A Digital Platform for Handling the Construction Build Process in Highways Infrastructure

Ibrahim Fawwaz Al-Ghraify

Operations Management and Decision Sciences Division
Sheffield University Management School

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بسم الله الرحمن الرحيم

: {يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ}
[المجادلة: 11]

In the Name of Allah, the Most Beneficent, the Most Merciful

﴿ Allah will raise those who have believed among you and those who were given knowledge, by degrees ﴾

Sorah Al-Mujadilah (11)

Declaration

This study was conducted in the Management School, Operational Management and Decision Science division (OMDS), The University of Sheffield during the period from 2015 to 2023. All sentences or passages quoted in this report from other people's work have been specifically acknowledged by clear cross-referencing to author, work and page(s). Finally, I declare that the work in this thesis is my own.

Name: Ibrahim Fawwaz Al-Ghraify
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Supervisors:
Dr. Andrew Brint
Dr. Chantal Cantarelli
Dr. Lynda Burkinshaw

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Abbreviation

ADMM: Asset Data Management Manual

BIM: Building Information Model

CATS: Construction Asset Tracking System

CMDS: Control Management Document System

COBie: Construction Operations Building Information Exchange

DBB: Digital Built Britain

FHWA: Federal Highway Administration

GIS: Geographical Information system

HA: Highways Agency (current name NH)

HADMS: Highways Agency Drainage Management System

HE: Highways England (current name NH)

ILCDS: Interlinking Life-Cycle Data Spaces

IQVT: Integrated Quality Verification Team

IS: Information System

IT: Information Technology

M1SM: Motorway 1 Smart Motorway

M1T3: Motorway 1 Tranche 3

NH: National Highways

O&M: Operation and Management

OEM: Operational Excellence Matrix

QM: Quality Management

QC: Quality Control

ROC: Regional Operation Control

SDP: Smart Delivery Platform

TiLoS: Time-Location System

TPMS: Technology Pavement Management System

TQM: Total Quality Management

Executive Summary

The construction industry has a long-established reputation for cost and time overruns. This is a particular concern for the UK government when commissioning major infrastructure projects. Therefore, the government is requiring that highways construction companies move to adopt new ways of monitoring projects in the future. Against this background, the thesis investigates the issues that make project management more difficult in highways construction compared with manufacturing, and how the government's proposals aim to improve the situation. The research resulted in collecting data from experts in the construction industry to find out the current issues of the industry and how digitising the current build process might help to tackle some of these issues. The research then looks at how one of the major UK highways construction companies can implement an asset tracking system that not only satisfies the government's vision, but goes beyond it to audit, track and manage the actual build process which saves cost and time in the reworking and handover process. The company's situation along with the government's proposals are analysed to identify the features required from the proposed system. A prototype system called CATS – Construction Asset Tracking System – was then implemented. The final stage of the research evaluated the strengths and weaknesses of CATS by analysing the data collected from interviewing thirteen managers and engineers in the company. The interviews covered what they saw as the issues in highways construction, followed by a demonstration of CATS if they had not seen it before, and concluded with a discussion of the role they saw for CATS and similar systems.

1.0 Introduction

This chapter offers an overview of the thesis. It starts with the research motivation in section 1.1, followed by the project background in section 1.2. Section 1.3 discusses industrial requirements before examining the reality or achievability of the Construction Strategy 2025 in section 1.4. Research questions are detailed in section 1.5, followed by an analysis of research contribution and impact in section 1.6. Finally, section 1.7 outlines the thesis structure, concluding with a summary in section 1.8.

1.1 Motivation for the research

This research project stemmed from the highways division of a large UK construction company (Costain) needing to develop an asset tracking model to conform with the government's requirements to be compatible with the specified levels of the National Highways' (NH) Building Information Model (BIM) features. Additionally, the model aimed to provide support for the government's vision of increasing the 'productionising of construction' to enhance efficiency, be sufficiently flexible to cater for the different stages in the lifecycle of highways, and assist in the development of a cross-company standard asset model for the highways industry.

This project was initially produced and supported by Costain Group to investigate how contractors can comply with the Construction Strategy 2025. Costain Group, founded in 1865 by Richard Costain, is a British engineering solutions provider with activities organised into six sectors: Rail, Highways, Power, Water, Nuclear, and Oil & Gas. As technology development has accelerated, Costain's clients are now seeking for construction projects to be delivered more quickly and cheaply than before, leading Costain to adopt new productive ways to remain competitive. Even though the construction industry has a process in place to manage construction and maintenance works, it still suffers from poor practices resulting in cost and time waste in doing the same job again (reworking). This issue and others discussed in more detail in chapter 5 create a need to build a digital model for handling and managing asset data during the construction phase, which will provide support in delivering projects with minimal waste in cost and time. Consequently, Costain wanted to not just meet the government/NH requirements mentioned in section 1.2, but to exceed them by developing an asset tracking model to enhance their internal efficiency.

Furthermore, at the time of the publication of the Construction 2025 strategy, construction projects were far from considering or incorporating digital tools into their daily operations and processes. In order to align contractors such as Costain with the government's strategy, this research was initiated to find solutions and provide guidance on how to proceed in line with the Construction 2025 strategy. The goal was to develop a digital system to ensure that, by the deadline for implementation, contractors and their supply chains would be sufficiently close to being BIM compliant.

At the heart of the research was the development of a prototype, proof of concept asset tracking system called CATS (Construction Asset Tracking System). The long term vision was that this prototype would be a step towards encouraging the development and introduction of a standard asset tracking model across the industry. For example, this would facilitate the handover of the highway data between different stages of its life, such as from construction to operations. This would benefit all parties involved in the construction, operation and maintenance of highways in a similar way to how the common standardised container specification has benefited the various parties involved in shipping goods.

Besides developing CATS, the project also identified the required and the desirable features that the CATS system should have, and then evaluated CATS against both these aspects and any other features that experienced construction staff saw as being important. The thesis splits into two main parts: the requirements that such an information system needs to comply with, and the development and evaluation of a prototype of such an information system. The first part of the thesis identifies what features are required from the asset tracking model. This covers the requirements that the National Highways (NH) is specifying future models should meet, i.e. the introduction of progressively more advanced models of BIM (Chapter 2). As offsite production of component sections for highways is far more restricted compared to building sections, the focus of enhancing the production of highways construction lies in refining Total Quality Management (TQM) procedures, especially in production, and addressing the challenges of implementing TQM in highway construction (Chapter 3). One significant disparity between manufacturing and highway construction lies in the ability to monitor progress in real-time, a capability crucial for implementing TQM procedures, and so real time asset knowledge needs to be at the centre of any construction asset tracking database. Chapters 2 and 3 are based on reviewing government and industry documents, as well as the academic literature to identify the requirements for an asset tracking model.

However, the most relevant and up-to-date knowledge of the significant problems affecting highways construction lies with experienced construction managers, leading us to the second part of the thesis. Therefore, interviews were conducted to discuss the features they deem necessary in an asset tracking system (Chapters 4 and 5). Additionally, this section examines how well current or existing asset models cover these features (Chapter 6) and identifies the essential features required from a highways asset tracking system, which were derived from interviews, industry reports, and academic literature (Table 4 in Chapter 7). Since none of the existing models met the requirements, a prototype model—the Construction Asset Tracking System (CATS)—was developed and described in Chapter 8. The model was evaluated to ensure it covered the requirements identified in Chapter 7 and the desired features according to experienced highways construction managers (Chapter 5). This research revealed that existing models and tools (discussed in Chapter 6) lacked the comprehensive requirements to transition the construction industry to be BIM compliant and thus align with government goals (section 2.2). Therefore, CATS was developed to re-engineer the construction processes using an Information System (IS) to enable proactive improvements.

The data collected from the experts shed a light on the current drawbacks and issues that the construction industry suffers from. These can be summarised as:

- A need to digitise the construction build process.
- A need to tackle the waste of cost and time in the current construction projects.
- A need to solve few of the societal issues such as work and cultural issues, political issues, and behavioural issues of the workers.
- A need for better communication and collaboration in the working environment.
- A need for better specifications of the Information Systems currently in use.

These drawbacks served as the foundation for the CATS model, which aimed to address as many of these issues as possible and improve the existing construction culture. Subsequently, CATS underwent evaluation by the interviewers to gather feedback and determine its effectiveness in handling these issues. According to the interviewees, CATS development is progressing in the right direction. The application of CATS in construction was perceived to result in cost and time savings, proactively address workers' behavioural issues, enhance communication through real-time reporting, and offer a means to digitise current construction processes (refer to Chapter 9 and Table 6 in Chapter 8). Moreover, the interview data presented in this research contributes uniquely to the gap in the knowledge in academia, shedding light on issues within current construction processes and proposing solutions.

1.2 Background

As well as representing what is equivalent to 10% of UK employment, the construction industry holds a significantly broader importance for the economy by being responsible for establishing, developing, and upkeeping the environments where businesses function and thrive, along with constructing the economic framework that ensures national connectivity (Department for Business, 2013).

The Department for Business, (2013) stated that

> "Construction is one of the largest sectors of the UK economy. It contributes almost £90 billion to the UK economy (or 6.7%) in value added, comprises over 280,000 businesses, and provides some 2.93 million jobs, which is equivalent to about 10% of total UK employment"

Construction industry is an extremely important sector in the UK as it

> "employs more than three million people and in 2010 delivered £107 billion to the UK economy […] It is highly diverse with a range of discrete sub-sectors […] It is a key contributor to UK growth with the global construction market forecast to grow by over 70% by 2025. […] In addition, the UK has a large and growing Facility/Asset Management sector ensuring that built assets are operated effectively and efficiently" (HM Government, 2015).

HMSO (2011) stressed that the construction sector's value contributes approximately £110 billion annually to the UK economy. This total is divided into three primary sub-sectors:

- commercial and social, amounting to £49 billion
- residential, totalling £42 billion
- infrastructure, accounting for £18 billion

(Department for Business, 2013) stated that

> “A modern, competitive and efficient construction industry is essential to the UK’s economic prosperity. Its contribution is also vital if the UK is to meet its Climate Change Act commitments and wider environmental and societal obligations”

A driver for this project was a trend among Costain’s clients who were seeking for construction projects to be delivered faster and 15-20% cheaper than five years earlier (HM Government, 2012; Teall, 2014). Sundqvist et al., (2014) mentioned that the views of project leaders within construction projects with regard to improving effectiveness, are concentrated on achieving the objectives of cost, time and scope requirements of their projects. Therefore, Costain believes that the only way it can meet the client’s expectations, and thus stay in the market, is with the support of technology and research. The outcome of this unity between research and technology is expected to achieve this effectiveness through:

- Decreasing the amount of reworking
- Eliminating the redundancy through creating one single source of truth (Core Record)
- Decreasing post construction surveying. (David McHugh, Technology Integration Manager, Costain, Personal Communication)

This research will broaden the understanding within academia about solutions to deal with challenges faced in asset management within construction by including the information system model in solutions.

1.3 Industrial Requirements

National Highways (NH) (formerly the Highways Agency) is a governmental company responsible for operating, maintaining and improving motorways and major A roads in England. It was founded as an agency in 1994 and converted into a governmental company in April 2015 (Highways Agency, 2015).

The main government ambitions mentioned in HM Government (2013) for Construction Strategy 2025, is to reduce both the initial cost of construction and the whole life cost of assets by a third, and reduce the overall time from project inception to completion for new builds and refurbished assets by half by 2025. These ambitions drove the specifications of the Digital Built Britain (DBB) plan to leverage the use of BIM to manage the construction industry by the government (section 2.3). Therefore, BIM is a fait accompli if construction contractors want to tender for highways construction projects.

The previous paragraph sets out the government's Construction Strategy 2025's main targets. These are cost and time targets for the built environment in general, not specifically for highways construction. Chapter 2 will discuss how these government targets apply to highways construction and what requirements highways construction companies need to comply with in the future.

In conclusion, there is a need to create a new asset model for highways construction that addresses the limitations of current models, is BIM compliant and contributes to the aims of the Construction 2025 strategy.

It is worth noting that this research will be discussing the first 2 targets of the Construction 2025 strategy mentioned in HM Government (2013), particularly the 33% reduction in both initial construction costs and the entire life cost of assets, as well as a 50% reduction in the overall time from project inception to completion for new builds and refurbished assets. It does not delve into the last two goals of the strategy, namely, the 50% reduction in greenhouse gas emissions in the built environment and a 50% reduction in the trade gap between total exports and imports for construction products and materials.

1.4 Are the Construction 2025 Strategy targets achievable?

The perception of UK organisations towards the Construction 2025 Strategy and its potential benefits for the construction firm's supply chain, industry advancement, technology utilisation like BIM in areas such as highways and rail, and its role in attracting a new, younger workforce into the sector is underscored in the works of Barker (2013), Fitzpatrick (2013), Hardy (2014), RICS (2018).

Maqbool et al. (2023) concluded that using “Modern Methods of Construction” (MMC) - which is also called off-site construction - would help achieve the targets of Construction 2025 Strategy. This comes in the shape of reducing costs, duration, greenhouse gas emissions and the import/export trade gap in the construction industry. As Maqbool et al. point out, MMC has been around since 1945 with the use of prefab housing to assist with the post war reconstruction. The government has often put forward prefabrication as a way to improve construction industry efficiency, e.g. in 1962 the housing minister (Keith Joseph) ‘pinned his hopes on what he called housing from the factory’ (page 5 of ‘A Northern Wind: Britain 1962-65’ D.Kynaston, Bloomsbury 2023). Hence, it is likely to have only a limited impact on an area such as highways construction where it is not naturally applicable, in the short or medium term.

While the previous discussion hailed the Construction 2025 Strategy, on another hand, Dziekonski et al. (2023) found Industry experts express uncertainty regarding achieving the set goals for reducing overall costs and time by 2025. However, there is a more optimistic outlook on the reduction of greenhouse gas emissions and narrowing of the trade gap. The survey results highlight reluctance to embrace change, insufficient implementation of new technology, industry fragmentation, and a failure to adopt modern construction methods as the primary obstacles to meeting the targets outlined in the Strategy. In conclusion, they stated that the UK's construction sector appears to be caught in traditional and inefficient structures and methods, impeding a swift transformation by 2025.

Following the failure of previous government initiatives, Green (2013) highlighted the opinion of most construction professionals that they believed the strategy would not succeed. Also, Gruneberg (2018) addressed the ambiguity of the process that the government is following to reach these targets.

Moreover, BAM (2015) stated that the difficulty to achieve the strategy seems to originate from the industry's divided and risk-averse culture. While suggesting innovative solutions is commendable, the pace of progress significantly decelerates when there is hesitancy to take the required leap of faith and experiment with novel products. Unfortunately, this reluctance is precisely what has impeded advancement in this setting.

Nevertheless, Mr. Rawlinson, from the Construction Leadership Council (CLC) responsible for monitoring and evaluating the achievement of the construction industry's 2025 strategy targets, admitted that the CLC is currently not measuring progress on these goals (Construction Index, 2017). This implies the absence of a readily available document that informs us about the performance of the strategy implementation. Furthermore, while the intended destination and the prescribed path of implementing the strategy is known, the actual extent of progress remains unknown (Construction Index, 2017).

In conclusion, while attaining the precise targets may seem challenging, incremental achievements can contribute significantly to fulfilling the overarching goal. Therefore, incorporating the use of CATS in construction projects would play a role in accomplishing specific objectives of the construction 2025 strategy, particularly the 33% reduction in both initial construction costs and the entire life cost of assets, as well as a 50% reduction in the overall time from project inception to completion for new builds and refurbished assets.

1.5 Research Aims and Questions

1.5.1 Research Questions

The government has launched the Construction Strategy 2025 and Digital Built Britain (DBB) plan. Sections 3.3 and 3.4 describe the plans of the government to integrate asset management lifecycle into Building Information modelling (BIM). This requires input from many aspects of the construction process, including both highway contractors and the supply chain, as these elements of the highway’s construction process are vital to the success of the strategy. This leads to the following research questions:

- Q1: What is needed to be done by highways contractors and the supply chain to integrate to Digital Built Britain?
- Q2: How well does the Construction Asset Tracking System (CATS) meet the requirements of DBB and compliance with BIM?

It is worth noting here that research question 1 is covered in chapters 2, 3, 4 and 5, and research question 2 is covered in chapters 6, 7, 8, and 9.

1.5.2 Research Problem

Details of the interview participants are provided in section 4.4. In this section, the same symbols are used to refer to the participants as those provided in table 3, i.e. P1 is a symbol that refers to Participants number 1, etc.

The government is pushing towards adopting a more digital approach in the construction industry. This is also accompanied by the desire from contractors and other stakeholders to be aligned with the governmental plans and strategy, because if they do not, they may suffer the consequences of staying behind and as a result being out-of-business. This is also stressed by interviewee P13

> *"Change of thinking in the organisation and in the people. It's to give people skills. Um, upscaling and the tools to do the software, the technology and so forth, but also do, while knowing how to use it.* ***So the implication of the companies is if we don't embrace it, and develop it, others will do and you are being left behind****"*

This was also discussed by P4

> *"I think Costain has got no other way to go, but to spend money to bring on these digital capabilities, because that's the direction we're going within the company […] If we don't do it now and invest in it, then we're going to be falling behind"*

Existing practices in the project construction process exhibit several deficiencies:

- Data Collection: This pertains to the traditional methods of gathering data, such as meetings, emails, and paper-based communication, which are not real-time and include reliance on the "Post-It Wall" (see section 5.2.5.1) for project management.
- Data Storage: The current approach results in multiple versions of data, making it vulnerable to loss or mismanagement.
- Integration with BIM: Given the government set a clear plan to adopt digital asset management, it falls upon contractors to report their work in a digitally compliant BIM format to remain aligned with industry standards and avoid falling behind, which is not the currently the case, see section 3.5.5.1 for the current state of construction process.
- Digitise Construction Processes: Collecting data related to the construction phase can enhance overall construction quality processes and integration with BIM Level 3, which is not the case at the existing process, see section 5.2.5.1 for the current state of construction process. Further details on this subject and its relationship with quality and digitisation are discussed in Chapter 3.

1.6 Contribution of the Research

1.6.1 Contribution and Impact

The thesis contributes to current knowledge in the field by uncovering the current issues and obstacles that hinder the industry from being aligned with the Construction 2025 Strategy and confirm to Digital Built Britain (DBB) plan. The experts also provided the data of evaluating the CATS model in respect to meeting the first couple of points of the Construction 2025 Strategy.

The main contribution of this study is to

- emphasise the application of Total Quality Management (TQM) theory: TQM principles guide the understanding of quality management processes to enhance project efficiency. By focusing on quality improvement and stakeholder engagement, TQM contributes to the overall goal of saving on cost and time.

- The creation of the digital platform called Construction Asset Tracking System (CATS): The CATS platform facilitates improved project communication and collaboration, essential for achieving Construction Strategy 2025's objectives. Through efficient data management and real-time tracking, CATS helps in reducing project duration and costs.
- The alignment of CATS features with the Construction Strategy 2025 to save on cost and time in construction projects by leveraging the use of Building Information Modelling (BIM).
- Thematic analysis of the data identifies themes on solutions related to cost and time-saving in construction projects, and reveals themes such as the effectiveness of digital scheduling tools in reducing project timelines.
- This research aims to contribute to the overall goal of saving on cost and time in construction projects through the adoption of digital technologies and efficient project management practices and be Construction strategy 2025 compliant.

The model will also align the contractors such as Costain with the new HM Government Construction 2025 Strategy by being BIM compliant, showcasing how the use of digital technology achieves the objectives of saving on cost and time in construction projects.

1.6.2 Academic Contribution

Most of the existing asset management tools and papers primarily concentrate on the maintenance of assets or prefab assets as stated in Maqbool et al. (2023), with little attention being given to the construction phase of such assets. This research contributes to current knowledge by exploring the importance of the construction stage in the asset life cycle. This research addresses the solution for the future construction projects within the highways industry.

The main contribution of this research is to add knowledge to, and enhance the understanding of tracking and managing assets in the construction phase of the highways sector. The literature in this area is mainly concentrated on finding specific solutions to specific issues, leading to an inconsistency in classifying and characterising solutions. This study is aiming to create a holistic model that unifies the existing solutions together.

From the point of view of academia, there are many published articles regarding BIM as a “tool”. However, when it comes to BIM as a “Better Information Management process”, there are very few publications (see also chapter 3).

Therefore, this research leads the way in considering the government’s policies regarding highways. It then creates a holistic model to deal with the construction stage of the asset life cycle while being BIM compliant.

This research will also enrich academia with the expertise and practical insights of managers within the construction industry, and thereby help bridge the gap between academia and industry.

Ultimately, this research will benefit service provider companies such as Costain in tracking and managing their assets in the construction phase, decreasing reworking, and providing invaluable support in the handover processes, which eventually will increase the efficiency of these companies and the way they deliver on projects, and will save cost and time.

