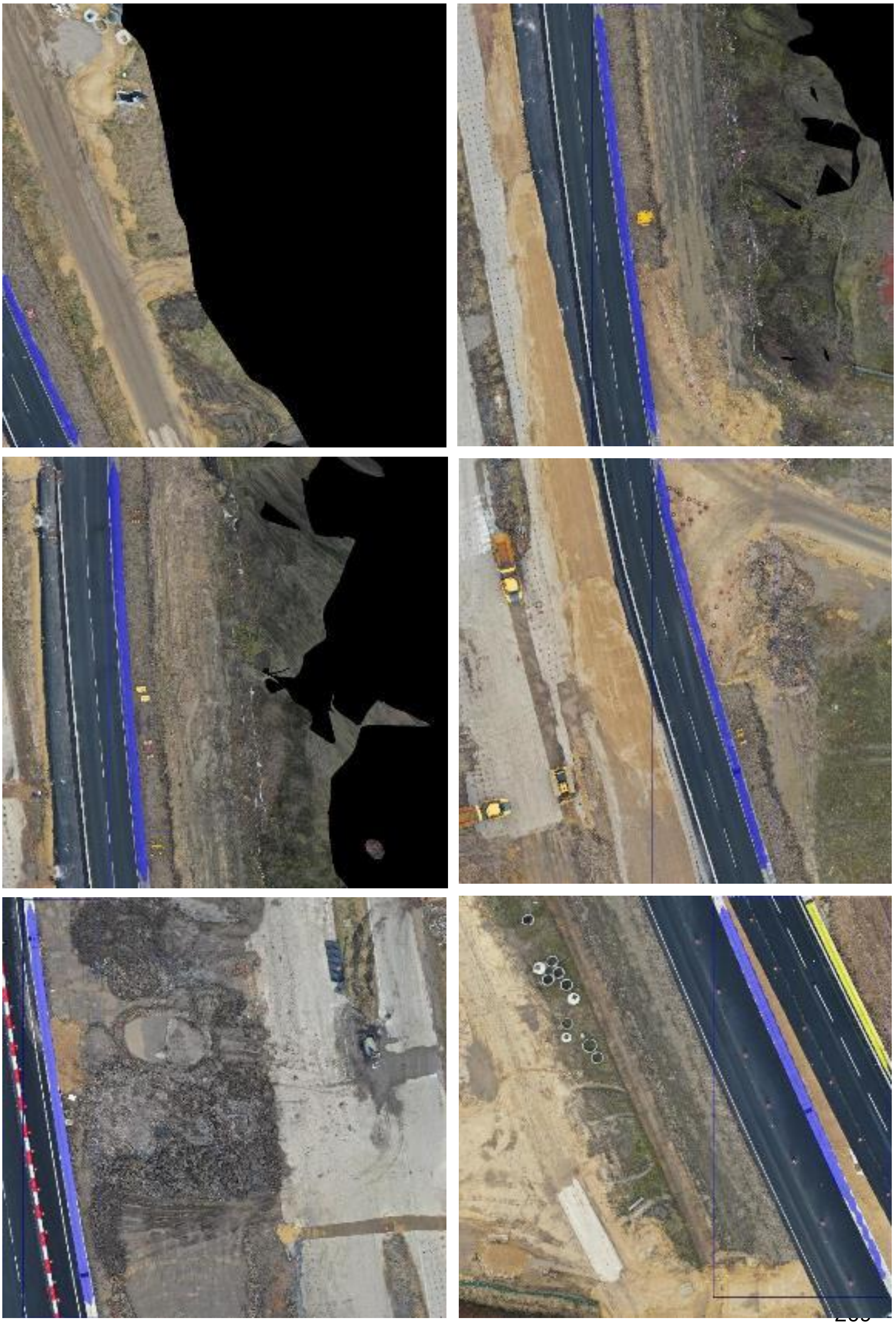
Enter your answer

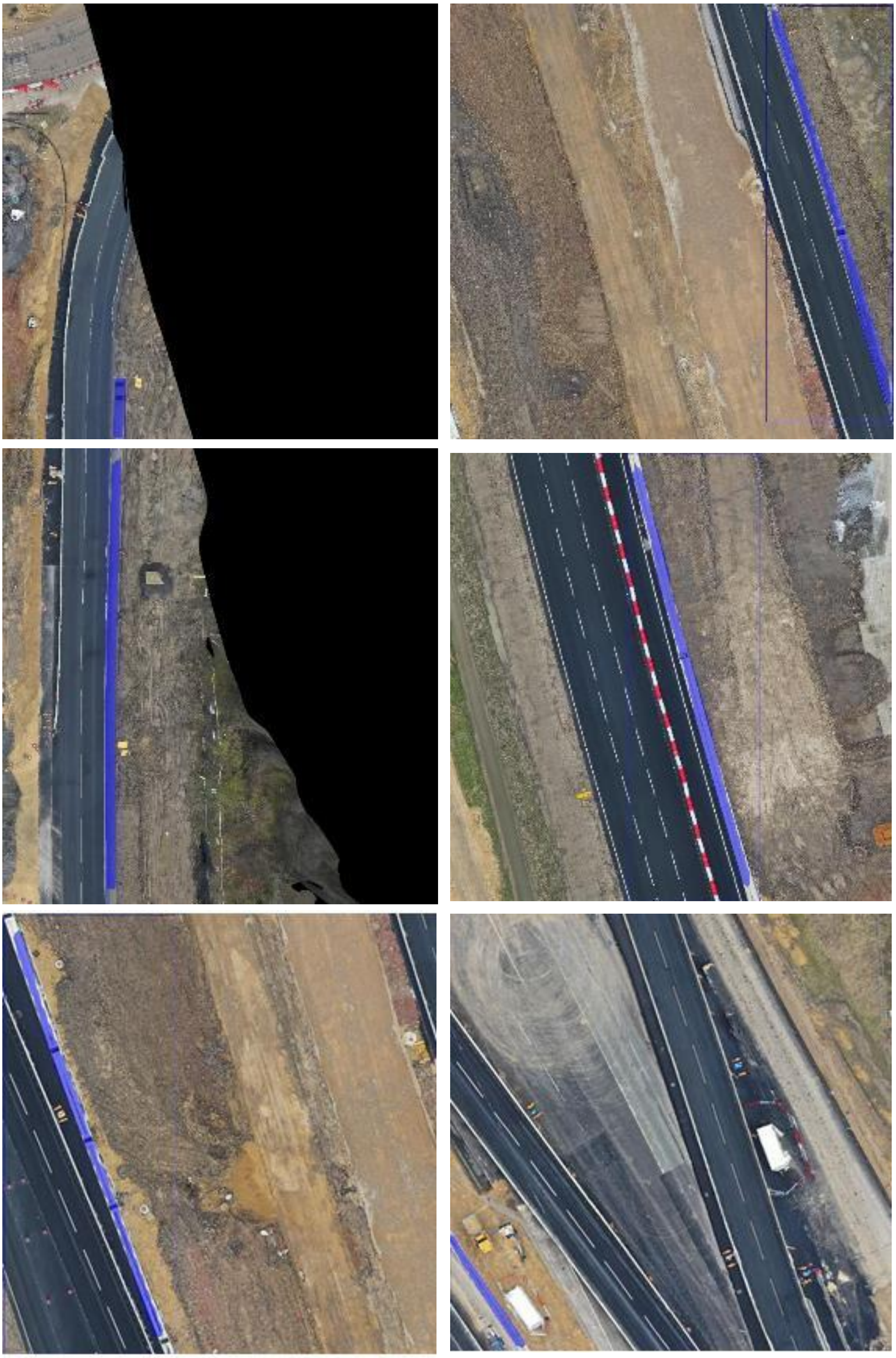
21. How long have you worked in the industry? *

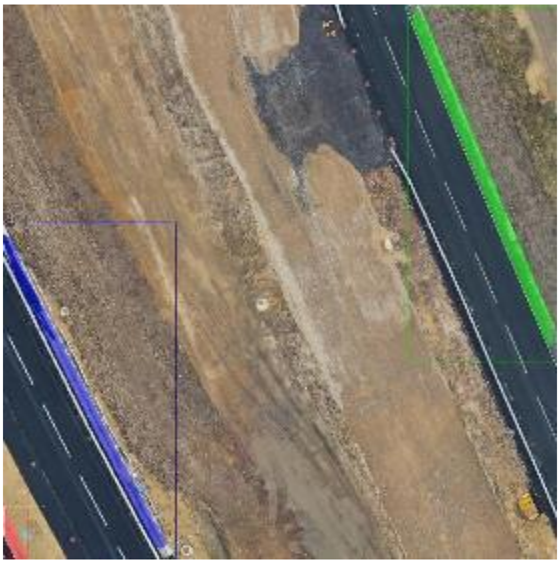
Enter your answer

Appendix B – Images showing Mask R-CNN (Starkey, 2022)

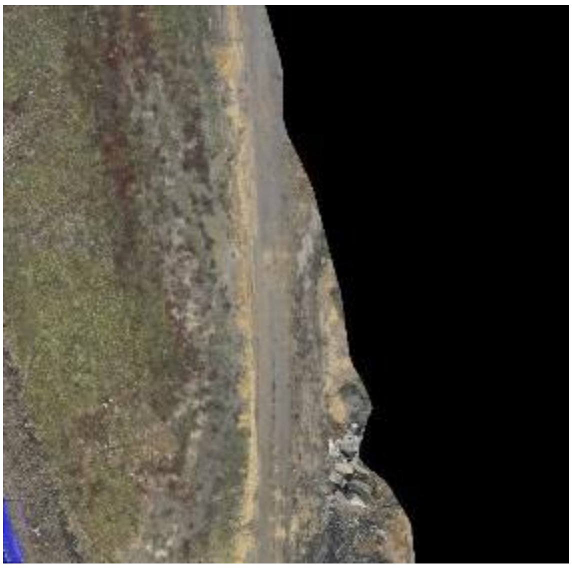










Appendix C – Framework Flowchart (Starkey, 2024)