1.7 Outline of the Thesis

A qualitative approach was adopted because it allows the researcher to acquire a comprehensive understanding of the subject from the people who work within the field, enabling the derivation of meaningful conclusions. It was used to explore existing models for tracking and managing asset lifecycle. Semi-structured interviews were chosen to collect the data from 13 participants. Thematic analysis was selected to analyse the interview transcripts. Interviews and existing database’s policy documents provided the raw material that was analysed to gain new insights and lead to the development of a more efficient and cost-effective database.

This thesis comprises eleven chapters, addressing the following topics: background and motives for conducting the study, review of the literature, industry positions and the government vision, the project vision, research methodology, Quality Management and TQM, The CATS model, assessment, discussion, and conclusion.

The following is the summary of the content of the chapters:

Chapter 1: Introduction

The introduction chapter offers a synopsis of the study's motivation, background, industrial requirements, critical reflection on the achievability of the Construction Strategy 2025, aims, research questions, contribution, and impact. It emphasises the gap in the existing process as a prelude to the subsequent chapter. Additionally, it provides a summary of the research methodology. The chapter concludes with an overview of the entire thesis.

Chapter 2: The Government's Goals

This chapter discusses the industry's current position and the government's vision, including the plans and strategies (i.e. DBB) that are driving the construction industry towards integrating to the Building Information Modelling (BIM).

Chapter 3: Literature Review: Efficiency in Construction and Manufacturing

The third chapter provides the literature review, which offers supporting evidence for the real-world issue surrounding the digitalisation of the construction process that is addressed in this study. It also examines earlier studies in the field of construction asset management. It also focuses on the literature review concerning quality management and the Total Quality Management (TQM) framework. It shows a general overview of quality management and a brief history of TQM before proceedings to expose the connection between TQM and the construction industry, explaining how it impacts project outcomes in the field of quality management.

Following this, the chapter examines the quality view within the current construction industry settings. It subsequently delves into the challenges faced by these settings in embracing TQM practices. Lastly, the chapter engages in a vital discourse on the utilisation of Information Systems as tools to implement TQM within the construction sector, enhancing both quality and cost and time savings.

Chapter 4: Methodology and Research Design

Chapter 4 provides an overview of the research method employed in this study, including the study's design. This chapter offers a comprehensive explanation of the research process, encompassing aspects such as the study's setting, the process of recruiting interviewees, the chosen sampling strategy, the research approach adopted, and the criteria used to select participants. Furthermore, it outlines the data collection management and analysis methods, as well as the ethical considerations integral to this study.

Chapter 5: Industry Position and Vision

Chapter 5 describes the industry's position and vision starting with laying down the construction processes currently employed by both the client (NH) and the contractor (Costain). It then expressed the problems in the construction industry to do with the current practices. It then explains the industry issues from the interview data that was collected as part of this study data collection. Finally, it summarises the thoughts from the interviewees on how the issues can be fixed from their perspective before delving into the features needed to be in the proposed solution to overcome the current issues.

Chapter 6: Total Quality Management (TQM)

This chapter deals with the recommended model created for this study that digitises the construction industry in the construction phase that enables construction projects to be BIM compliant and confirmed to DBB. At this chapter, an initial description of existing ad-hoc databases and models that the academic papers have so far was introduced. Those models set the scene for the most important configuration that is needed to digitise the current build process.

Chapter 7: Existing Databases

This chapter explores a critical reflection on the current existing databases or models that were created to solve issues that reacted to this research (support construction phase of asset lifecycle). It also shows a reflection on the features found in the interview data.

Chapter 8: The Model (CATS)

This chapter provides a description on the software development methodology of Agile (a methodology that controls the development of a software tool) that is followed in creating Construction Asset Tracking System (CATS) model. Then, a thorough description of CATS is provided with a screenshot and models' structure. Finally, a comparison between CATS and the existing models is provided to explain how CATS is different and how CATS has the potential to offer far more 'flexibility' and contribution to DBB. It also has a critical summary reflecting on how CATS is aligned with features find in the literature.

Chapter 9: Evaluation of CATS by the Interviewees

This chapter highlights the issues found in the literature as well as the interviewees opinions in the current configuration of the construction industry to do with the build phase of assets' life cycle. Then the chapter introduces an assessment of CATS that offers to solve and deals with these issues. Finally, an evaluation from the interviewees on CATS and their opinions on how CATS meets the requirements needed to be done to overcome the of dealing with the construction phase issues was introduced.

Chapter 10: Discussion

This chapter presents the researcher's self-evaluation of the project, encompassing a reflection on CATS and its alignment with the literature review, the achievement of goals, along with recommendations for future improvements. Additionally, it offers insight into the path forward and an overall perspective on the project.

Chapter 11: Conclusion

Chapter 10 concludes how this study was delivered as part of a PhD and how it meets the research requirements as well as the research contributions, strengths, limitations and recommendations for future work.

1.7.1 Link between the Thesis Chapters

This study consists of 11 chapters as outlined in section 1.5. These chapters are linked as follows. The introduction chapter summarises the whole study while briefly setting out the methodology followed in this study, this methodology was then explained in detail in chapter 4 as shown in the right side of Figure 1.

Figure 1 also illustrates the literature review involved in this study that consists of 3 chapters namely, the government goals, efficiency in construction and manufacturing, and existing databases. These chapters influence the study’s vision that was discussed in chapter 5 and CATS model discussed in chapter 8.

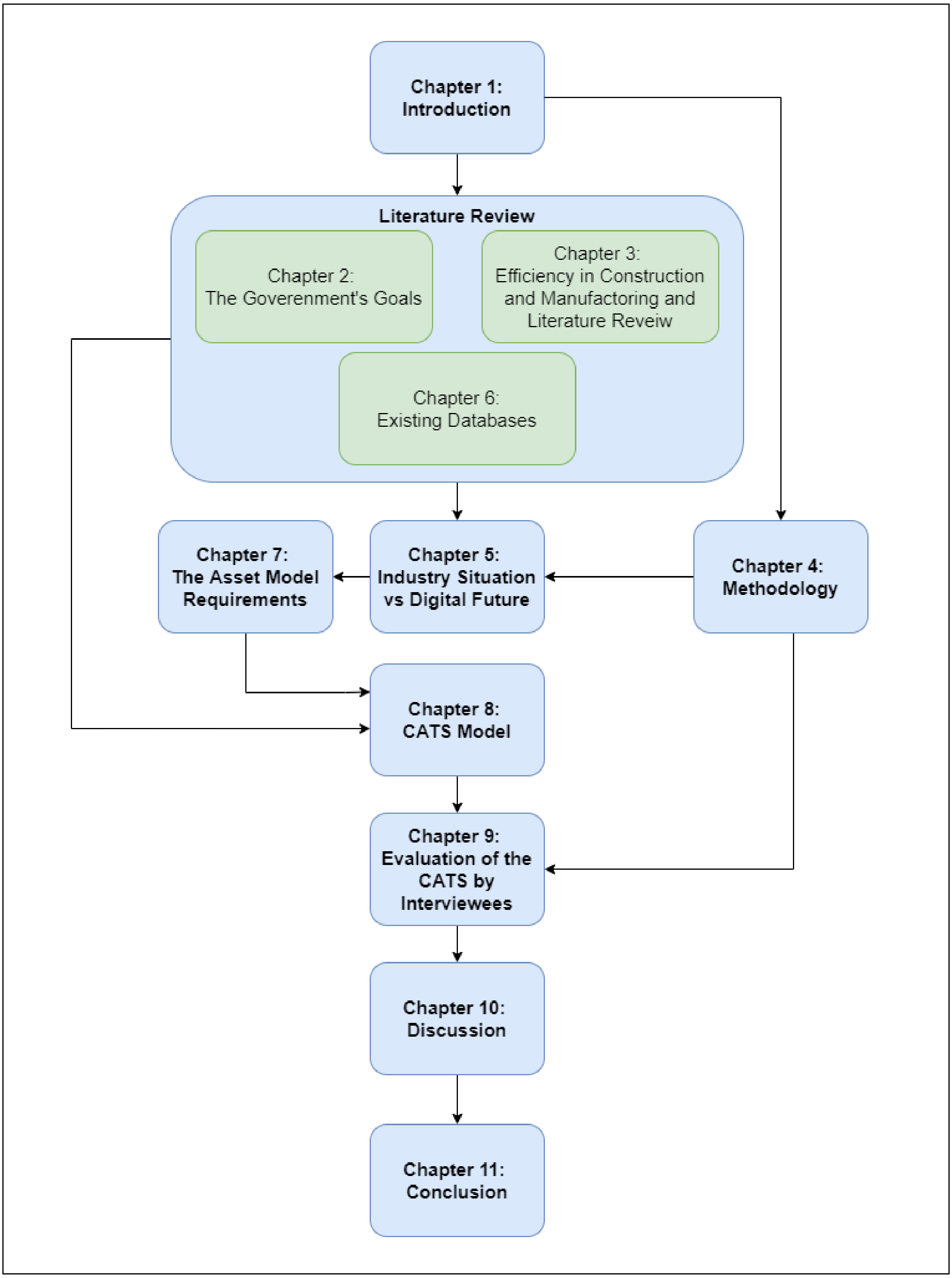

Figure 1: The relationship between the study's chapters

The CATS model (which is a model that was designed and developed to support the construction build phase) introduced in chapter 8 and the methodology in chapter 4 lead into the assessment and evaluation summary in chapter 9, which in turns leads into the discussion and conclusion of the whole study.

1.8 Summary

2.0 In summary, this chapter outlined the motivation behind the research project, which originated from Costain's Highways Division's need to develop an asset tracking model that aligns with government requirements and enhances internal efficiency. The Construction Asset Tracking System (CATS) prototype was developed to address these needs, aiming to streamline asset data management during construction while conforming to industry standards like BIM. Additionally, the chapter discussed the broader context of the construction industry, highlighting the importance of innovation and technology adoption to meet evolving client demands and government strategies. The next chapter will delve into the government's vision, including the plans and strategies (i.e. DBB) that are driving the construction industry towards integrating into Building Information Modelling (BIM).

➢ 2.0 The Government’s Goals

2.1 Introduction

In Section 1.3, we explored the need to align the highway construction industry with the government's Construction Strategy 2025. This chapter provides a deeper look into this strategy, outlining the primary goals of the government as outlined in HM Government (2013) for Construction Strategy 2025.

This chapter offers insight into the government’s vision. It begins with an introduction in Section 2.1, discussing the government’s perspective on the construction industry. Section 2.2 then delves into the government's vision, followed by an examination of the Digital Built Britain (DBB) plan in Section 2.3. Additionally, BIM is explored from the perspectives of National Highways in Section 2.4 and the professional 3D designer’s community in Section 2.5. Finally, the chapter concludes with a summary in Section 2.6

The UK Government (HM Government, 2015) has stressed the importance of finding new ways of doing business and connecting supply chains to make building and engineering services more efficient. To make these new methods work, they need to create new organisations, teach new skills, and set up new systems.

The government highlighted the importance of digital applications in the construction industry when they mentioned it in their Construction Strategy 2025 below as well as the DBB commitment in figure 2.

“Adopting these innovative technologies will provide asset owners with a full understanding of the performance of their assets, both during construction and throughout their design life […] ***the construction industry needs to position itself at the forefront of smart construction and digital design by driving forward the Digital Built Britain agenda****. If it doesn’t, the UK will be left behind. If it does, UK supply chains will secure a substantial share of this rapidly growing market both at home and overseas, where UK expertise in advanced*

engineering and design leaves our businesses well placed to capitalise on significant export potential." (HM Government, 2013, p.32)

The commitment

Industry and Government will fully commit to building the UK's competitive advantage in smart construction and digital design by supporting the launch of Digital Built Britain.

Figure 2: DBB commitment (HM Government, 2013, p.33)

Costain's vision regarding the governmental aims of Construction 2025 Strategy is:

- Acquiring real-time knowledge on their construction processes to assist with quality management processes that have been used in production (chapter 3).
- Having a flexible, comprehensive, and usable model that could be used by different construction and operating companies – its features are discussed in Table 4 in Chapter 7).

2.2 The Government Vision 2025

Ernst & Young (2018) stressed that

"In 2015 the government set out its visionary plan for a Digital Built Britain. By digitising the entire lifecycle of the UK's built assets it will reduce whole-life costs and carbon while ensuring availability and resilience of infrastructure…".

Also, the government published on their website

"A key focus of the programme is developing new tools to digitise the built environment and operations management industries. One of these tools is Building Information Modelling (BIM). Over the last 6 years, the programme has developed BIM Level 2, which by 2015 had already saved £2.2 billion across the government." (Government, 2019).

So, it is clear that the government is concentrating on creating a digital environment for asset life cycle to achieve the Digital Built Britain vision:

"*By working in partnership, the construction industry and Government jointly aspire to achieve by 2025:*

1. *A 33% reduction in both the initial cost of construction and the whole life cost of assets.*

2. *A 50% reduction in the overall time from inception to completion for new build and refurbished assets.*

These are long-term ambitions shared by industry and Government jointly.

The Construction Leadership Council will develop an action plan to achieve *these ambitions between now and 2025*."

as mentioned in HM Government (2013).

This research project is contributing to the first two points. This will come through enabling a reduction in the cost (by aiming to decrease reworking), in the completion time (by decreasing the amount of time the project delivery and handover takes to complete), and in the resources needed during the build phase. It will also contribute to data collection in the build phase to enable direct integration with BIM level 3 in alignment of the government vision.

The outcome of this project is in the form of a model that aims to digitise the built process where possible. This would provide the functionality to lead and track the construction in the highways industry to save cost, time and resources while enabling better quality as mentioned in Construction Strategy 2025 (HM Government, 2013). This is further discussed in chapter 9 where the CATS model is evaluated.

2.3 Digital Built Britain (DBB)

HM Government published in 2016 their Construction 2025 strategy and introduced BIM Level 3 in a new definition called "Digital Built Britain" (DBB).

"In 2011 the Government Construction Strategy mandated the use of Level 2 BIM on all public sector projects by 2016. … BIM has been identified as a significant contributor to the savings of £804m in construction costs in 2013/14 recently announced by the Cabinet Office. … this innovative technology is central to the development of new rail

projects like Crossrail and HS2 where it is confirming the UK's leading role in the development of digital technologies for infrastructure and construction.

This Digital Built Britain strategy takes the next step in integrating these technologies, transforming our approaches to infrastructure development and construction and consolidating the UK's position as a world leader in these sectors."

Page 5, HM Government (2015)

Therefore, DBB are in the Government policies to be adopted by 2025. Hence, there is a requirement from NH to the contractors to have the handover data of the construction projects to be BIM level 3 compliant. (David Owens, Highways England BIM Programme, Personal Communication)

The government's Construction Strategy 2025 aims to use Building Information Modelling (BIM) as a mean to digitise the construction industry as emphasised by Young (2018, page 8)

*"This DBB programme brings together the Industrial Strategy, **including the Construction 2025 Strategy**, the Business and Professional Services Strategy, the Smart Cities Strategy and the Information Economy Strategy to provide a consistent vision of how a high performing, transparent economy that efficiently delivers services to all of its citizens can be created. The aim of DBB is to provide a seamless transition from the achievements of Level 2 BIM and the Construction Strategy in to an environment where technology and working with technology is second nature in construction."*

Digital Built Britain (DBB), previously referred to as the 'BIM Task Group', aims strategically to enhance productivity throughout the lifecycle of assets in construction by leveraging digital technologies, Young (2018). HM Government (2015) stated that DBB strategy aims to integrate advanced technologies into infrastructure and construction, positioning the UK's leadership in these fields. The goal is to make fully computerised construction the standard, and to extend the advantages of these technologies throughout the UK. Additionally, the strategy aims to export these technologies and related services worldwide, capitalising on the projected $15 trillion global construction market by 2025.

The government policy also points out that conventional approaches follow a step-by-step process. Clients identify their needs, create a project plan, and then move through design, procurement, construction, and operation. However, this traditional approach lacks a feedback mechanism to improve performance.

The vision of Digital Built Britain strategy concerns creating a transformation in how infrastructure projects are designed and procured (HM Government, 2015). This transformation involves:

- Creating a platform that brings together a diverse group of suppliers, including small and medium-sized enterprises (SMEs), and stakeholders to collaboratively develop informed solutions for infrastructure challenges, allowing them to bid for providing these solutions.
- Challenging the traditional roles of consultants, contractors, and suppliers to improve technical solutions and reduce costs.
- Developing new business models for designing, delivering, operating, and adapting infrastructure and assets, based on a broader use of service performance data.
- Ensuring national security by incorporating security measures and protocols into the design and ongoing management of Building Information Modelling (BIM) projects as data availability expands (HM Government, 2015).

The same vision was repeated within the UK government (UK Government, 2017) publication under the name of ‘*Creating a Digital Built Britain: what you need to know*’, which stressed that DBB aims to revolutionise the approach of the UK construction industry and operations management experts towards infrastructure through the utilisation of digital technology. This encompasses redefining how planning, construction, and maintenance are strategized and how infrastructure is utilised, as well as the rebuilding, substitution, and establishment of new built assets. Also, Young (2018, p-8) stated that

"The aim of DBB is to provide a seamless transition from the achievements of Level 2 BIM and the Construction Strategy into an environment where technology and working with technology is second nature in construction. This will fulfil the vision of digital enabled transformation of the full lifecycle of the built environment to increase productivity, improving economic and social outcomes. This will enable a thriving UK Digital Economy for the Built Environment, encouraging growth and competitiveness and facilitating dramatically better use of current and future built environment assets"

This comprehensive initiative is poised to empower individuals to optimise the utilisation of built assets, thus generating enhanced social outcomes in response to the challenges presented by urbanisation and a burgeoning population. Simultaneously, it is poised to elevate the UK's productivity and facilitate economic expansion.
The UK government (Gov, 2017) summarises the key objectives of DBB as follows:

- Help people become skilled at using technology for construction and asset management.
- Assist all types of UK businesses to make more money using technology, both at home and abroad.
- Create and support rules and practices that make the construction and management sectors strong and innovative.
- Come up with new ways of working together that keep the UK as a leader in the field.

The mission of DBB is to digitally transform the life cycle of built assets in the United Kingdom. Those assets play a pivotal role in providing essential services to citizens. Incorporating digital technologies in the design and construction phases can enhance their "*effectiveness and efficiency*", thereby elevating user experiences. Additionally, this endeavour is expected to boost the UK's productivity and that of other nations, opening avenues for growth through exporting expertise and services.

The main goals of DBB can be summarised in The UK government (Gov, 2017) as:

1. Enhancing understanding of user needs and facilitating 'right first-time' delivery.
2. Ensuring the expedient and efficient construction of buildings and infrastructure.

Moreover, adopting a digital approach promises increased transparency and the ability to gather insights into how citizens interact with public services, thus enabling future enhancements based on their experiences.

From a contractor's perspective, embracing a digital approach to delivering construction projects aligns seamlessly with the government's DBB objectives and strategies. As a result, contractors stand prepared and eager to seamlessly integrate with any government initiatives aimed at advancing DBB practices.

2.4 Building Information Modelling (BIM)

Highways England is looking to achieve improvements in their asset cost, value and carbon performance. This is planned to be fulfilled through a collaborative working environment and sharing asset information. This collaborative platform is going to happen through Building Information Modelling (BIM) (BIM Employer's Information Requirement, HE, 2015).

BIM is defined (Ding et al., 2014, p-83) as:

> *"BIM is a digital representation of physical and functional characteristics of a facility. A Building Information Model is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition''.*

It is important not to think about BIM purely in terms of just being a 3D model used in projects. BIM goes beyond this to allow significantly greater cost and value improvements by gathering and utilising the data to maintain and operate assets.

Moreover, another important, yet different definition of BIM was published to embrace the collaborative way of working from the HM Government (2015) when they define BIM as:

"Building Information Modelling (BIM) is a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, delivering and maintaining physical built assets. BIM embeds key product and asset data in a 3D computer model that can be used for effective management of information throughout an asset's lifecycle".

Hence Highway England's mission to achieve success in BIM is:

"To deliver efficiency, standardisation and co-ordinated information throughout the lifecycle of an asset allowing informed, intelligent decisions to be made."

Highways England (BIM Employer's Information Requirement, HE, 2015).

BIM processes are widely used in both new buildings and infrastructure projects, and they offer valuable assistance in retrofit and refurbishment projects, particularly when combined with technologies like laser survey techniques and rapid energy analysis. Also, BIM stands as one among several tools to digitise both the built environment and operations management sectors. It takes a central role in the Digital Built Britain initiative due to its ability to offer an intricate analytical perspective of a constructed asset throughout the design and construction phases of a project (HM Government, 2015).

BIM is employed alongside British Standards processes to establish a collaborative work approach. Individuals involved in a construction project can create and exchange information at specific project stages. These methodologies, when combined with BIM, facilitate the effective design, delivery, and upkeep of infrastructure and buildings. The data generated becomes accessible to others within the supply chain, aiding them in making well-informed decisions to enhance efficiency and minimise wastage. This is confirmed by Graham Watts, OBE, Chief Executive Officer, Construction Industry Council in (HM Government, 2012)

"BIM will integrate the construction process and, therefore, the construction industry. But it will also have many additional benefits for the nation. It will enable intelligent decisions about construction methodology,

safer working arrangements, greater energy efficiency leading to carbon reductions and a critical focus on the whole life performance of facilities (or assets). Of even greater importance are the benefits for the economy that will accrue from better buildings and infrastructure delivered by the construction industry."

2.5 BIM Levels and Dimensions:

The UK government's 2011 Construction Strategy introduced 4 levels of BIM, designed to guide clients and suppliers in the utilisation of BIM and digital technologies in projects. These levels were structured to progressively build capacity at each level and ensure appropriate standards for successful and equitable procurement. Currently, government-sponsored projects operate at Level 2, in line with its Construction Strategy 2016-2020. Level 3 is under development and is anticipated to be introduced in the mid-2020s.

The Four BIM Levels from the government view are:

- Level 0: Basic 2D computer-aided design (CAD) drafting without much collaboration. Information is mostly shared on paper.
- Level 1: A mix of 2D and 3D CAD drafting. Information is shared electronically in a common space. There may be some standard data formats.
- Level 2: Projects use smart, data-rich objects in a 3D BIM environment. Everyone involved can share and collaborate through a common digital space, ensuring data quality.
- Level 3: Full collaboration. Everyone works together in one shared digital space with controlled access and editing, promoting seamless data integration.

When it comes to the point of view that sees BIM as a digital representation of an asset, BIM has 5 dimensions as follows:

- BIM 2D: Data Management

- BIM 3D – Modelling: BIM 3D is a model with graphical and non-graphical information. The model will have the ability to share this information with the Common Data Environment (CDE). The information will become more detailed as the project progresses.
- BIM 4D – Sequencing: It visually shows the development of the construction project over time.
- BIM 5D: Cost Estimation: This includes the cost information of the asset which contains its capital cost, running cost and the cost of renewal/replacement.
- BIM 6D: Asset Information Management: BIM 6D "involves the inclusion of information to support facilities management and operation to drive better business outcomes. This data might include information on the manufacturer of a component, its installation date, required maintenance and details of how the item should be configured and operated for optimal performance, energy performance, along with lifespan and decommissioning data. Adding this kind of detail to your information model allows decisions to be made during the design process - a boiler with a lifespan of 5 years could be substituted with one expected to last 10, for example, if it makes economic or operational sense to do so. In effect, designers can explore a whole range of permutations across the lifecycle of built assets and quickly get an understanding of impacts including costs. However, it is at handover, that this kind of information really adds value as it is passed on to the end-user" (NBS, 2023, https://www.thenbs.com/knowledge/bim-dimensions-3d-4d-5d-6d-bim-explained),

The Publicly Available Specifications of British Standard (PAS) 1192:2 – which is the framework standard for BIM Level 2 - mentioned that the Governmental Strategy Paper (published on 2011) called on the construction industry to achieve Level 2 BIM (3D, 4D and 5D) by 2016.

Knowing there is a trend going forward adopting BIM Level 3 which includes the collaborative environment to Asset Information, it is necessary for the construction industry to be prepared for the future changes. Therefore, this research project will concentrate on how to integrate asset information from construction into BIM Level 3, so when the platform is implemented, the construction corporation will be BIM compliant.

Figure 3 displays the HM Government requirement for BIM, the figure also shows the red barrier line where the construction is taking a more integrated way into better information management called iBIM or DBB where all services are integrated together in one environment.

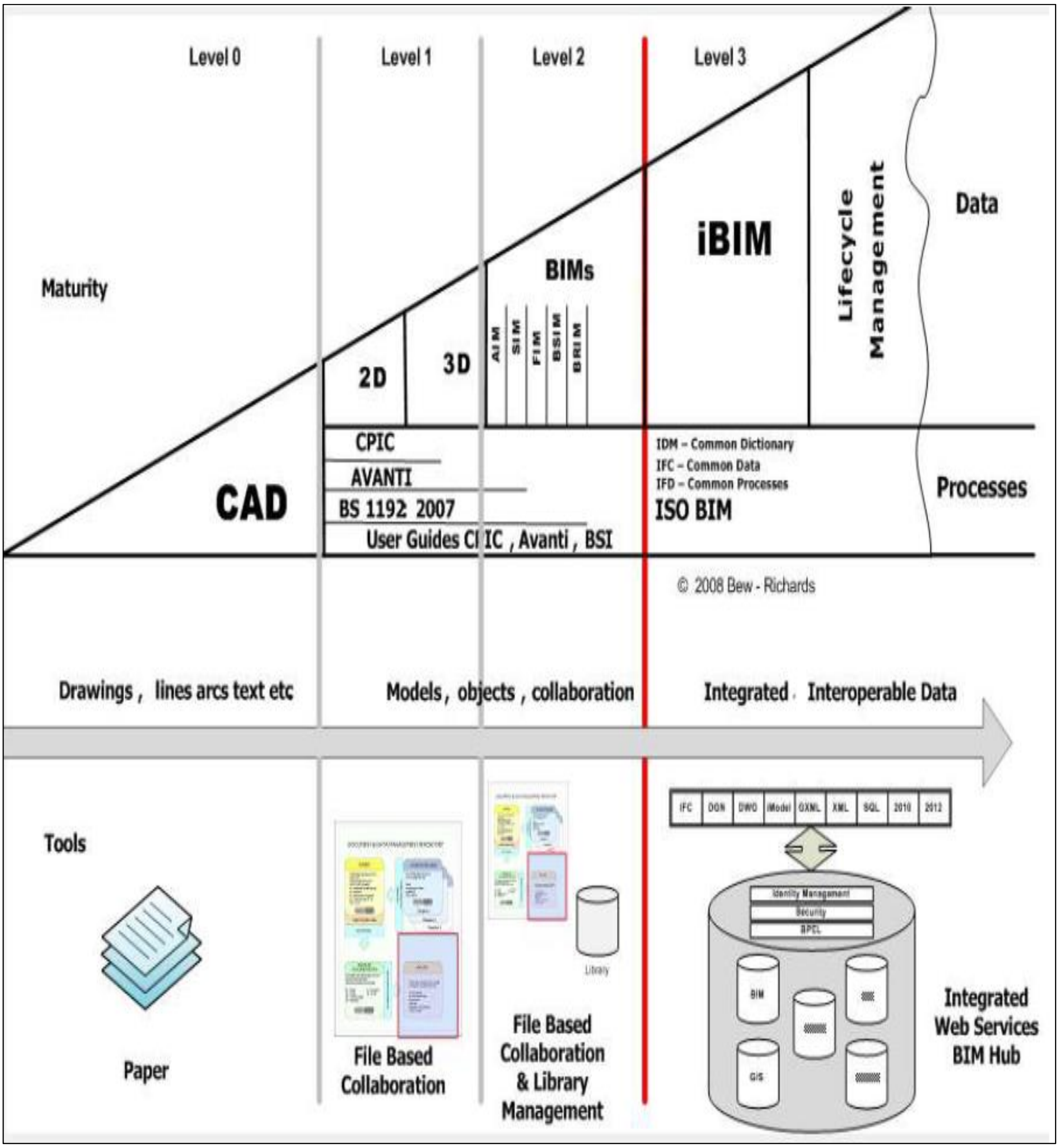

Figure 3: Government Requirement of BIM (BIM Industry Working Group, 2011)

2.6 Summary

The government's DBB goal requires the construction industry to be using BIM level 3 systems by 2025. While being a 3D representation of the constructed facility, for example, a highway, BIM level 3 is much more than digital wallpaper. It is an asset model that holds knowledge of an asset's properties and relations to other assets. Hence BIM level 3 will be a digital framework for constructing and operating the facility. For example, it will make it far easier to alter the design when unforeseen problems arise during the construction phase. However, while the government has stated in general, high level terms what BIM level 3 should do, the details of a suitable asset model have not been considered or specified for highways construction. Therefore, this project's goal is to develop a prototype asset model that meets the BIM level 3 requirements but that is also able to track the construction build process, save in reworking, and support the handover phase with easy to manage extractions that would decrease the time consumed in the handover process.

3.0 Literature Review: Efficiency in Construction and Manufacturing

In Section 1.1, we discussed the project's motivation, aimed at enhancing the productivity of the construction industry through the use of BIM Level 3, aligned with the 2025 strategy. This effort would influence highway construction projects by encouraging the adoption of digital solutions integrated within the DBB. Building on our exploration of the 2025 strategy, BIM Level 3, and DBB in Chapter 2, this chapter delves into reported issues hindering construction efficiency and examines quality management approaches that have boosted productivity in the manufacturing industry.

3.1 Improving construction productivity

Construction productivity is widely viewed as low when compared with manufacturing productivity (Haupt & Whiteman, 2004; Shoshan & Çelik, 2018).

The government sees digitisation as being one element in improving this as stated in the HM Government - Construction 2025 (2013). Moreover, the government's Construction Strategy 2025 aims to use Building Information Modelling (BIM) to digitise the construction industry as emphasised by Young (2018). Another element that they have identified is using standard elements that can be manufactured offsite, such as a base of a cabinet that can be produced offsite as a standard and then brought to the site for installation.

"Availability of digital information will also enable more effective design for manufacture and assembly. This will make offsite construction solutions, which are often precluded by current procurement practices, more readily applicable in the future. As demand for low carbon and sustainable construction continues to increase, the potential of offsite construction to deliver assets with half the waste and 25% less energy in use will make it an ever more attractive option.

Other benefits of offsite construction can include greater precision and quality, reduced overall manufacture/assembly time, and safer and cleaner working conditions. It is crucial that all construction options are considered on a level playing *field to ensure assets are built in the most efficient way"* (HM Government - Construction 2025, 2013, p-61)

An example of offsite manufacturing and how it could save cost and time in construction was published on the government portal as a mean to boosting construction productivity using offsite,

"*Methods such as off-site manufacturing, where projects are part-constructed before being assembled on location, can boost productivity by reducing waste by 90% and speed up delivery times by more than half (60%). For example, a school that typically takes a year to build could be done in just over 4 months*" (HM Government, 2017)

Furthermore, Institution of Civil Engineers (ICE) stated that one of the factors of low construction productivity is not adopting offsite manufacturing method here

"Designs not maximising opportunities for modern methods of construction, including offsite production opportunities" (Institute of Civil Engineering, 2020, P-2)

However, even with all the benefits brought with the offsite manufacturing for highways, the required productivity improvement will still require major enhancements to managing the actual construction process itself. The process which control when and how the offsite manufacturing assets would be used as

- Better control of when and how the offsite manufacturing assets would be used would need to be developed. In particular, improved tracking of assets on site will be essential.
- The construction of highways has less scope for offsite production of major components than the construction of buildings.
- Offsite production has a long history as being viewed as going to revolutionise the building industry, e.g. Sheffield's City Architect J.L.Womersley noted in 1963 that "we are on the verge of a vast upsurge in our production of dwellings because of the greatly increased use of mechanisation and of factory-made building components" (page 257, Kynaston, 2023).

Therefore, features of a highways asset tracking system that could improve construction efficiency over and above the requirements specified by BIM/DBB are explored. This investigation involved two strands: firstly, considering how quality management procedures employed in manufacturing could be supported by the asset tracking system, and secondly, interviewing experienced highways construction managers about the features they saw that would help an asset tracking system deliver improved construction practices – this is detailed in Chapter 5.

3.2 Difficulties Faced by Construction

Construction projects involve many stakeholders. This makes their delivery complex. Additionally, the data transfer between parties is often weak and improperly managed as stated by Fan & Yin (2020). Yuan et al. (2017) expressed that the ease of access and the increased safety requirements during the construction phase of the asset lifecycle make it a good time to collect asset data. Furthermore, during construction inspections and documentation, the crucial information needed for operation and maintenance (O&M) inventory is already being gathered. Therefore, an arrangement that facilitates the transmission of asset data obtained during construction to asset management information systems is a key need. Adopting an Information System (IS) to do the job of data collection was discussed by Dehlin & Olofsson (2008). Information and Communication Technology (ICT) investments in construction projects usually represent a small part of project resources in comparison to the entire cost, however, their potential worth or impact on the project's profitability is often disregarded.

Considering the current/traditional construction processes that contribute to the decreased efficiency, Li (1996) emphasised that initial research suggests that construction process re-engineering holds significant potential for improving the construction industry's performance. He supported his argument with a case study that further explored time-saving possibilities through the integration of concurrent construction, lean construction, and process redesign.

Teall (2014) explained the challenges existing between the asset owners' databases and major project Building Information Modelling (BIM) tools (such as AutoCAD software application used by designers to create a 3-dimensional model of the road segment). These need to be fixed to enhance the overall asset lifecycle in National Highways (NH) roads. The challenge is mainly related to the fact that it is extremely difficult to organise asset information due to the enormous amount of data, coupled with the management of several small and large-scale projects all at the same time

Moreover, Yuan et al. (2016) stated that few of the USA governmental bodies have come together to tackle the issues faced in the current practices of asset management through using a more digital approach throughout the asset lifecycle. Reasons for this are mainly the data blockage and data sharing of asset's information during its lifecycle with relevant stakeholders.

Yuan et al. (2016) highlighted the value of the data from the construction phase for the asset owners especially in enabling data-driven processes, and the operation and maintenance phase. Le et al. (2018) supported this by claiming that the current culture of working suffers in the handover processes. Also, collecting up-to-date information about assets by the asset owners is laborious and costly.

Regarding the integration with the Building Information Modelling (BIM) during the construction phase of the asset lifecycle, Patel et al. (2021) proposed a drone or an unmanned vehicle that can be controlled remotely to fly over construction projects, capturing the progress of the build phase and the use of supported software to analyse the data and integrate it with the BIM Model. The idea of collecting data with tools was also mentioned by Abdullah et al. (2021) who proposed a 360 degree camera as a way to save in the cost and time of collecting assets' information. He et al. (2017) proposed a similar way of collecting data using light detection and ranging (LiDAR) as a means to obtain better information related to highway assets.

The main issues facing construction industry that found in academic literature are:

3.2.1 Data loss

Aziz et al. (2017) stated that the handover phase of the construction project suffers from data loss from the building phase. Additionally, Pickard et al. (2023) stated that data is prone to loss when it is converted from one format to another, i.e. Geographical Information System (GIS) data translated to Building Information Modelling' (BIM) data type, unless tools can be used to eliminate the loss in the translation process.

Moreover, Floros & Ellul (2021) and Le & Jeong (2016) mentioned that data interchange presents substantial difficulties since different project participants use private software platforms with different data formats. This can result in data loss, damage, and the need for time-consuming processing in later phases. Interoperability problems cost the US capital facilities sector at least $15.8 billion annually, with two-thirds of these expenses occurring during the operation and maintenance phases, according to a 2004 report by the National Institute of Standards and Technology (NIST). The main expense is related to the time needed to locate, verify, and convert the facility and project information into a format that can be used. This demonstrates how inadequate data collection and transmission from the asset management stage to the design and construction stage results in increased operational costs.

Furthermore, in a survey conducted by Yuan et al. (2016), the main challenges in implementing the current practices within State Highways Agency in the USA are the separation between the construction documentation process and the asset in-place data collection process. This disconnect results in data loss and redundant data collection. This was also confirmed by Alshboul et al. (2023) stating that the main issues confronting decision-makers within transportation agencies include a weakness in information control and a decline in stakeholder interactions necessary for making well-informed decisions.

Abou-Zeid et al. (1995) stressed that the construction business is highly fragmented, with several varied organisations actively participating in the design, development, and completion of each project. The smooth conveyance of sizable amounts of project-related information is necessary for effective collaboration among different project stakeholders. The exchange of information among participants, in all its forms, depends on communication. The danger of project delays and rework may be decreased by ensuring the easy availability and prompt transmission of vital data for various project activities, thus increasing productivity.

3.2.2 Reworking

Rezahoseini et al. (2019) stated that reworking is one of the main issues that the construction industry suffers from, it affects a project’s cost, time and overall quality. Therefore, rework and the inefficient utilisation of resources and materials within workshops, are the main reasons for having a consistently substantial wastage of resources, materials, investments, and the time of the workforce. This was also supported by Ahuja et al. (2010) who stated that costly networking and construction defects result from poor communication between teams that need to be addressed.

3.2.3 Cost and Time

Gifford & Carlisle (2004) stated that the completion of highway projects within the allocated deadlines and budgets is a typical difficulty for State Highway Administration's (SHAs) in the USA. These difficulties might appear during both the design and construction stages. In order to effectively complete all highway construction activities within their agreed timetables and budgets, the Virginia Department of Transportation (VDOT) launched the Dashboard programme in 2002 in response to these problems. The firm produced an innovative web-based performance measurement tool by utilising already existing technologies. This application was created with the express purpose of giving regular information on the status of building projects around the state at all stages of development. The interesting result on the delay of the delivery projects from their agreed timeline was summarised by Gifford & Carlisle (2004) when they stated

> *“A 1985 FHWA study showed that on average, 31 to 55 percent of all highway projects finish beyond the original contract time. The overall average time delay was 44 percent ... the problem of timely completion has not improved in the last 17 years ... many approaches have been tried to reduce the delay problem. However, in spite of past efforts the problem remains.”*

HM Government (2015) stressed that

> *“In 2011 the Government Construction Strategy mandated the use of Level 2 BIM on all public sector projects by 2016. This bold decision has led to the Government and the construction industry working together to develop the industry’s skills and reduce the cost of infrastructure. BIM has been identified as a significant contributor to the savings of £804m in construction costs in 2013/14 recently announced by the Cabinet Office”*

Aslam & Tarmizi (2018) confirmed how leveraging the use of BIM would tackle the issue of wasting cost, time and minimising human interference error when replacing the currently-in-use paper-based manual inspection method.

In summary, addressing data management challenges, reducing reworking and inefficiencies, and improving cost and time management align with the aims of Construction Strategy 2025. By implementing solutions to these key issues, such as adopting Total Quality Management (TQM) principles to digitise construction processes, the industry can enhance efficiency, save on costs, and reduce project timelines. TQM's emphasis on continuous improvement and quality control can streamline operations, minimise errors, and optimise resource utilisation, ultimately leading to improved project outcomes and greater success in meeting the objectives of Construction Strategy 2025.

3.3 Quality management in manufacturing

3.3.1 TQM Introduction

One method for attaining quality in organisations is through the adoption of Total Quality Management (TQM), which will be discussed in detail in the following sections. It is important to note that the TQM approach will not be strictly adhered to in this thesis but will be employed as a framework and facilitator to enhance quality within the construction industry by leveraging Information Systems to apply TQM principles to the construction process.

This section outlines the importance of quality in construction delivery in terms of delivering good quality to and adopting more efficient ways of performing the work that applies the mentality of doing the job “right first time”. This section provides an introduction of Total Quality Management (TQM): definitions, history, and the TQM concept in section 3.4.

A literature review of Total Quality Management (TQM) is conducted, and the process is described in section 3.5. Furthermore, the current practices of project control related to quality are discussed in section 3.6 as well as the need to adopt TQM in the construction industry. Likewise, the challenges that TQM deployment faces in the construction industry is discussed in section 3.8 and finally section 3.9 explains how Information Systems (IS) is linked to TQM as a tool to enhance quality in the construction industry. The themes appear in the literature review in section 3.5 which talks about the TQM in general is discussed in section 3.4, and themes related to construction industry are discussed in sections 3.6 – 3.9.

3.4 Total Quality Management (TQM) in General

3.4.1 Definition, features and benefits

Harrington et al. (2012, page 352) defines TQM as

> *"The management approach of an organisation centred on quality, based on the participation of all of its members and aiming at long-term success through customer satisfaction and benefits to all members of the organisation and to society."*

The adoption of TQM has been proven to support efficient management of organisations within different industries (Helms et al., 2011). However, the construction industry seems to lag behind other industries in adopting TQM (Haupt & Whiteman, 2004; Shoshan & Çelik, 2018)

While discussing TQM in organisations, it is important to distinguish Quality Assurance (QA) from Quality Control (QC). QA was defined by Arditi & Gunaydin (1997, page 236) as

> *"a program covering activities necessary to provide quality in the work to meet the project requirements. QA involves establishing project related policies, procedures, standards, training, guidelines, and systems necessary to produce quality".*

QC on the other hand is the actual implementation of this programme and activities. Hence, QA and QC are part of TQM and deployed through project implementation. TQM is considered the strategic philosophy adopted by the firm on a continuous basis from the pre-start of the new project way until after the end.

Tang et al. (2009) discusses the features of TQM, which are customer satisfaction, measurement and improvement, total involvement, leadership, training, empowerment, teamwork, motivation, systems/processes approach, and culture. They also stress that these factors were used in the construction industry as the international quality standard ISO 9000 – which is a series of global quality management standards that can be implemented by various types of companies to achieve enhancements in their quality processes and products. Moreover, Shoshan & Çelik (2018) mentioned that the success of the organisation depends on having the quality included in every level of the organisation production. The benefits of TQM to organisations were discussed by Harrington et al. (2012). These benefits mainly concentrate on using the TQM framework to achieve the features mentioned earlier as well as meeting specifications, gaining a larger market share, achieving higher productivity, and aiming to fulfil zero defects.

Additionally, the successful implementation of TQM can effectively lead to the attainment of intended outcomes on both a domestic and global scale (Fukuda, 2018). Nonetheless, this achievement hinges not solely on the organisational culture at play but also on the broader national culture, as highlighted by Harrison & Lock (2017). Consequently, TQM can be succinctly described as the pursuit of industrial value through the optimised creation of opportunities with exceptional efficacy and efficiency.

3.4.2 History of TQM

Even before the Industrial Revolution of the 18th and 19th-centuries, expert craftsmen and factory producers engaged in evaluating the work of their peers to assure the excellence of their products and services, a matter of considerable personal pride. As the Industrial Revolution advanced, the manufacturing process underwent a radical shift, transitioning to the utilisation of interchangeable components. This shift significantly diminished individual control over the final product and consequently necessitated the implementation of quality control at subsequent production stages.

The TQM concept was founded as early as the 1920s. It was then developed in the Japanese manufacturing industry by the 1940s to reduce the cost and increase the productivity and product reliability (Amui et al, 2017). Since then, it has been adopted by the United States industries where the scope of TQM was developed from product quality to management-oriented quality.

Yet, the TQM concept did not find a footing in the construction industry until the 1970s where it began to be implemented in Japan (Arditi & Gunaydin, 1997).

3.4.3 TQM Concept

The TQM context has witnessed a rapid growth in both industry and academic fields in and after the 1970s. This growth came from the implementation of the operational excellence concept after the ad-hoc industrial wave, which happened directly after the Second World War, which focussed mainly on increasing product volume and reducing the cost (Basu, 2018).

The core concept of TQM is concentrating on empowering the quality practices to thrive bearing in mind the connections between customer and stakeholders, following Deming’s 14 principles model of quality management, which is a set of practices to help organisations enhance their quality and increase productivity (Lameijer et al, 2017).

Deming’s 14 principles are (Lo, 1997):

1. The improvement of services and products must be consistent.
2. Embracing the new philosophy
3. Cease dependence on inspection as a means of achieving quality
4. End the applying the business practices alone to minimise total cost, such as granting projects on price-based factor alone.
5. Constant improvement of the process in planning, service and production systems.
6. Creating and enforcing on the job training programmes
7. Create and adopt leadership thoughts
8. Eliminating fear
9. Ceasing the organisation’s internal barriers between staff

10. Eliminating pressure and targets for employees
11. Eradicating numerical objectives and measures for staff and managers
12. Removing barriers that prevent staff from taking pride in their work
13. Establish and encourage the staff's self-improvement
14. Educate the staff that accomplishing the transformation is a teamwork and everyone has an input in it.

3.5 Literature Review on using TQM in construction Industry

A literature review was conducted to assess the role of quality management in the construction industry, and identify the relevant gaps in knowledge. This review found 375 relevant papers, which discuss TQM in the Construction industry as well as the use of Information Technology systems as a tool to achieve better quality.

This review was performed using the SCOPUS and Web of Science (WoS) databases (see Table 1).

Keyword	**Original No.**	**Same Database Duplication** (identified with previous search keyword)	**Different Database Duplication**	**Without Duplication/ Relevant**
"Total Quality Management" AND "Construction industry"	391	9	39	343
"Total Quality Management" AND "Construction industry" AND "Application"	87	86	0	1
"Total Quality Management" AND "Construction	28	28	0	0

industry" AND "Challenge"				
"TQM" AND "Information Technology" AND "Construction"	14	1	0	13
"TQM" AND "Information System" AND "Construction"	8	2	1	5
"Total quality management" AND "Management Information System" AND "Construction"	19	6	0	13
	547	**132**	**40**	**375**
		172		

Table 1: Keywords and Number of Papers

Table 1 highlights the keywords and search strings used to search for the relevant papers. The literature search identified 547 articles when using these keywords and search strings. From the 547 papers, 172 papers were duplicated, which means the same papers were shown for different search strings or different databases.

Table 2 shows the number of the papers that were identified for each database and for the two types of duplication:

1. Duplication when the same paper is identified using different search strings in the same database. This was the case for 132 papers (112 in Scopus and 20 in WoS).
2. Duplication when the same paper is identified using different databases. The count of the papers in this scenario was 40 (40 papers were identified both in Scopus and WoS)

Database	All Papers	Repeated within same database	Repeated within different database	All Repeated	Not Repeated
Scopus	441	112	40	152	289
WoS	106	20	0	20	86
Scopus & WoS	**547**	**132**	**40**	**172**	**375**

Table 2: Papers per Database

After removing the duplications, 375 relevant papers remained. Based on an article's themes, they were divided into 3 categories:

1. 266 papers discussed the definitions of TQM and relevant quality frameworks such as ISO 9001 which aids organisations in ensuring they meet customer and other stakeholder requirements while adhering to statutory and regulatory mandates concerning their products or services (Poksinska et al., 2002).
2. 78 papers talked about the challenges & benefits of implementing TQM as a framework in construction projects, and
3. 31 papers discussed the use of Information Systems as a tool of implementations of TQM in the construction industry.

This indicates a limited number of academic papers addressing the topic of using Total Quality Management (TQM) and Information Technology systems in construction. This research aims to fill this gap. We previously discussed the second theme in section 3.4, and the third theme will be explored in section 3.6, followed by a reflection on the current practices of UK contractors for comparison.

3.6 TQM in Construction Industry

Arditi & Gunaydin (1997) highlight that for quite some time, the construction industry has grappled with the challenge of achieving satisfactory levels of quality. Each year, substantial amounts of time, finance, and resources — both human and material — are squandered due to inefficient or non-existent quality management procedures. Drawing inspiration from the manufacturing sector, Total Quality Management (TQM) principles have resulted in increased productivity, lower product costs, and improved product reliability. These principles are applicable to the construction industry, with Japanese construction companies starting to incorporate TQM methods in the 1970s after learning from manufacturing practices (Arditi & Gunaydin, 1997). Despite the distinctively innovative and singular nature of construction processes, the Japanese construction industry readily embraced the TQM principles, even when scepticism existed regarding their applicability.

One of the reasons for the slow adoption of TQM in the construction industry was its difficulty to get senior management level behind the concept (Haupt & Whiteman, 2004). They need to have full commitment and understanding of the theory for it to flourish and achieve the best quality control in the organisation (Arditi & Gunaydin, 1997).

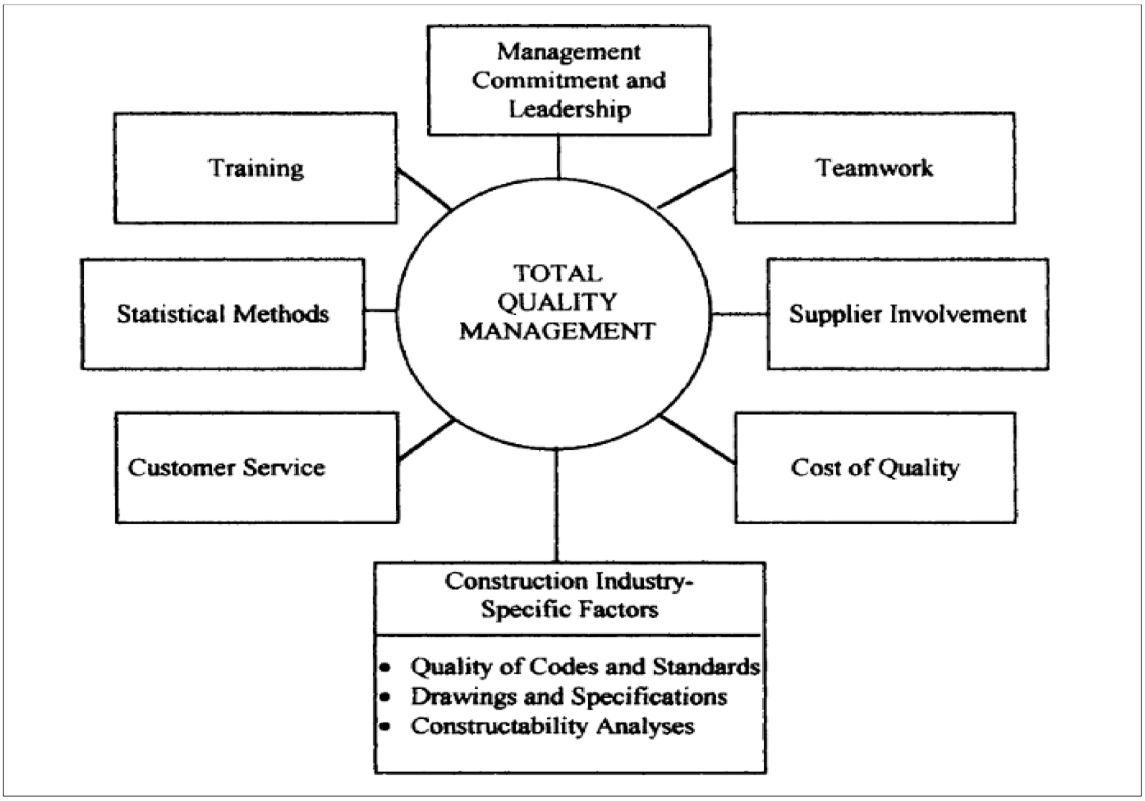

Figure 4: Elements of total quality management in the construction (Arditi & Gunaydin, 1997, page 237)

Figure 4 shows the main points which any successful implementation of TQM should have. These points mentioned in Arditi & Gunaydin (1997) are as follows:

- The senior management team must be committed to TQM and its processes.
- Training must be provided on all levels of management and operation and the construction phases of plan, design, construct and operation and maintenance.
- Teamwork effort, especially in the construction industry as it is concentrated around building and delivering a project as a whole, therefore all partners and subcontractors involved must all work and share responsibilities to succeed in delivering the project and achieving the customer/owner satisfaction.
- Statistical methods monitor the process of delivering the project. This could take different shapes such as feedback and lessons learnt which eventually could have a positive effect in the future projects.
- The cost of quality should not be looked at as an extra expense but instead it should be treated as an investment, which would increase the organisation's opportunities in the future.
- All parties involved in the construction process, must be looked after and be satisfied, this includes the client, employees, contractor and the subcontractors.
- To achieve the owner/client satisfaction, the objectives must be clearly defied at the beginning of the work and the requirements must be captured and agreed upon in the early stages of the project life.
- Design drawing and objectives classifications must be as clear as possible for the project outcomes to be delivered as expected.

Infrastructure is currently seen as a priority area by the government and there is a drive to productionize the construction element (Transforming Infrastructure Performance, Infrastructure and Projects Authority, December 2017). For smaller, standard or repetitive construction, this could be partly met using production directly for prefabrication, while for larger, more complex projects, construction needs to learn from operational excellence concepts i.e. Quality Management and Total Quality Management, Lean thinking, etc. (Basu, 2018).

3.6.1 The Need for TQM in Construction Industry

This section will summarise the main findings from the papers and journals found within the literature review conducted in section 3.5 which is about the challenges and benefits of implementing TQM as a framework in construction projects.

Zantanidis & Tsiotras (1998) emphasised that Quality is one of the main providers of competitive advantage to organisations in the construction industry.

TQM principles can help companies sustain their place in the competitive business market. Therefore, the construction industry is inspired to use the same concepts. Based on a study of a Japanese contractor, it was found that the construction industry was constrained by national markets where clients, subcontractors and site operatives were not inspired with the same quality culture because of the lack of implementing the TQM framework (Altayeb & Alhasanat, 2014).

The benefits of using TQM in construction include reduction in defects and quality costs, employee job satisfaction, client satisfaction, reduction in the amount of reworking, influencing the subcontractors with better quality systems, and closer relationships with stakeholders. Consequently, the construction industry is in need for TQM implementation (Pheng & Teo, 2003). Shoshan & Çelik (2018) mentioned the benefits of adopting TQM in the Turkish construction industry, including increased customer satisfaction; reduced occupational accidents; reduced waste; and reduced production deficiencies. Similarly, according to Chileshe (2007), the benefit of adopting the continuous improvement concept of quality management is to offer

> *"A system in place to stop defects as they occur, rather than through inspection and rework" which is aligned with the Quality Driven Agenda, which defines quality as "the total package exceeding customer expectations and providing real service."*

3.7 Construction Industry: The Traditional Way of Project Delivery

3.7.1 Traditional way of Project Management/ Control

The value of quality management has been proven by its successful implementation in various industries through the use of quality tools such as TQM, Six Sigma, Lean Thinking, etc. However, this is not the case in the construction industry due to the typical one-off unique quality of major construction projects This leads to a different approach to the management of construction projects (Basu, 2018). The traditional project management objectives are scope, cost, time and risk, which did not have quality at its core until later in the project.

Tezel et al. (2018) mentioned the drawbacks of the traditional construction project approaches, including the short-term organisation/project structure, the competitive tendering nature of the projects and the issue of engaging with the stakeholders. These issues give rise to the stereotype of construction projects having time and cost overruns, quality and safety issues and low productivity.

3.7.2 Quality Control and Project Performance – LEAN

Lean construction is one of the current approaches in construction. Basu (2018) and Tezel et al. (2018) stated that Lean construction was adopted in construction projects to better manage the construction process with the goals to increase value, reduce waste and achieve benefits for all stakeholders. It is claimed that construction problems can be reduced by adopting Lean Principles. These principles are summarised in:

- Focusing on reducing process waste
- Increase productivity by deploying visual management and productive maintenance.
- Create a work standard in all work-related processes.
- Make sure the production is always up to the time
- Reduce the size of batch production
- Enhance quality control
- Ability to adapt or change to a new production process when needed
- Group the project's teams in the production cell.

- Apply Kaizen circle for continuous improvement
- Create a long-term relation with supply chain and support them for development

3.8 The Challenges TQM deployment Faces in Construction Industry

Harrington et al. (2012) mentioned the following obstacles of applying TQM in construction:

- The traditional or conventional practice of the construction industry, e.g. bids are evaluated frequently placing the heaviest emphasis on price
- The construction industry is known for its fluctuations , such as sudden market changes that threaten the survival of contractors, which has the effect of making construction firms reactive rather than proactive.
- TQM requires an organisation culture change which could face resistance.
- Failure to monitor & manage the progress of TQM implementation.
- TQM as an internal process may face a major difficulty in its implementation as it does not take into account other supply chains.

Shoshan & Çelik (2018) mentioned the barriers to adopting TQM in construction include

- The lack of top-management commitment
- The perception that application is costly and time-consuming
- The lack of or insufficient education and training;
- The lack of communication between top managers and workers
- Challenges in changing organisational culture.

Moreover, McIntyre & Kirschenman (2000) discussed several issues that needed to be addressed in order to achieve a successful level of TQM, including

1. An increased effort in the education and training requirements regarding the implementation and application areas of TQM
2. An increased effort in determining, satisfying, and measuring customer needs and customer satisfaction
3. An increased emphasis on the concepts of team building and teamwork
4. A more systematic approach to the collection and analysis of data concerning the overall TQM

3.9 The Need for Suitable Information System (IS) as TQM Tool in Construction

Following on from the literature in section 3.6.1 that expresses how IS in construction industry is in a need to solve many issues to do with defects, cost and time saving and reworking, it is clear that Information Systems are key to delivering TQM.

Moreover, Deming's principle number 5 of 'Constant improvement of the process in planning, service and production systems' has a direct connection with digitising the construction industry through the use of IS. IS supports construction project's delivery by using digital models that track and manage construction processes. The model also improves the handover process through the amount of data that is already being collated while the construction phase is ongoing.

In fact, Information Systems are more important in construction because of the environment - different sites for each project, and one-off quality based projects (not a factory) - including exposure to the weather. Furthermore, information systems have an added importance in construction as they are needed for managing the constructed item's operational life by providing a framework for maintenance and refurbishment scheduling, and ensuring that the item remains in a safe condition. In fact, this information system answers point number 4 from the issues mentioned earlier (section 3.8) by McIntyre & Kirschenman (2000) that requested

> *"a more systematic approach to the collection and analysis of data concerning the overall TQM".*

Fan & Yin (2020) also advised that enhancing the quality of construction projects could be achieved by finding a solution to auditing and tracking the construction work.

Mitreva et al. (2013) mentioned the connection between TQM and information system to improve the communications between the stakeholders, and Ahuja et al. (2010) discussed the importance of Information Communication Technology (ICT) in enhancing the project communications for providing an effective way to manage the data especially with the drawbacks that the project managers face in controlling the project communications. ICT provides more than better communications, as it also enhances the access to the project data in real time. This enhances the quality in doing the work in a better and faster way. It also provides a faster way to access the common data environment and decreases the errors in the project's documents.

Rezahoseini et al. (2019) stressed the benefit of adopting Information Technology Systems in the Construction Industry and how it improves the overall quality of the construction project. This quality comes in the shape of reduction in cost and time (Arditi & Gunaydin, 1997). See figure 5 for more details.

The Causes of Rework	Solutions to Reduce Rework	TQM Elements
A-Weak communications and conflict between project factors	Effective and comprehensive use of the workforce, and teamwork on all levels	Teamwork across all levels of the project
B- Inefficient use of IT	Using new technologies of the project management field and constant improvement of work	Constant improvement of work and the use of technologies
C- Errors and Negligence, and clients' and stakeholders' inappropriate view of the project	Gaining the satisfaction of the client, and focusing on the workforce in order to reduce errors and negligence	Gaining the satisfaction of the clients and stakeholders
D- Weak planning as a result of not assigning enough time to the planning and design processes	Assigning more time to the design process and more precision in calculations	Assigning more time for developing a quality guarantee system
E- Using low-quality materials and low-quality suppliers	Managing suppliers and treating them like stakeholders/partners	Procurement and suppliers management
F- Workers not having the required abilities and lack of a skilled workforce	Training the human resources and using the experiences from previous projects	Training the human resources and using the learnings
G- The insecure and inappropriate work environment	Project management's responsibility and support for meeting the standards of the project	Leadership and project manager(s) commitment

Figure 5: Rework reduction through TQM Summary (Rezahoseini et al., 2019, page 9)

Through the literature review, this research investigates the existing Information Technology's (IT) applications and solutions that influence the highways construction industry. The applications found were then analysed to help in reaching a coherent model that fills the gap in the construction industry.

3.10 Summary

Addressing data management challenges, reducing reworking, and improving cost and time management are crucial objectives of Construction Strategy 2025. By implementing solutions to these challenges, such as adopting Total Quality Management (TQM) principles, the construction industry aims to enhance efficiency, save costs, and reduce project timelines. TQM emphasises continuous improvement and quality control, which can streamline operations, minimise errors, and optimise resource utilisation.

This chapter delves into quality control in construction, focusing on TQM as a key approach to delivering better quality. A detailed discussion on TQM is provided, followed by a literature review on its use in the construction industry combined with Information Systems (IS). The literature reveals a gap in knowledge regarding the use of IS as a tool to enhance construction project delivery. The themes extracted from the literature review, including TQM's use in construction, the current state of quality control, challenges in implementing TQM, and the need for IS adoption to support TQM, are thoroughly examined.

4.0 Methodology and Research Design

4.1 Introduction

In Chapter 1, we explored the motivation behind the project, while Chapter 2 provided a literature background on the government's planned strategy. This strategy was developed to address the current challenges faced by the construction industry, as discussed in Chapter 3. Therefore, this part of the thesis aims to discuss the methodology used to acquire the knowledge necessary to shape the proposed solution to these challenges and align the construction industry with the Government Construction Strategy 2025.

In this chapter, Section 4.1 introduces the chapter and connects it with previous literature, while Section 4.2 discusses the research design and justifies the rationale for selecting a qualitative approach over alternative methodologies. Data collection is examined in Section 4.3, and the criteria for selecting participants in this thesis are explained in Section 4.4. Section 4.5 delves into the interview process, followed by Section 4.6 which discusses the mechanics of the data analysis process.
Section 4.7 emphasises clarifying the approach taken to ensure research quality, highlighting strategies for validity and reliability embraced in this study to uphold the credibility of the findings, alongside ethical considerations linked with the research. Finally, Section 4.9 provides a summary of the chapter.

4.2 Research Design: Qualitative Research

The project is about developing a prototype asset tracking system that will meet the requirements of BIM / DBB (as detailed in Chapter 2) and go beyond these to provide additional functionality for improving the management of highways construction projects (Chapters 3 and 5). This prototype will not only demonstrate the knowledge and solutions developed by the project but will also allow the users to reflect on the value of the features it supplies and identify any extra features that would be beneficial.

The project involved the identification of the features the system should provide, and the assessment of the strengths and weaknesses of the prototype. This was achieved through interviewing experienced construction managers. This qualitative approach was adopted because it is the most appropriate approach to address the research questions, also it would allow for in-depth responses to be gained from the participants about their experiences, perceptions and points of view which are necessary to identify the deficiencies in current models.

Furthermore, the present study opted for a qualitative approach due to many aspects of software development relating to qualitative characteristics (Hove & Anda, 2005). The limited availability of resources shown by the literature review on digitising the construction industry's build phase made it evident that a comprehensive understanding of this context was necessary. This favoured a qualitative style to obtain insights about the required features within a model that are needed to tackle the current issues facing the construction industry through a field study. Additionally, the qualitative method presents a more direct approach to accessing the data source.

4.3 Data Collection

Interview structures are classified into three types: structured, semi-structured, and unstructured. The structured interview has a set of questions to be asked, usually with short answers, and the questions are presented in the same order in each interview. On the other hand, a semi-structured interview has a variety of main questions, with a flexibility of the question order. Each question has sub-questions to be used by the interviewer – if necessary – to achieve the purpose of the main question theme. Finally, the unstructured interview has no set of questions but topics or themes that will be asked about. The interviewer adopts questions that may arise from the discussion to keep the interview on-going (Rowley & Rowley, 2014). Reflecting the data collection for this research, I employed the semi structured style within the interviews as it kept the discussion open. This was especially the case when I felt there is more data to gain from the interviewees when they mentioned something interesting such as their reflection in quality and efficiency in using digital in their projects, or how contractors could be aligned with DBB strategy.

To ensure a smooth and effective progression of questions during the semi-structured interviews, an interview blueprint was added to the interview presentation that consists of both description contents and questions. This approach forms the discussions and guarantees comprehensive coverage of all relevant subjects (Bryman, 2008). The interviewer had the flexibility to navigate through different thematic pathways as the conversation evolved, allowing for organic deviations from the initial interview plan when relevant (Bryman, 2008). For instance, the sequence of questions could be modified or additional queries introduced based on the interviewee's responses (Bryman, 2008).

The interview material discussed with the interviewees was a presentation which included a plan to manage the interview by dividing the interview into sections. The structure of the interview presentation and question plan adhered to a coherent sequence of topics, facilitating dynamic and informed conversations. This design was carefully crafted to guarantee the exploration of pertinent themes during the interviews, while upholding a concentrated approach to asking pertinent questions (Bryman, 2008; King & Horrocks, 2010). Additionally, it empowered the interviewer to employ terminology that was relatable to the interviewees, avoiding the inclusion of complex theoretical or professional terms that might have caused confusion or uncertainty among participants during the interview (Bryman, 2008 The use of semi-structured interviews enables data providers, in this case, a group of professionals, to contribute their deep insights into the industrial process and the application of digitising construction processes and managing assets throughout their lifecycle.

Fletcher (1973) mentioned that to conduct a useful interview, it should have key points. These points start with a clearly proposed plan, followed by research about the related information and facts. After that, it is important to sort ideas, problems, and the possible solutions all in advance of the meeting. Finally, the interviewer must know that the interview itself has a protocol that should be followed during the meeting. This approach was followed in the interviews, having the presentation with the plan helps shaping and controlling the interview's progress.

In shaping the plan, questions were categorised into three distinct sections. The first section encompassed inquiries about the Government’s Future plans of DBB as mentioned in chapter 2 ; the second segment centred on the quality management in construction projects; and the third segment delved into the use of Information systems in general. It also covered questions to gain feedback on the model of Construction Asset Tracking System (CATS) that was created after a trial in M1 Smart Motorway Tranche 2 Junction 23A-25 Project (M1SM T2 J23A-25).

The research looked for both subjective and objective views held by the interviewees. The former, i.e. the subjective, provided an insight into the interviewees' views about existing processes and applications in use and how these could be improved. An example of objective views included examples of the handover requirements that the asset owners requested from the contractors.

4.3.1 Interview questions

As mentioned earlier and in shaping the interview plan, questions were categorised into three distinct sections:

4.3.1.1 Digital Built Britain (DBB) general questions

The main questions in this part were based on the contractor's knowledge of DBB, these questions are:

- What do you think are DBB's benefits to HE and contractors?
- What is the achievement so far and what needs to be done?
- What are the barriers to achieve it?
- What are your company's plans to be DBB compliant?
- What are the implications for your company / your role?

4.3.1.2 Implementation of better quality questions

This set of questions focuses on implementing better quality management in construction projects. The aim is to understand how applying quality principles can enhance project management. The questions for this part are:

- What actions has your company done to overcome the traditional practices of the construction industry (i.e. bids based on price not quality)?
- How to make the industry act proactively rather than (i.e. wait for things to happen to deal with it, e.g. reworking)?
- How to overcome the cultural resistance to organisational change?
- How to manage the progress of implementing TQM?
- How to overcome the lack of standardisation and the many players involved in construction activities?
- What are your company's blockers to implementing TQM?

  - i.e. funds to improve quality, lack of quality minded employees, and subcontractors not interested in TQM

4.3.1.3 Role of Information Technology (IT) questions

This section discusses the role of Information Technology (IT) in helping to deliver construction projects. It is divided into two subsections. One discusses the general IT questions, while the other one specifically discusses CATS.

- **General IT questions**
  - How can Information Systems help in achieving the DBB ambition (decrease cost, reduction in overall time from planning to completion)?
  - What Information Systems are currently in use?
  - What are the deficiencies of the current Information Systems?

- **CATS questions:**
  - What are your views on CATS?
  - What are the key functionalities needing to be added?
  - How to improve construction Information Systems in general?

4.4 Participant Selection

I interviewed 13 participants from Costain within the period from the 11th September to the 17th December 2020. All interviews were conducted using Microsoft Teams. Face-to-face interviews were not possible due to the COVID pandemic at that time.

Participants were selected from different roles within projects to widen the data and to ensure that the opinions are gathered from a variety of projects rather than from a single team.

The research participants are anonymously represented in this thesis by assigning them codes. Table 3 below shows information about the participants of the interviews conducted by this project researcher.

	Symbol	Job Title	Sector/Project
1	P1	Lean & Performance Improvement Manager	Highways/ Motorway 1 Tranche 3 project (M1T3)
2	P2	Technology Integration Manager	Highways/M1T3
3	P3	Enterprise Architect	Head Office/All Sectors/All Projects
4	P4	Quality Manager/Senior Engineer	Highways/M1T3
5	P5	Head of BIM	Highways/M1T3
6	P6	Quality Director	Nuclear
7	P7	Project Quality Director	Nuclear
8	P8	System and Performance Manager	All sectors
9	P9	System Safety Assurance Manager	Highways/M1T3
10	P10	Performance Improvement – Quality and Lean/ Head of Business Improvement	Highways/M1T3
11	P11	Quality & Handover Manager – Technology	Highways/M1T3
12	P12	Project Director	Rail Sector
13	P13	Senior Project	Highways

Table 3: Data collection participant information

4.4.1 Criteria of the Selection

Determining the appropriate number and categories of participants constitutes a foundational concern within qualitative investigations. Given that interviews offer insights into participants' perspectives and insights regarding the utilisation of adopting digital platforms within organisations, the careful selection of suitable interviewees assumes paramount importance. This subsection explains the process by which interviewees were chosen for this study.

The interviewer actively pursued a spectrum of viewpoints (King & Horrocks, 2010) that could offer valuable insights into digitising the build process in the construction industry. Clark et al. (2021) asserted that participant selection or sampling can be approached through two methods: purposive (non-probability) and probability sampling. Purposive sampling entails strategically selecting information-rich units that are more inclined to offer pertinent insights into the research questions and which align directly with the research objectives. Probability sampling represents a random sampling technique. However, there is not a clear-cut guideline for employing probability sampling in a qualitative context. Yet, it could prove valuable when the research aims to extend its findings to a broader population (Clark et al., 2021). Given that the present research has a naturalistic and interpretive orientation (Rubin & Rubin, 2012) mirrored in the engagement of interviewees, participants were thoughtfully selected through purposeful sampling (Clark et al., 2021).

Rather than focusing on gathering a sizable participant pool, this study prioritised data quality. The goal was not to encompass a multitude of participants, but rather to identify individuals who could most effectively contribute to addressing the research inquiries. Prior to approaching potential interviewees, specific participant selection criteria were established, and the potential strengths and limitations of the sample were acknowledged.

My situation in the workplace and how it helped this research is as follows:

- Costain[1] provides the main domain knowledge in the build process
- During my 8 years work at Costain I managed to develop a knowledge base that enables the chosen criteria of the right participants depending on the right skills.
- At the outset of the research project, while collecting relevant literature, I encountered several professionals with roles related to this research topic. The participants' roles included BIM Developer, BIM Manager, Project Manager, Network Intelligent Manager (Highways England), Technology Team Package Manager, Highways Performance Manager, BIM Program Lead in National Highways (NH), and Bidding Manager.

[1] Costain Group is a British engineering solutions provider. It was founded in 1865 by Richard Costain. Costain's activities are organised into six sectors Rail, Highways, Power, Water, Nuclear, and Oil & Gas (Costain, 2013)

- During my time at Costain, I had access to two senior managers who provided me with assistance and support. One of them was the Innovation Manager, who later became the Innovation Director, and the other was the Technology Integrating Manager. Given their deep understanding of Costain's setup and the organisation's capabilities, they guided me by suggesting colleagues who worked on various projects and sectors and possessed the skills and knowledge relevant to my research questions. I reached out to them during the data collection phase to gain their insights.

The criteria used to choose participants was:

- The participants had knowledge of the Construction Build Process in their projects and sectors.
- The participants were aware of the government's Construction Strategy 2025 plan or BIM L3 process.
- The participants were aware of the quality management practices in their projects that were related to their project's build process.
- The participants were aware of the current information systems that were being used.
- The participants were either aware of Construction Asset Information System (CATS), or if not, a full and comprehensive presentation of CATS and its functionality was shared with them.
- The participants were working for the Highways sector or had worked for it before.

I, with help from resources in Costain, chose two participants as pilot interviews to begin the interviews process. After that, each one of them provided a couple of names at the end of each interview that were directly related to the topic of the research and most likely would influence the direction of the research. This technique is called snowballing sampling (Atkinson & Flint, 2001).

The recommended names increased up until 15, then all the new interviewees began to mention the names of the people I had already interviewed, and no new names were mentioned.

I contacted by email all the persons mentioned to me, requesting approval and a time slot in their calendar to conduct an interview. 13 of them replied with their availability.

I then sent them the consent form and information sheet. The other 2 did not reply to my emails, and so they were removed from the list.

4.5 Interview Process

4.5.1 Conducting the Interviews

During the interview session, I initiated the interaction by introducing myself to the participants. I commenced with a brief, casual conversation with the interviewees, elucidating the research's objective and outlining how my professional and academic experiences in Information Systems development motivated me to undertake this investigation. This approach promoted a pleasant and relaxed environment, reducing the potential perception of me being a complete outsider (Hove & Anda, 2005). Additionally, I conveyed my gratitude, underscoring the interviewee's indispensable role in the study's advancement.

4.5.2 Recording Interviews

In order to maintain the exact phrases and sentences mentioned by the interviewees, I conducted all interviews via Microsoft Teams, recording each session as a video with the permission of the participants. Subsequently, I uploaded all the video recordings to Microsoft Stream, where I also utilised the platform to generate transcripts for the interviews.

Next, I downloaded the transcripts, which included timestamps for each line, resulting in a less coherent text. To address this, I turned to an online service (found here in VTTCleaner[2]) that specialises in refining transcript files downloaded from Stream (known as ".vtt cleaner").

After removing the timestamp annotations, the text remained approximately 90% accurate in relation to the original recordings. However, to rectify any differences, I adopted a comprehensive approach: I precisely reviewed each interview line by line, comparing the transcribed text with the spoken words in the recording. This was crucial for maintaining descriptive validity (Maxwell, 1996) and attributing the text to the appropriate speaker (either me or the interviewee), while also differentiating between questions and answers.

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[2] https://web.microsoftstream.com/VTTCleaner/CleanVTT.html

This thorough validation process spanned nearly 6 months, with dedicated attention given one day per week. Making sure all transcripts precisely reflect the spoken words, it took me time and energy to re-listen to the recordings and update the transcript to reflect what had actually been said.

Following the recommendation on conducting pilot interviews described by Hove & Anda (2005), two interviews were done as part of a pilot exercise to determine the suitability and depth of the questions, spot any possible problems with wording or interviewer input, determine the length of the interviews, and start basic data analysis. Following the pilot interviews, to promote intelligibility during interviews, I simplified technical phrases like Total Quality Management (TQM) and Digital Built Britain (DBB). This pilot exercise improved the interviewing procedure and paved the way for further phases that involved more interviews and analysis. Finally, it is worth noting that the initial pilot interviews involved participants P1 & P2.

Conversations with participants and subsequent discussions with my research supervisors post pilot study indicated that there was a need to enhance the information sheet. It was suggested that the sheet should be revised to convey information more effectively through visual aids such as images and concise bullet points, rather than lengthy text paragraphs.

The interview durations displayed slight variation, ranging from the shortest at 70 minutes to the longest at 130 minutes.

4.6 Data Analysis: Thematic Analysis

In broad terms, there are three types of qualitative data analysis: content, thematic and theoretical. Using thematic analysis, the focus is on units of data, such as the number of words, sentences or paragraphs which refer to a concept, and the generation of a particular ‘code’ would then follow. These are then extracted and examined with more care, for generating new and refined themes (Braun & Clarke, 2006).

In order to analyse qualitative research, a basic approach is to review the data and identify themes (Braun & Clarke, 2006; Bryman, 2016). Thematic analysis has been seen as a "foundational method for qualitative analysis" and it is used in interpretive studies (Braun & Clarke 2006). Braun and Clark (2006, page 79) define thematic analysis as a method "for identifying, analysing and reporting patterns (themes) within data." These themes are developed from a thorough reading and rereading of the transcript (Bryman 2016). It was suggested that thematic analysis is an "essentialist or realist method", because it reports the participants' personal experiences, meanings and realities. Furthermore, thematic analysis can also be viewed as a 'constructionist' method, by examining how factors such as events, facts, meanings and occurrences influence the different discussions taking place in society (Braun & Clarke, 2006). Therefore, thematic analysis methods work to reflect reality and/or to explain it (Braun & Clarke, 2006). Thematic analysis has 6 steps as shown in Figure 6. This research followed these.

Phase	Description of the process
1. Familiarizing yourself with your data:	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2. Generating initial codes:	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes:	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes:	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
5. Defining and naming themes:	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6. Producing the report:	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

Figure 6: Phases of Thematic Analysis (Braun & Clarke, 2006: page 87)

The collected data was uploaded to the NVivo software for further analysis. NVivo is a computer software that assists in the qualitative data analysis process.

4.6.1 Conducting the Analysis

A thematic analysis approach was adopted in this research to discover the main themes following the guidance advised by Braun & Clarke (2006) with the support of the NVivo software that was used to manage the data. The six phases detailed in

Figure 6 were followed. Emphasising the significance of the matter, it should be noted that the process of analysis is not strictly linear; rather, it takes on a recursive nature, as pointed out by Braun & Clarke (2006). Consequently, researchers do not always adhere to a specific order when proceeding through the phases. Instead, they engage in iterative movements, constantly navigating back and forth across the data as needed to address the research objectives (Braun & Clarke, 2006).

4.6.1.1 Familiarising yourself with your data

The comprehensive background review of chapters 2 and 3 as well as the literature review of section 6.1 paved the way for initial insights into the advances that come from adopting digital technologies in the construction industry. Consequently, before commencing the interviews, I had already acquired a preliminary understanding of the potential data that would emerge from these discussions. All interviews were personally conducted by myself using Microsoft Teams, transcript using Microsoft Stream, converted into text only using VTT convertor portal[3] and accurately transcribed using Microsoft word. This approach ensured a higher level of accuracy and yielded rich data because the interviewer was intimately familiar with the interview content, supported by the detailed interview notes taken during the conversations.

Throughout the interviews and transcription process, continuous familiarisation with the data took place. Each interview transcript underwent multiple checks and revisions to ensure accuracy. As an example, I faced challenges with the transcription process due to the tools used. Specifically:

- After acquiring the text from .vtt conversion, I then manually divided this paragraph into meaningful segments, correctly attributing them to the respective speaker (interviewer or interviewee) and identifying questions and answers within the text. All of this happened while I was listening to the recording to compare the spoken words with the transcript.
- Additionally, I carefully reviewed the newly structured text, correcting any spelling mistakes or inaccuracies that might have occurred during the conversion process.

[3] https://amsglob0cdnstream13.azureedge.net/vttcleaner/CleanVTT.html

Furthermore, every transcript was carefully reviewed by listening to the audio multiple times to verify its precision (Bryman, 2016).

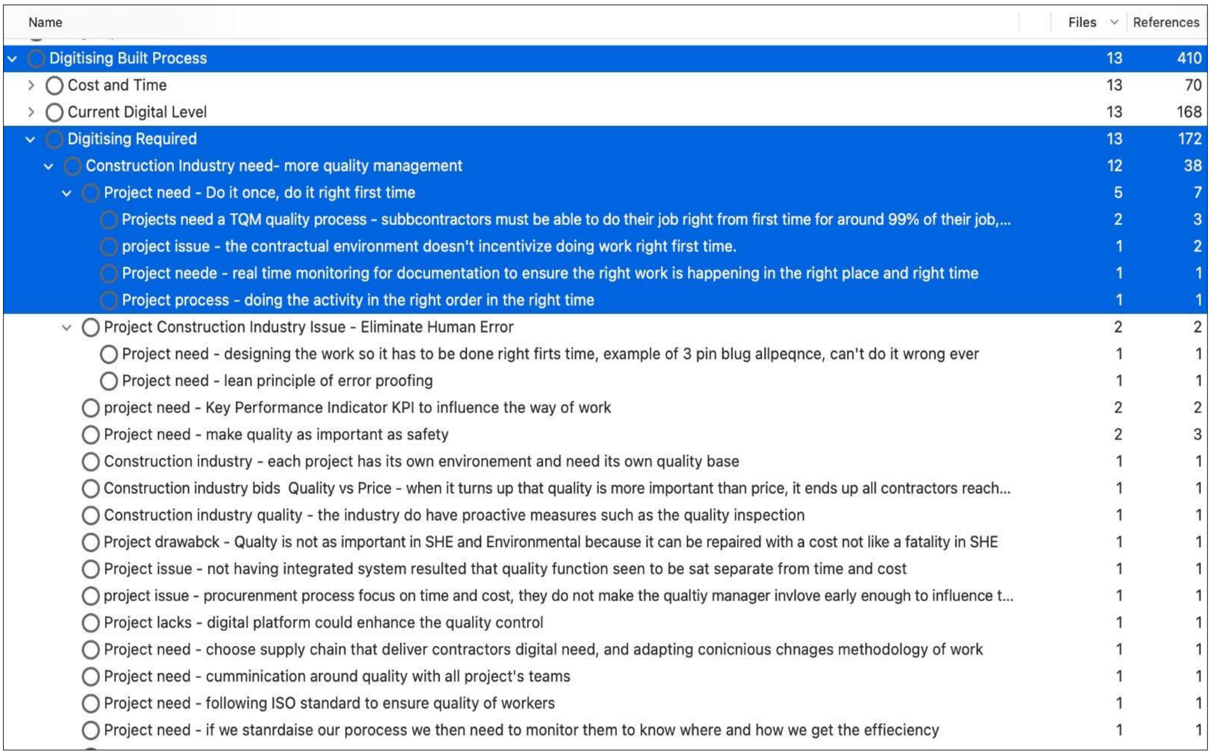
4.6.1.2 Generating initial codes

During this phase, the data is systematically analysed by identifying and coding interesting features across the entire dataset. Relevant data is collated under each code. The coding process in this phase serves to organise the data into coherent and meaningful groups as described by Braun & Clarke (2006). I selected NVivo as it was the most appropriate qualitative data analysis program for coding. It was used for coding the interview data.

Initially, a collection of open codes was generated, derived from the content of the first interview. Additionally, notes were taken to identify emerging themes and explore their potential connections. These codes were organised within the NVivo directory, where I refined them by assigning descriptions to each code, thereby clarifying their meaning. Through iterative work, I continuously improved the codes by revisiting and modifying their descriptions multiple times during the first interview. This process facilitated my deeper comprehension and proficiency in the coding process and the underlying codes.

Based on the interview with P4 that was picked randomly to begin the coding with, a list of 168 initial codes was produced. The coding for the second interview was developed in the same way and 89 new codes emerged. The codes consisted of the features, using digital tools in the construction process, actions taken to help manage the tool/s, in addition to information such as participant's role in using and promoting the tool/s within their organisation. For each code that was developed, a brief definition was also created to ensure consistency in the coding process, to keep the meaning of the codes clear, to know what each code represented and to help avoid vague and repeated codes.

Throughout the analysis process, the codes were continuously compared to one another to detect similarities, differences, and overall patterns. Certain sections of the text were assigned multiple codes as they pertained to multiple themes. Some codes were entirely replaced and reclassified under different codes. Moreover, new codes were introduced, and there were instances of overlap or similarity in the content of a few codes. In such cases, a thorough review of their definitions and consideration of the specific segments were undertaken. Subsequently, a decision was made whether to keep these codes separate or merge them based on their distinct characteristics. Figure 7 illustrates an example of how codes and sub-themes were created. Before generating the first codes, I read the transcripts several times. These initial codes consist of sentences that represent specific ideas or actions related to the research questions and interview plan.



Name	Files	References
Digitising Built Process	13	410
Cost and Time	13	70
Current Digital Level	13	168
Digitising Required	13	172
Construction Industry need- more quality management	12	38
Project need - Do it once, do it right first time	5	7
Projects need a TQM quality process - subbcontractors must be able to do their job right from first time for around 99% of their job,...	2	3
project issue - the contractual environment doesn't incentivize doing work right first time.	1	2
Project neede - real time monitoring for documentation to ensure the right work is happening in the right place and right time	1	1
Project process - doing the activity in the right order in the right time	1	1
Project Construction Industry Issue - Eliminate Human Error	2	2
Project need - designing the work so it has to be done right firts time, example of 3 pin blug allpeqnce, can't do it wrong ever	1	1
Project need - lean principle of error proofing	1	1
project need - Key Performance Indicator KPI to influence the way of work	2	2
Project need - make quality as important as safety	2	3
Construction industry - each project has its own environement and need its own quality base	1	1
Construction industry bids Quality vs Price - when it turns up that quality is more important than price, it ends up all contractors reach...	1	1
Construction industry quality - the industry do have proactive measures such as the quality inspection	1	1
Project drawabck - Qualty is not as important in SHE and Environmental because it can be repaired with a cost not like a fatality in SHE	1	1
Project issue - not having integrated system resulted that quality function seen to be sat separate from time and cost	1	1
project issue - procurenment process focus on time and cost, they do not make the qualtiy manager invlove early enough to influence t...	1	1
Project lacks - digital platform could enhance the quality control	1	1
Project need - choose supply chain that deliver contractors digital need, and adapting conicnious chnages methodology of work	1	1
Project need - cumminication around quality with all project's teams	1	1
Project need - following ISO standard to ensure quality of workers	1	1
Project need - if we stanrdaise our porocess we then need to monitor them to know where and how we get the effieciency	1	1

Figure 7: Codes and themes creation example

4.6.1.3 Searching for themes

As detailed by Braun & Clarke (2006), the third phase of analysis involves searching for themes. In this process, codes are collected and grouped into potential themes, with all relevant data associated with each theme gathered accordingly. At this stage, all the data had been coded and compiled, leading to the identification of various codes within the dataset. The focus then shifted towards examining these different codes and organising them into potential themes.

The research questions discussed in section 1.5.1 were the basis for setting the themes used in the semi-structured interviews.

During phase 1, which involved familiarising myself with the data, a list of initial theme ideas was recorded (Braun & Clarke, 2006). These initial ideas were utilised in the subsequent stage to develop themes. Some of the initial codes formed the foundation for the main themes, while others were categorised as sub-themes. In cases where certain codes were repetitive or no longer relevant, they were eliminated from consideration. Additionally, some codes did not fit into any existing theme, prompting the creation of new temporary themes.

As the process unfolded, the codes associated with potential themes were carefully assessed over time to determine the most suitable and appropriate theme for each code (Braun & Clarke, 2006). This iterative approach allowed for refinement and ensured that the final themes accurately captured the essence of the data.

At the outset, I partitioned the data into three primary groups, based on the structure of the interviews which also had these three parts, to facilitate a comparative analysis of themes and identify similarities and differences. These groups were as follows:

- Strategic data-group: This encompassed Digital Built Britain (DBB) and Costain's plans.
- Quality perspective: This discusses the use of digital in projects and its connection with the project's overall quality.
- Information Systems in general, with a specific focus on Construction Asset Tracking System (CATS).

Upon investigation, I discovered that the codes and themes were common and applicable across all three groups. Figure 8 shows an example of themes and sub-themes while searching for main themes, this happened through gathering similar sentences with the same topic into one main theme consisting of a few words – not a sentence like the previous phase - .

Name	Files	References
Societal Issues	13	168
Behavioural Issue	12	50
DBB Barrier - Behaviour	10	19
Construction industry issues - behavioural issues	8	21
IS issue - Behaviour issue	3	3
TQM need - behavioural change of individuals	3	4
CATS Benefit - Cultural behaviour of individual resistance to chaneg or accept new way of working	2	3
Political Issue	12	57
Construction industry issues - Political issues	11	22
DBB need - political	9	22
TQM need - Polotical aspect from leaders	7	10
IS issue - Political Issue	2	2
poltical solution	1	1
Current Culture Issue	11	61
Construction Industry Issue - Culture issues	10	37
DBB barrier - culture	6	13
Positive - How to Fix	6	8
TQM need - cultural change to adopt quality	2	3

Figure 8: Theme and sub-themes example searching for main theme

4.6.1.4 Reviewing themes

This marks the fourth phase, focusing on exploring the themes derived from the coded extracts and the entire dataset, effectively creating a thematic 'map' of the analysis (Braun & Clarke, 2006). During this stage, various themes were interconnected, with some distinct themes merging to form a unified theme. Conversely, certain themes containing different content required further subdivision into separate themes.

As outlined by Braun & Clarke (2006), this stage involves two levels: the review and refinement of themes. During the review process, all collated extracts for each theme were carefully examined to ascertain if a coherent pattern emerged. If a pattern was evident, the themes were refined accordingly. However, if I encountered difficulties in moving forward, the themes would be reconsidered, assessing whether new themes should be introduced, or if certain themes needed replacement or removal from the analysis.

To facilitate the categorisation of themes and enhance data comprehension, all codes sharing similar themes were grouped together in NVivo. This process significantly aided in organising themes and gaining a deeper understanding of the data.

I conducted the analysis of the data in three distinct groups: Governmental future plans or ***Strategy***, ***Quality*** management in construction projects, and ***Information Systems (IS)*** and how it could help integrate with the government plans. Each group's data was examined independently to explore the emerging themes. In the Strategy data, particular attention was given to themes related to digitisation processes, needs, and challenges within the construction industry. See section 4.3.1 for more information related to the groups and questions asked in the interviews.

Similarly, I applied the same process to the data from the quality-related questions, focusing on identifying relevant themes. The same analysis approach was then repeated for the IS data, focusing on themes related to Information Systems in the construction sector.

Upon producing the findings, it became evident that no new themes surfaced from the Strategy or Quality questions that had not already been identified during the IS interviews. This discovery served as a crucial indicator of theoretical saturation, reassuring me that the analysis encompassed all relevant themes and that the consistency of results was confirmed across the different data samples. Figure 9 shows an example of reviewing the themes while deducting the main themes.

Name	Files	References
Design Spec and R&D	13	156
Design Required	13	101
IS need - Process efficeincy	11	38
IS Need - better design and specification	8	17
CATS need - Efficiency and digital functionality	7	12
DBB need - Design and specifgication	5	7
IS need - continious R&D	5	8
TQM need - design, spec and standardisation	5	6
IS need - more quality control	2	3
CATS drawbacks - why would you just limit it to highways	1	2
cats feedback - seems to be a maintenace managemnt tool	1	1
CATS need - future proof - understanding of the input and t...	1	1
CATS need - Single Sign in	1	1
CATS need- minimise human input to avoid errors	1	3
Views on SDP - Needs easy navigation, integration, group a...	1	2
Design Enhancement applied	11	23
Construction Industry Best Practice	8	12
digital benefit for Client - R&D opportunity	4	7
View on SDP and CATS - important not to be left behind - d...	2	2
CATS possitivity - works on all platforms, follows bring your...	1	1
Cats System is Perfect to use	1	1
Interoperability	11	27
Interoperability Required	10	23
Interoperability Enhancement	3	4
Construction Projects - Contruction project lifecycle stages	2	5
Asset lifecycle	1	1
Handover process - projects handover to the area team an...	1	1
Hierarchy of asset lifecycle	1	1
Maintenance lifecycle	1	1

Figure 9: Example of reviewing themes

4.6.1.5 Defining and naming themes

As described by Braun & Clarke (2006), this constitutes the fifth phase of the analysis, which entails a continuous refinement of each theme and the overall narrative that emerges from the analysis. During this stage, I further defined and clarified the themes, placing emphasis on their significance and meanings. The goal was to create precise and well-defined definitions and names for each theme, enhancing the understanding of their importance in the context of the study. Figure 10 shows an example of finalising the main themes and sub-themes as the last stage is almost concluded.

Name	Files	References
Communication and Collaboration	13	104
Communication Required	13	60
Reporting and Monitoring	12	35
Communication Enhancement	7	9
Design Spec and R&D	13	156
Design Required	13	101
Design Enhancement applied	11	23
Interoperability	11	27
Construction Projects - Contruction project lifecycle stages	2	5
Digitising Built Process	13	410
Cost and Time	13	70
Current Digital Level	13	168
Digitising Required	13	172
Societal Issues	13	168
Behavioural Issue	12	50
Political Issue	12	57
Current Culture Issue	11	61

Figure 10: Main themes and sub-themes

4.6.1.6 Producing the report

Regarded as the sixth phase, this stage presents the final opportunity for analysis, as outlined by Braun & Clarke (2006). Here, I selected vivid and compelling quotations from your participants as evidence, conducted the ultimate analysis on these chosen extracts, and established connections between the analysis, research question, and existing literature. The outcome is a scholarly report that effectively communicates the narrative of the data and persuades others of its worth and credibility. This concluding phase serves to encapsulate the essence of the research, presenting a convincing portrayal of the data's significance and validity.

4.7 Research Quality

The study follows a naturalistic inquiry approach, as proposed by (Golafshani, 2003), and is characterised by its interpretive nature. In this section, we will present the specific criteria used to assess the study's appropriateness. The terms "validity" and "reliability," commonly employed to gauge research quality, are relevant to this study and will be further explored in the subsequent parts of this section.

4.7.1 Research Validity

According to Bryman (2008), the primary criterion for assessing research quality is validity, which involves the accuracy of research conclusions. Validity, as explained by Cresswell and Miller (2000), relates to how well a study accurately represents participants' perceptions of social phenomena and whether these participants find it credible. In qualitative research, Creswell (2007) defines 'validation' as an effort to evaluate the accuracy of findings based on both the researcher and participants' descriptions. Guion et al. (2002) approach validity in qualitative research by examining "truth" (accuracy of results) and "certainty" (evidence sufficiency) related to findings.

Creswell (2007) suggests several validity approaches for qualitative studies, including triangulation, disconfirming evidence, researcher reflexivity, member checking, prolonged field engagement, collaboration, audit trail, rich description, and peer debriefing (Cresswell & Miller., 2000, page 126). While conducting this research, I selectively applied those of these approaches that were most relevant to enhance the study, rather than strictly adhering to all of them (Cresswell & Miller, 2000, page 126).

In this study, I used *Peer debriefing, member checking* and *researcher reflexivity*. First, peer debriefing was used to make sure the findings of this research were accurate. The supervisors kept a close eye on the research all the time (Cresswell & Miller, 2000, page 129; Lincoln & Guba, 1985). The person doing the research and the supervisors talked about how to do the research, what certain words meant, and what they thought about the interview data. According to Lincoln & Guba (1985, page 308), the peer debriefer's role is like a "devil’s advocate", someone who asks challenging questions to make sure the researcher is being truthful. These questions can be about how the research was done, what words mean, and what the data means. By using peer debriefing in the study, it helps make sure the person doing the research collected good and reliable information

Second, “member checking” is considered as the "most crucial technique for establishing credibility” as pointed out by Cresswell & Miller, (2000, page 127) and

Lincoln & Guba (1985). This research followed a process where an initial model was developed (based on NH databases, government plans, literature, and industry process) using an Information System named CATS as discussed in section 8.2. This model was then tested during the Smart Motorway Framework Tranche 2, at the M1 Junction 23A-25. The model, user interface, and functionalities were shared with the 13 participants, and their feedback was collected during the interviews. The feedback received from the participants was carefully analysed and used to refine the model.

An additional method used to ensure the reliability of this study was referred to as “researcher reflexivity”. During this research, several strategies were adopted to cultivate a critical and reflective mindset (Cresswell & Miller, 2000). The role of the researcher was carefully examined, considering potential biases, as well as the potential impact the researcher's background, experiences, preferences, and biases could have on the phenomenon being studied (Cresswell & Miller, 2000; Malterud, 2001). This approach aimed to acknowledge the significance of reflexivity and to recognise that the researcher's social identity and personal factors might have influenced the research process (Malterud, 2001).

Potential bias, in the coding stage, based on my background experiences as a System Engineer could be:

- Concentrating on coding the data to include technical solutions (i.e. system efficiency or functionality) and ignoring the less or non-technical data (i.e. usability or user experience)
- I could use technical terms that non-technical readers might not fully understand, which could result in elimination of important insights.

Reflexivity entails "a systematic attention to the context of knowledge construction, particularly focusing on the researcher's impact throughout the research journey" (Malterud, 2001, page 484). The objective was to minimise the potential for bias, particularly in terms of any unintended influences, when analysing and coding the data (Malterud, 2001, page 484). Since I was solely responsible for conducting the interviews, there was a possibility that my past experiences and knowledge might have influenced the participants’ perspectives while observing the use of digital platforms in construction projects during the interviews and during the subsequent analysis. This influence could potentially impact the notes taken during observation, the interpretation of gathered data, and ultimately shape the overall findings.

Considering that this study was undertaken as part of a research project, it was carried out by myself. In the light of this, certain approaches were taken to counteract bias. The data underwent thorough re-examination on multiple occasions, and ongoing discussions were maintained between myself and my supervisors to mitigate bias. For instance, the initial stages of coding for the first interviews were extensively discussed, followed by the provision of specific examples to illustrate how themes and sub-themes emerged from the data. Furthermore, the observations noted were consistently cross-referenced against the interview data. By continually scrutinising both the data and its interpretations, the process of reflexivity was upheld (Malterud, 2001, page 483).

Special care was taken to ensure that the presented results truly reflected the range of expressed viewpoints, and quotes were selected from various interviewees to accurately represent their perspectives.

4.7.2 Research Reliability

Reliability pertains to “a degree of which the study can be replicated” (Bryman, 2016) and concerns whether consistent results can be obtained when the same research approach is repeatedly applied to the same subject (Lewis, 2009, page 7). Thus, a study is deemed reliable if other researchers can reproduce its outcomes (Lewis, 2009). To assure the reliability of this study and as recommended by (Bryman, 2016, page 384), detailed records of interviews and observation notes were kept, including documentation of: the research problem formulation, research participants, interview data, recording, transcript and notes, research design, and the procedures undertaken in the data analysis. For example, the report provided detailed insights into the process of selecting participants, outlined the number and types of interviews carried out, and described the use of NVivo software to analyse the interview data. Furthermore, the report extensively covered the analytical procedures, including my involvement in the data, creation of initial codes, identification of overarching themes, rigorous scrutiny of these themes, culminating in the synthesis of the comprehensive report. This thorough description of the procedural sequence not only enables fellow investigators to replicate the study – albeit given the nature of the research of timing, contractor involved and current practices - using same methods, standards, and techniques, but also affords an opportunity for individuals to critically evaluate the appropriateness and thoroughness of the research conduct.

4.7.3 Research Ethics Considerations

Within this section, I will outline the ethical considerations inherent in the current thesis, encompassing the process of acquiring ethical endorsement from Management school at the University of Sheffield.

Ethical considerations hold paramount importance in all forms of research (Orb et al., 2001). Hence, ethical principles encompassing avoiding harm to participants (Bryman, 2016), academic integrity, honesty, transparency, mutual respect, confidentiality, and trustworthiness will be rigorously adhered to in order to uphold the rights of the participants engaging in this research (Miller et al., 2012).

I adhered to ethical principles throughout the research phase to prevent any potential harm from occurring. These principles encompassed the safeguarding of confidentiality, guaranteeing anonymity, and securing informed consent. Furthermore, this section will address ethical difficulties that arose during the data collection process involving interviews with participants.

Regarding ethical difficulties, a couple of the interviewees stressed the need to keep their participation anonymous because they felt the contractor they talked about may not be happy with their input identifying the issues the contractor is facing.

Authorisation to conduct this study was diligently sought and obtained from pertinent bodies at academic level. This refers to the Management School entity at the University of Sheffield, the research ethics application (with reference number 002933) was submitted on the 17th February 2015, and approved on the 13th May 2015. The ethics information is presented in appendix 12.6.1.

I engaged with participants asking them if they were willing to partake in the study by sending them an email asking them, or calling them directly using Microsoft Teams from my Costain's account as I was working for Costain at the time of the data collection. The Prospective participants were provided with Consent Forms and Information Sheets. The Information Sheet furnished participants with comprehensive insights into the research study, the problem, government plan and research goal. Participants were made aware of their right to withdraw from the study at any stage. Furthermore, and because the interviews happened over Microsoft Team calls, I indicated at the beginning of each the confirmation that the participant had received the consent form. The consent form highlighted the prioritisation of the participants' needs over the study's demands for data collection.

To ensure the confidentiality of the interviewees' identities and information, as well as the projects or sectors they represented, pseudonyms were employed instead of actual names. Participants were informed that recorded interviews would be securely stored on my laptop, accessible solely by the team of the researcher and his supervisors. Transcribed interviews were reserved for exclusive access by myself and primary research supervisors for the duration of the study. These transcripts were anonymised and securely stored on my laptop and protected university-based cloud connected to my university account.

4.8 Conclusion

In this chapter, the rationale for adopting a qualitative methodology was provided, outlining the study's practical aspects, data collection methods (primarily interviews), and participant selection. The data analysis process was explained, following Braun and Clarke's (2006) framework, with a focus on maintaining high-quality analysis standards.

The chapter also discussed research quality, including strategies like peer debriefing, member checking, and research reflexivity to ensure validity. Reliability was addressed through comprehensive documentation of the research design and execution, enabling future replication.

The themes identified at section 4.6.1.5 will be used in chapter 5, 9, and 10.

The next chapter will discuss the research vision and the issue that the construction industry is facing from the perspective of interviewees and the current practices involved in construction projects.

5.0 The Current, Pre-Digital, Industry Situation Versus a Digital Transformation for the Future

The previous chapters explored the motivation behind this research, the government requirements, the literature review focusing on construction industry issues from an acidic perspective, and the methodology used to gather data from industry experts. This chapter delves into the construction project's process from inception to handover stages, alongside the current situation of the construction industry as perceived by interviewees and their thoughts on how digitization of the construction process could offer a solution inline with the government's requirements of DBB.

This chapter describes the motivation for the project (Section 5.1) before detailing the information transfer between the highway construction phases (Section 5.2). An overview of the problems with asset models facilitating this information transfer follows in Section 5.3, before the following section details the thoughts of the interviewees on digitisation and the current issues of the construction industry.

5.1 Introduction

This research was initiated and supported by Costain Group to investigate how contractors can meet the requirements outlined in Construction Strategy 2025. As technology development has accelerated, Costain's clients are now seeking for construction projects to be delivered quicker and more cheaply than before. This is leading Costain to adopt new productive ways to be able to keep in the market. Even though there is a process in place to manage construction and maintenance works, the construction industry still suffers from poor practice resulting in cost and time waste in doing the same job again (reworking). This issue and more - that will be discussed in this chapter - creates a need to build a digital model for handling and managing asset data in the construction phase. This model will provide support in delivering projects with minimal waste in terms of cost and time. This model contributes to the asset management field in construction or build phase (Teall, 2014).

Asset management can be defined as

“the process of guiding the acquisition, use and disposal of assets to make the most of their future economic benefit and manage the related risks and costs over their entire life” (Kostic, 2003),

i.e. it offers a solution to managing assets throughout their lifespan. Infrastructure networks such as highways have distinct construction and operating phases. These phases have significantly different data requirements e.g. excavations and tracking the completion status of assets in the construction phase is not important in the Operation and Management (O&M) phase. The aim of this research project is for the specified digital model to create a solution to an asset management problem in the build phase, this would be fulfilled in functionality to lead and track the construction in a highways industry to save cost, time and resources while enabling better quality.

5.2 Current Industry Process of Project Control

National Highways (NH) divides the whole construction process from A-Z into 7 stages called the Stage Gate Assessment Review (SGAR) (National Highways, 2017; Hall,2023).

Each one of the SGAR 0-7 are considered as a hold point between each stage. This hold point is a precise point of time to have all documentations approved before being able to move onto the next stage.

5.2.1 SGAR 0 - Development Phase

SGAR 0 is the development stage. This stage is completed by NH. Also, NH investigates what is required, and where the funding will come from. They also perform a desktop survey to decide what the new building requires, for example are there any rivers that may require bridges. If we move to an adjacent area that satisfies our requirements but away from the river, will it still work so we can save on cost and build time? In this stage, the desktop survey confirms and determines the target for the design.

5.2.2 SGAR i3 - Interim SGAR 3

Once NH have decided on a brief idea of the requirements, they determine where the funding will come from and briefly imagine the expected outcome. The project then moves to SGAR i3 stage. Which introduces the steps related to what needs to be designed and goes on to create the early detailed design.

In the early detailed design phase, NH begins to mobilise the leadership team which consists of a project lead, technology lead, and design lead to only concentrate on designing the project at this early stage. There will be no construction partners involved at this stage because it is too early.

At this stage, the dedicated leadership team will also be looking at the project scope, risks, very early ideas and developing the strategies by:

- Looking at some baseline plans and packages
- Initiating workshops with NH and supply chain partners to get their feedback on the early design.
- Mobilising the early design phase delivery team with specific design skills to help visualise the requirements on the design.

The designers then create design Fix 1 and freeze it before move onto the next step, which is to initiate the design 3D model. This is the beginning of the Building Information Modelling (BIM). In this model, the client can visualise the project and how it may affect the neighbourhood.

Once the early design is completed, it then moves to the step of gaining approval from National Highways (NH) Board before starting the next Stage.

5.2.3 SGAR 3

SGAR 3 is the detailed Design stage and it begins with Step 2 of creating a design Fix 2 for technology assets. In this stage, NH interfaces with technology stakeholders such as Regional Operation Control (ROC) who are the stakeholder (part of NH) who is controlling the signals on the sides of the motorways.

Also in this stage, NH begins to receive survey data to create design Fix 3 which includes what assets are required to be installed on the site, and what is the best design of where to install the assets. The design will also include a traffic management for the site to address construction and maintenance.

The design incorporates environmental measures in respect of the site area. It also considers any gas pipes already existing in the area that may affect the construction process.
After completing the detailed design, it is likely that the cost of the project will increase to tackle any issues found in the survey or adopt any new design recommendations that were not included in the previous stage's earlier design.

Once the detailed design Fix 3 is completed, it then moves onto the approval hold point before moving onto the next SGAR stage.

5.2.4 SGAR 5

After finishing SGAR 3, the project moves to the Design Closure phase within SGAR 5. This is the stage where the designers finalise all the earthwork and the landscaping design.

In this stage, the client will be looking at the final commercial and technical assurance which is ready for construction reviews. It also includes the engagement with civil contractors to get a price for doing the work. Hence between SGAR 3 and SGAR 5, the client would send out the design to civil contractors and request a quote for carrying out the work. The contractor would need to provide not only a cost estimate for the construction work, but also the costs for managing safety, environmental issues, quality assurance, and everything else that accompanied the construction project process.

On the successful completion of SGAR 5, the contractor begins mobilising the field construction team and the field procurement. Now that the contractor has the detailed design from the client (NH), the contractor reaches out to the sub-contractor and requests a cost estimate for doing the work. The cost from the subcontractors will then be passed to the client for approval to make sure the estimate is within the expected project cost. Once the cost approval process is complete, the contractor manages the project throughout the SGAR 6 steps.

5.2.5 SGAR 6

Once the cost approval process is completed and the subcontractors are all set, the contractor manages the project progress step by step through the build, Site Acceptance Testing (SATs), Safety Audits, Removing Temporary Traffic Management and opening for traffic. This reaches the handover step. From SGAR 5 to SGAR 6 could take up to 3 or 4 years. The move from SGAR 5 to SGAR 6 is often faced with many failures. The reasons for this are discussed in more detail in section 5.2.5.4.

5.2.5.1 Construction Process

The actual construction begins with earthwork, then the foundation and the drainage work. After that, the structure work occurs, and this is followed by the technology team installing the technology assets.

After completing each phase of work from earthworks team, foundation, structure and technology, the Integrated Quality Verification Team (IQVT) performs some testing and investigation to check if the work has been completed up to the quality specification.

The majority of the construction process is actioned in conjunction with other activities. For example, any section of the scheme at any point of time might be under earthwork or it could be in a more advanced stage such as in an active field testing because most of the installation stage is completed.

It all depends on the earthworks team completing the work on a section of the scheme before moving to another. As the project's construction must be staged and planned, the project has something called a Plan Wall or Post-It Wall, where the whole scheme or the sections of the project are drawn on a wall. Post-Its are attached to the wall to indicate what job each team is doing at which section of the scheme/road and at what time. Figure 11 shows an example of a Post-It wall.

Figure 11: Post-It Wall - example of traditional work

5.2.5.2 Reworking

Reworking may happen when the earthworks team finds some underground cables or pipes that are not included in the design. They then go back to the designer requesting a new design. The designers then update the design by, for example, moving the design 2 metres away from the underground cables to avoid extra work. The new design is then communicated to the technology designers to update their design. In this case, the 3D BIM model helps in communicating the new or updated civil design to the whole team so that the impact of the new design influences all follow up designs such as the technology design.

Another case of reworking may happen when the client (NH) decides to have something new added to the design or requests a change to the original to adopt a new type of asset. An example of this is NH requesting the redesign of Smart Motorway projects so as to install a new Stop Vehicle Detection System. This happened after the installation of other types of technology assets was completed. The project then had to be redesigned, which involved removal of the old technology and installation of the newly requested asset.

Construction projects are trying to overcome this type of reworking by leveraging the use of 3D BIM models, so that any changes happening in any design can be shared and communicated to all other disciplines' design teams straight away to avoid mistakes.

5.2.5.3 Construction Programme and Plans

Going back to the stage where the contractor asks subcontractors for the cost estimate of their work, the contractor also asks for the duration expected in performing the actual work. Once the contractor has the duration from the subcontractors, they produce a high-level programme stored in a software called Primavera 6 or (P6). The programme is then passed to the client for approval, and once approved, the contractors will then get the go ahead to start the process from the client.

The contractors then gather the site managers from the contractors' side and the subcontractors in a room to plan the work on a weekly basis, ensuring that everyone of them knows what job is being performed by whom at the specific location during which week. This type of meeting is called a TiLoS meeting. TiLoS is a project Management Software that helps plan the work in more details than P6. See figure 12 for an example of TiLoS.

In the meeting, everyone will participate to update the wall. The wall is a massive layout of the motorway verge. All involved parties gather to plan the coming week's work by agreeing when each team will be working at a particular place. For example, all teams will agree a timeline for earthworks to take place in a specific location in the scheme that may last for 3 days. After that, they plan for the foundation and drainage team to begin their activities that may last for 7 days. Following this, the structure team will start their activities and this may last for 3 weeks, and so on for the technology team and how long they need to perform their activities at that specific point. Once a plan for that specific point location is completed, they then move to the next one to plan each team's work and timeline, and so on. A wall plan meeting highlights where the clashes may happen and it also highlights who can be doing what in what area and when.

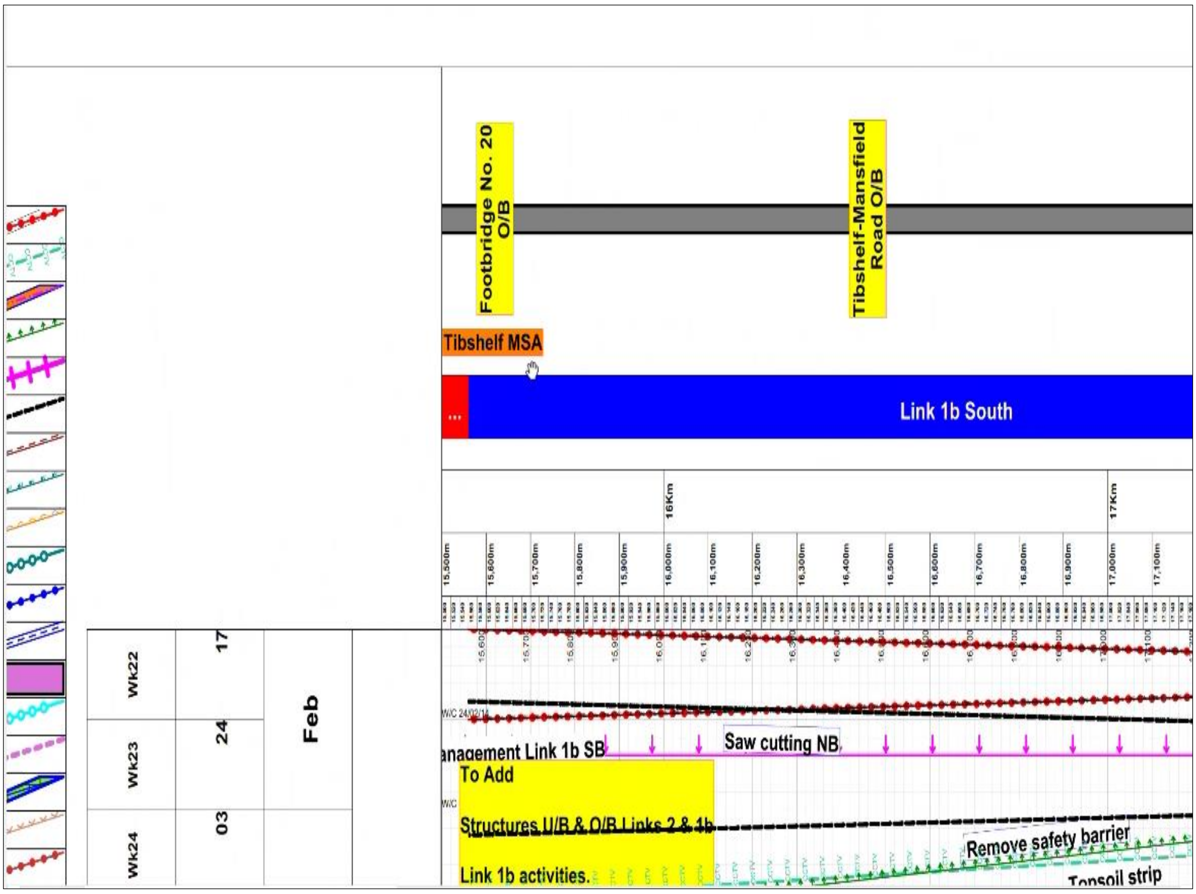


Figure 12: Close up TiLoS example

All these plans and meetings and agreed actions feed into the programme. Additionally, a 4 week look ahead is created from these meetings.

An example of an issue arising from these TiLoS meetings is of a subcontractor sending the wrong person to these TiLoS meetings and confirming a work for his side team. The person reports back to the team what has been agreed but the managers disagree to do the job because of resource issues at that time and location. This will affect the plans of other subcontractors if they depend on the work in question.

Each one of the subcontractors should have a package manager from the contractor side that manages their work and helps unblock any issues they may face and make sure that they are doing what they are supposed to do in the agreed time.

5.2.5.4 Handover Phase

Once all assets are installed and Site Acceptance Testing (SATs), which makes sure everything is operating correctly, is completed, then the handover phase is started to collate all this information.

The handover phase begins from the beginning of the project and continues in the background while the work is happening. It does not start at the end of the project. The installation information is collated and linked with all the SAT tests that are prepared to be handed over to the client whenever a part of the project is completed depending on how the project is being divided.

Subcontractors do not report their work directly to the contractor because they are involved heavily in doing the work with less attention given to reporting back directly. They gain the required signatures directly after the work finishes to be able to complete their paper based reports. Hence, it becomes a significant challenge to request handover materials at the precise moment when subcontractors are about to conclude their work. Leaving it until after they have completed it, is a problem as they might depart from the project without providing the necessary handover materials. This situation has, in the past, posed difficulties in obtaining subcontractor information for inclusion in the handover package. There is a massive and desperate need to introduce technology and IT into this stage to capture the handover data at the site as the work is happening. Technology is needed to gain the signatories required as early possible as the work is completed in a real-time manner. This is where the Construction Asset Tracking System (CATS) (which is a model that was designed and developed to support the construction build phase, see chapter 8) can play a massive role in supporting the handover, see section 8.2. Each site supervisor is required to be IT literate to be able to use technology where needed on site.

Finally, all the deliverables go on to the National Highways Business Collaborator (Data Storage) and everything has to adhere to the BIM metadata (Hall, 2023).

5.2.6 SGAR 7

In this stage, the completion and project closure are reached. This happens when the scheme is basically built and handed over to the client (NH). Only a few things still need to be done such as completing the road safety audits and any outstanding works that the project was committed to as part of the handover process such as painting gantries, see Figure 13.

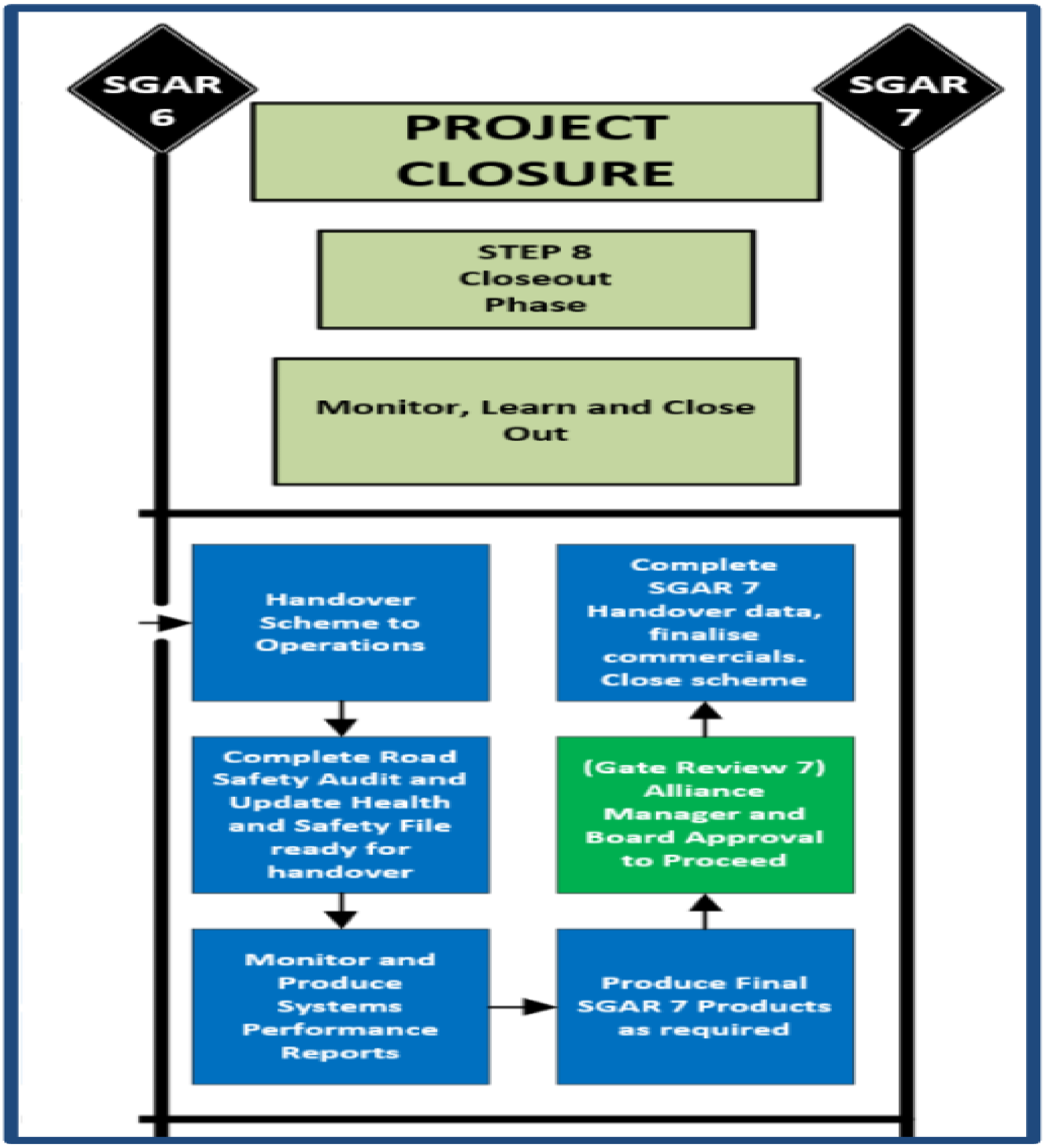


Figure 13 SGAR 7 (taken from Hall, 2023)

5.3 Costain's Current Situation

The previous section discussed the current industry position from the client perspective (NH in this case). This section will highlight Costain's current situation from the interviewees' point of view as they are the ones who work and live in this situation. The current situation of Costain is not satisfactory because of the amount of reworking, the traditional way of performing the work, and not being BIM compliant, i.e. with the requirements the government established in their DBB and Construction Strategy 2025.

The interview participants have been allocated symbols in section 4.4, and so, the same symbols will be used here. i.e. P1 is participant number 1.

P6 shares his view on what has been achieved so far in Costain to be aligned with DBB or BIM L3 as there are good initiatives being achieved to adopt BIM L2. He highlighted the widespread adoption and rapid development of Building Information Modelling (BIM) across various industries. Also, he is impressed by how quickly projects have transitioned to digital processes, even on long-term projects. The focus has been on digitising and modelling plans, incorporating product and data information. While they acknowledge significant progress, he is uncertain about the next technological phase. Overall, he emphasises the achievement of having fully digitised plans ready for digital client handover.

Costain also created a model to test construction projects against the reports of quality and performance to determine how digital the project is, this was mentioned by P6

> *"To support that the number of tools that we put in place so the quality excellence matrix we developed basically to have a benchmarking so pulling out the key things within the Costain way. Getting people to recognise that there are, if you focus on certain things within quality then that will give you, improves the culture so that everyone is focusing on the key things to do with quality to get things right first time and also the monitoring performance so things like OEM where we're focusing on performance management, sorry, we focus on measuring and making sure that people who are actually doing what they should be doing. The key things on a lot of projects you will see dashboards as well, which*

again is required to this quality dashboard, sorry, required to monitor quality performance so you can focus on where you need to take action to bring about this improvements for contest dancing"

This also was mentioned by P13 with an extra description regarding the tools of Smart Deliver Platform (SDP, which is a platform that used by Costain to include all software and digital tool sin used by construction n projects

"introducing the operational excellence model, which has got its pillars to address the infrastructure and the skills, behaviours, and other elements to success. Its enablers, and also the SDP, which is the tool box if you like, which are on progress as we discussed so that they're focusing on the elements at the moment, ***but I don't think the company has got a game plan from our conversation****".*

Also, P4 has the same view as P13 when he mentioned Costain's Operational Excellence Model (OEM) and Smart Delivery Platform (SDP) as a plan to be BIM compliant.

However, P11, mentioned Costain's Leading Edge Strategy towards digitisation summarising the efforts from within Costain to digitise the build process

"That's where our leading edge strategy would come for, and certainly with the sector that you're now working in, you know. I know, [someone], [someone] tried to implement things from within the scheme and has met a lot of resistance because the state the scheme, Get on site and they just steamroller ahead with doing it the way they've always done it, so it kind of needs a separate division within a company to come up with the way forward to make the company become DBB compliance. And that's why I'm hoping you and [someone] they're doing"

P12 summarises Costain's side of moving towards digitising by mentioning

"Our plan I would say is significantly focused around the ***Operational Excellence Technology*** *pillar that says how many of our plans and processes are planned to be digitised, what proportion of them are*

*delivered in house, and that's the long and the short of it. And we judge the percentages on whatever our **OEM** score says. And obviously we want to be as digital as possible, and we want to do as many in-house as possible. So that's bang in line with **Leading Edge Strategy,** so that's along the short of it, as much as possible and as much in-house as possible"*

Overall, Costain is on the right path of promoting the use of digital within many of their construction projects. However, to be aligned with the government achievement, and given that Costain has the master knowledge of the construction process, Costain is required to implement more digital tools that integrate them with BIM and the 2025 Strategy requirements.

5.4 Problems Identified in the literature

This section summarises the issues in the current practices in the construction industry that was discussed in Chapter 3.

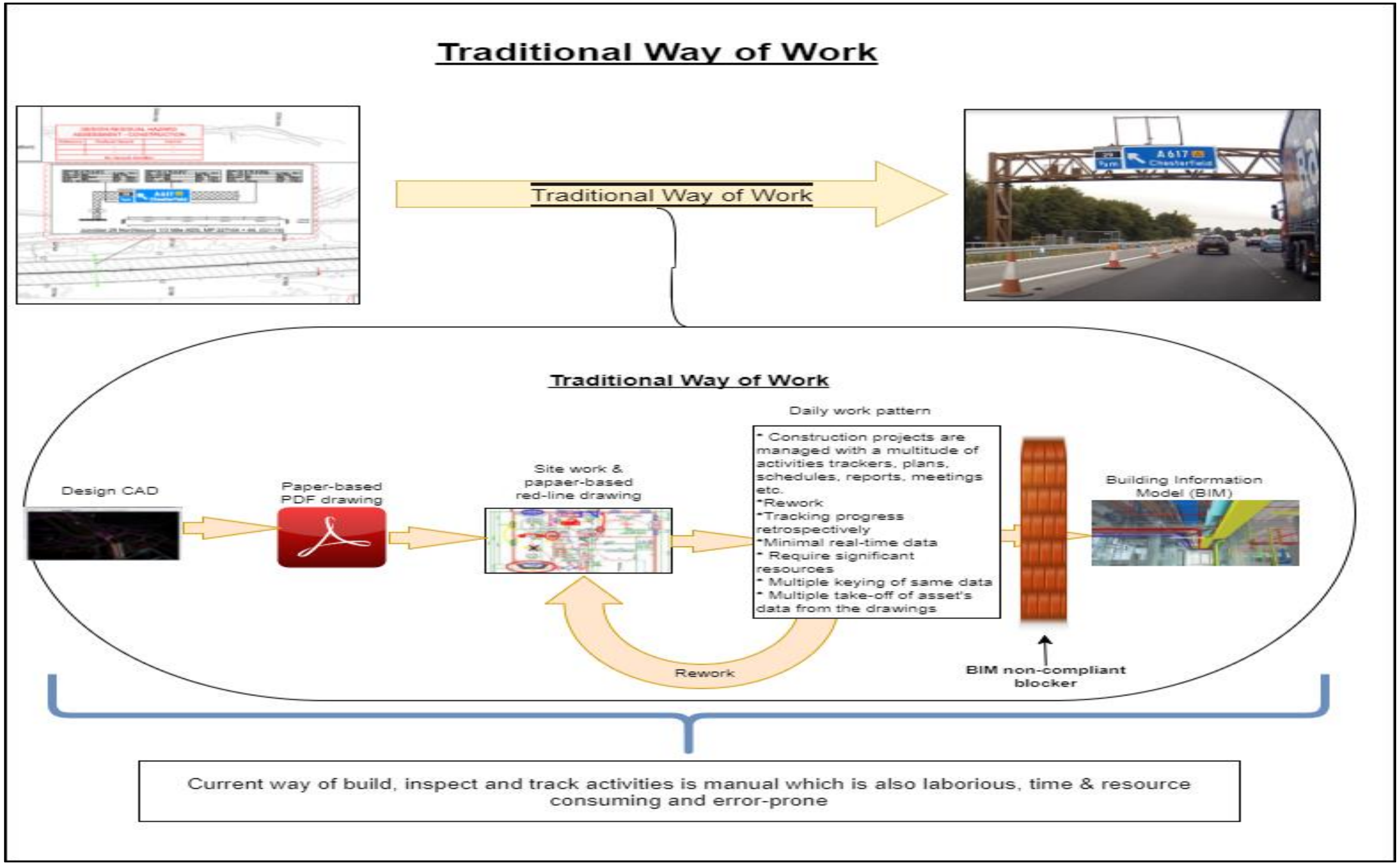


Figure 14: Traditional Way of Work

Figure 14 depicts the current or traditional operational approach. It illustrates the extensive steps involved in transforming a conceptual asset from a design drawing into a tangible physical entity on the road. This transformation includes the following practices (refer to section 3.2, 3.9, and 5.5 for more details):

- Construction projects are managed with a multitude of activities reports, plans, schedules, reports, meetings, etc.
- Rework
- Tracking progress retrospectively
- Minimal real-time data
- Require significant resources
- Multiple keying of the same data
- Multiple take-off of asset's data from design drawings
- All of the work inspection and track activities are manual, which is also laborious, time and resource consuming and error prone

Key issues with the traditional way of working are the amount of reworking that needs to be tackled, as well as the incapability of the traditional way of work to integrate to BIM as NH promotes.

The literature review in chapter 3 summarises academic papers that support the need for a practical Information Systems solution in the construction industry to overcome the traditional way of working and adopt a more digital delivery process. (Rezahoseini et al., 2019, Arditi & Gunaydin, 1997, Mitreva et al., 2013)

Moreover, section 3.9 discusses the relationship between enhancing the construction industry's quality and how the use of information systems help to achieve it.

Reworking Issue:

Rework is a significant concern within the construction industry, with Love et al. (2014) noting that over 10% of construction project budgets in Spain were spent on reworking. Similarly, Bew (2016) found that rework costs accounted for 20% of budgets in the UK as discussed in section 1.4.2. To address this issue, construction projects are increasingly adopting 3D Building Information Modelling (BIM) models, such as Hall (2023) suggests, allowing changes in design to be quickly shared and communicated across disciplines to prevent errors. This study aims to leverage Information Technology (IT) to digitise the construction process and reduce rework.

The government emphasises the need to transition towards more BIM-compliant and digital practices in construction, as outlined in the Construction Strategy 2025 policy (HM Government, 2013). This focus is evident in their program, which aims to develop digital tools for the built environment and operations management industries. A key tool in this regard is BIM, with BIM Level 2 (see section 2.4 for more information related to BIM levels) alone having saved £2.2 billion for the government by 2015 (Government, 2019).

5.5 Problems with asset management databases

Although some asset management database systems exist, they often have significant deficiencies, risking severe incidents. One such model is the National Bridge Inventory (NBI), an asset management system that records data on the status of structures in roads in the USA. For example, in 2007, the Mississippi River Bridge collapsed, because NBI did not appropriately represent the exact status of the bridge. If it had the right information in an integrated database system, the actual status of the bridge could have been identified early on and the incident could have been avoided. This shows the need for a robust representation of assets within databases and the need for managing them in a coherent information system.

Furthermore, the cost of creating new databases is enormous, as National Highways (NH) used to create a database management system whenever they added a new asset type in their roads. For example, for pavements NH has a system called HAPMS, for drainage they have a system called HADDMS and TPMS is the system for technology and communication assets (D. McHugh, Technology Integration manager-Costain, personal communication, Nov 14, 2016).

Each stakeholder's need for information drives the specification of their asset management systems, resulting in multiple instances gathering data and driving activities differently (D. McHugh, Technology Integration manager- Costain, personal communication, Nov 14, 2016).

Therefore, a model to track assets life cycle that covers all asset types with different definitions and relations is needed. This model shall create associations between assets, activities and documents.

The next section will discuss issues that appear in construction and operational phases of asset life followed by a brief discussion related to the current situation of handling information in construction projects.

5.5.1 Construction Phase

Construction projects require a huge amount of data, most of it without automatic correlation, so multiple information sets have to be prepared, assimilated and maintained. Most of these data and documents require regular updates and multiple reviews. Figure 15 shows an example of documents involved in the construction phase of a project.

Figure 15: Construction Phase Data

These documents require a bewildering number of activities, all needing preparation, coordinating and tracking. The data is collected after performing an activity on either an asset or location. The number of assets per project determines how much data would need to be collected, and how huge the number of activities would be. Assets come in different types, with examples of types being point, linear, area and volumetric assets, or definitions such as Geographic Information System (GIS) 2D, Building Information Modelling (BIM) 3D, and can have a hierarchical relationship with each other (i.e. a concrete *foundation* is a parent of a *column,* which is a parent of a *beam,* that is a parent of a *sign/signal*).

5.5.2 Operating phase

Asset lives are long, which creates a tendency for asset owners to defer action until an actual asset problem occurs. Therefore, gathering the best knowledge about an asset is the key factor for maintenance and future work. The problem that most existing systems and databases face, is that the data are often collected for different purposes such as commercial and programme requirements based on the information required by the asset owners. Moreover, many assets were installed before modern information systems, which may eliminate construction phase data as it could be hidden underground. These reasons and many more, raise the need to ask: what existing data can we make use of? And what data would we like to collect that would help the operation phase in doing a better job by providing enough information about assets? i.e. construction data, height, completion status, asset status, etc.

5.5.3 Information transfer between the phases

Traditionally, managing all that data, documents, activities and assets is conducted through a multitude of trackers, plans, schedules, reports, meetings and so on. Much of it works retrospectively, with minimal real time data and a higher chance of multiple keying of the same data. One drawback of such a traditional approach is that it requires a significant amount of resources.

The data collected throughout the asset lifespan is as follows (see figure 16):

- Design data feeds construction data.
- Construction data grows until the project approaches completion, then gets stripped away before handover
- At which point the data relevant to the Operation and Maintenance (O&M) phase is transferred
- Following the handover, O&M data grows over the asset life

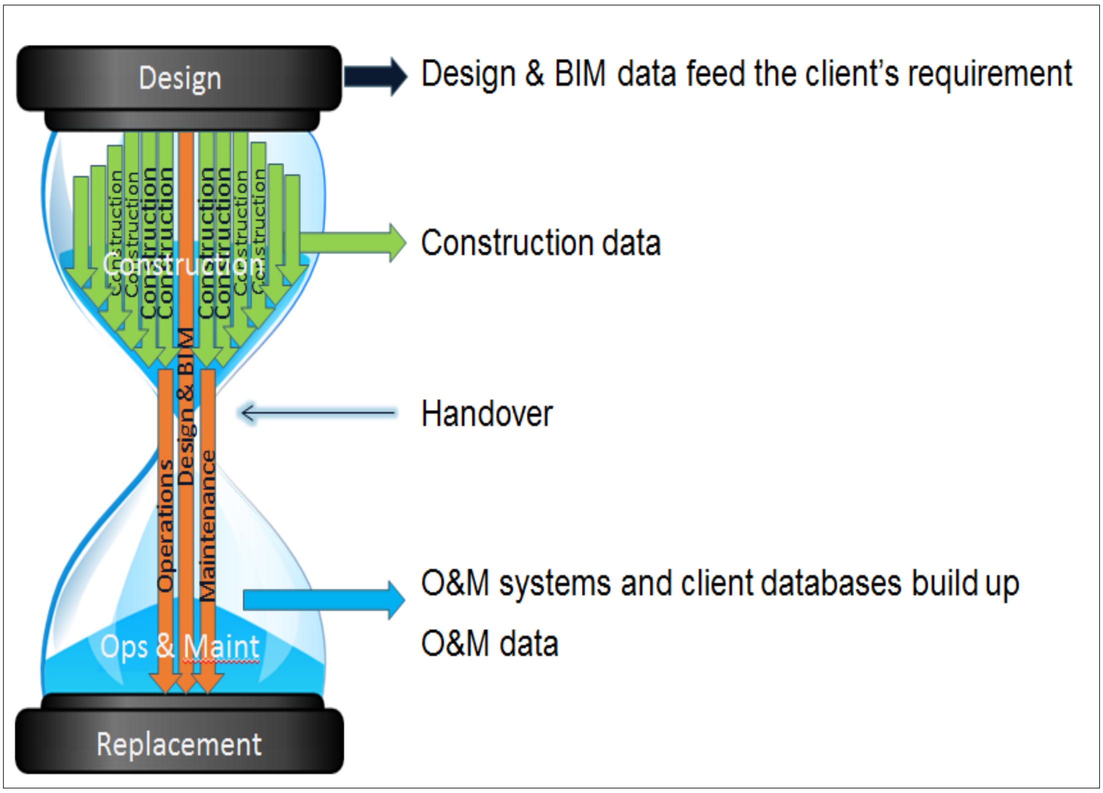


Figure 16: data collected through asset lifespan

The next section provides reference to the thoughts of those who work in the construction environment in the light of the problems identified previously and summarises themes from the interview participants.

5.6 Problems identified from the data collected

It was clear from the data collected in the interviews that the participants realised several major issues within the construction industry. The five main themes are digitising the build process, cost and time waste, societal issues, communication and collaboration, and information system design specification, these themes are discussed further in section 5.7.

5.6.1 A need to digitise the build process:

A need to digitise the construction process is a main theme that was mentioned by the 13 interviewees multiple times during the interviews. This shows how important it is to the participants. It stresses the need to replace the traditional way of performing any given construction job with one controlled and managed by a digital platform. The traditional way of working relies on work packages (i.e. when a job of placing ducting pipes in a construction site location is allocated to a subcontractor, it is then called a package, and the person from the contractor's side that manages or supervises this work with the subcontractor is called a package manager). Managers and reporters personally visit the working site all the times to report on the progress (McHugh, 2023). The disadvantages of performing the work in this way is the amount of resources needed to achieve it as well as the time and cost wasted in collecting the data.

The discussion in section 5.5 mentioned the amount of work and number of tasks required to complete a construction project, for that, the participants appreciated the digital role in supporting and managing these processes.

P12 mentioned that

"We do same things [same process of building assets] but with fancy digital tool kit, we need to change the process itself to achieve better quality"

which shows the need to change the current build process to achieve better quality. Also, P7 stressed the problem of managing and tracking the built data using the traditional way of working

"My team is actually doing quite a lot around management of the tracking and management of records in line with schedules. That's traditionally a big problem".

P2 provided a concrete example illustrating the problem with the current work method, highlighting that it does not accurately reflect the on-site reality due to the lack of real-time data updates and reporting. P2 expressed

"So if you imagine you got a three step crisis there of working out what's happened, by the time that's happened, you could be up to a week behind. Because it was, you know, at best you could do it. On a daily basis, and you'd probably be 24 hours on a date with what happened. In reality, people wouldn't do it [fixing defect/issue] every day, so you might

get it done twice a week at best, maybe once a week. In advance of the management meeting".

And he added, basically*, "we work flowed wrongly"* to point out the need for a change in the current workflow.

Furthermore, P12 raised questions about the number of processes planned for digitisation and emphasised the importance of documenting more workflows within quality management plans. P10 emphasised that there are currently no digital processes in the construction environment, not even for individual tasks, and highlighted the absence of connectivity between these processes and data when he mentioned

"so at the moment we haven't even got digital processes, never mind completely you know those individual processes then being able to talk to each other".

P11 indicates that the current practice of Post-It Wall or Plan Wall (see figure 11 in section 5.2.5.1) suffers from data loss as a result of falling notes

"but TiLoS [Time-Location System] in its raw form is still a massive wall of data that you stand in front of and you move sticky notes on"

While P2 stresses that

"the information can be lost and I always used to use that photograph of the post it notes on the wall with a post it note lying on the floor. That falling off the wall so that meant a job didn't get done. Someone didn't do whatever they had to do. It never got captured in the plan".

P11 and P3 discussed the need for digital and how it is important for the contractor to stay in the market in the future. P11 mentioned

"It's all well and good thinking about where the construction industry is going to be in five years time"

while P3 said

“I think getting an understanding of where you are now helps at least shape or your next steps are going to be into the future”

The need to digitise the construction build process comes with important features that need to be catered for. These features can be summarised as:

5.6.1.1 More Integration required

A few participants also stressed the importance of the integration part between the software applications that are in use in the construction industry. For example, P2 said

“the capability of the construction contractor is in the workflow management and the construction task. The capability of the software company is in building software systems built on processes. But very often the processes that are used in the construction environment are not compatible with a software system requirement or in developing a user specification, because all of it is based upon manually managing the information management”

While P2 stressed the need to have all the data stored and accessed in one place

“one place for all information, accessible by all including subcontractors”

as a solution to the current issue of the data not being all in one place, for example the data loss problem with the manual reporting on the Post-It Wall as discussed previously.

5.6.1.2 A need for better way of doing construction work

The need to have a better way of working was an important matter to the participants. P2 mentioned the need to breakdown the construction process to enable better process management as stated

“And there's a real issue between the constructor understanding how that complex information management process can be broken down into a set of Digitally recognizable elements to build the software package”.

P10 added that

"I tend to use the term projects don't end, they just don't complete. They just seem to die a slow lingering death. They, you know, they drag on for ages and one of the factors in that is collecting all of that asset handover information"

as a sign to have a better way of managing build data for a better handover process.

5.6.1.3 Lack of Standardisation

Six participants raised concerns about the absence of standardisation in work processes. P4 emphasised that restricting project flexibility, as seen in the automotive industry, can reduce risks

"if you limit the amount of opportunity projects get to choose what they want to build, you also eliminate risk, that's the whole beauty of the automotive industry".

In contrast, P2 expressed worry that clients are steering away from standardisation towards output specifications. Instead of specifying precise installation details, they now demand that components meet performance criteria, which raises concerns about potential negative impacts on quality. P2 pointed out that this shift to performance-based specifications may lead to increased rework, not only on-site but also in the design phase. Standardised designs, once used across multiple projects, are being replaced by specifications that require constant adaptation, introducing complexity and redundancy into the process.

5.6.1.4 A need to have more quality control

Quality management of the construction projects was mentioned 38 times from 12 participants. 5 of them stressed the need to have the culture of '*Do it once, Do it right first time*'. For example, P10 claims that

"So the contractual environment doesn't incentivise doing work right first time"

and that the construction projects

"actually incentivises rework"

because it needs

"lot of the time is set up".

Two participants highlighted the significance of quality, suggesting that it should be given the same level of importance as safety, as expressed by P1, who stated,

"make quality as important as safety"

while P8 raise the question of

"Let's have a dedicated session online or in person dedicated to asking. What could go wrong in your experience? And if we did, if we did more of that. Along the same lines as he's done in safety, we do it for quality. Then we might minimise rework".

P10 stated the need for an integrated Information system to enhance the quality management in construction projects as mentioned here

"So in terms of what I produce is somebody else's input, and if I don't produce that, my output to the required standard, it affects the next input. When we're not even at the stage of breaking down those silos at the moment, um, so you know, that is potentially a symptom of not having a completely integrated system. The quality function is seen to be sat separate from the time and cost function, which is another one of the principles of you know, taking into account all aspects of asset, not just time and cost, the cheapest option is not necessarily, it's a false economy. It will give you a poor quality output that you then have to go back and fix".

Participants emphasised the importance of treating quality with the same level of importance as safety and environmental concerns. This perspective likely arises from the fact that quality issues and defects can typically be addressed through rework, which impacts cost and time but that does not pose the same risk of fatalities as safety or environmental incidents. P4 summarised this in his words

"… for example SHE [Safety, Health and Environment] take precedence because of the consequence of fatality and another prosecution. That could come out of their noncompliance of that function. Quality is some whatever a bolt onto the end of a project, whereby if you find something's

not right, you end up repairing it, You know doing the cost of rework and things like that. So it's not really a strong consequence at the time for the people completing the work that can be changed if we adapt our quality management system into a digital function…"

5.6.1.5 Better project management

A call to alter the current construction project's management was argued by 3 out of the 13 interviewees, the main discussion was around enhancing the projects' quality through choosing a supply chain which promotes quality and for the projects to opt to choose a supply chain based on their quality and performance not cost as mentioned by P4 and P6.

P1 and P6 also stressed the need to have a management system that ensures all projects operate in the same way of quality and enforce accountability to guarantee the process is managed in a better way and to learn from mistakes.

5.6.2 Cost and Time Waste

The second main theme of problems that was identified by participants was cost and time waste. 12 out of the 13 participants addressed issues of cost and time waste in the construction industry, and it was mentioned 34 times in the 13 interviews. The main sub-themes related to cost and time are: reworking, cost of funding, cost considerations, and the cost of digitising.

5.6.2.1 Reworking

The data from the interviewees revealed several reasons behind reworking, such as the pressure on the programme and keeping cost within the estimation, insufficient time to do the task, wrong design, pushing labour to complete their work quickly or the clashes between different supply chain parties (subcontractors) working in the same area on different tasks.

These reasons shape the working environment to be in firefighting mode and working reactively to solve reworking issues as mentioned by P4. To minimise the reworking issues, P9 suggested giving the subcontractor's teams in site (called gangs) more time to achieve a lower productivity target than what they have currently.

P7 stressed the need for better planning as he mentioned

> *"My team is actually doing quite a lot around management of the tracking and management of records in line with schedules. That's traditionally a big problem, it causes overrun because you need lots of verification documentation to get licence to operate, or to Commission certain elements of plants or to operate in their nuclear facility, and they often overrun because they're not tracked effectively and managed effectively."*

An example of reworking was given by P11 in the shape of a project's issue of reworking – the Technology team is digging trenches to install ducting that was dug and covered by a drainage subcontractor when they were doing civil work. This case and others can be tackled by having a better quality management system and monitoring of the progress through live data and lessons learnt practice as mentioned by 3 of the interviewees.

5.6.2.2 Funding Issues (training, fixing snags and implementing digital)

As highlighted by three participants, cost concerns within the construction industry have extended to subcontractors and employees. This has led to a cautious approach regarding training packages, whether they originate from contractors or the client (in this instance, the government). Specifically, when training needs to involve the supply chain, participants mentioned that only mandatory training packages are typically offered to minimise training expense.

It was also argued by one participant that the cost of fixing snags or defects in construction may depend on the higher cost of doing the fixing. Finally, cost of distributing Information Technology (IT) Tools and devices need to be accounted for in construction projects to enable digitisation of work and this should not be a blocker as mentioned by P4.

P5 stresses the issue of the high cost to prevent from adopting an Information Systems (IS) that would help digitising construction projects.

5.6.2.3 Cost driven issues

Five out of the 13 participants delved into the underlying causes of problems in the construction industry, primarily driven by cost considerations. Specifically, P7 and P8 contended that a significant issue stems from bids being centred on price rather than quality. On the other hand, P2 and P10 criticised cost-saving practices that involve hiring unskilled workers overseen by a manager, arguing that this might seem more economical in the short term but can lead to increased expenses in the long run. Additionally, they disapproved of hiring inexpensive supply chains that often result in defects, necessitating additional payments for rectification. This ultimately outweighs the initial savings and demonstrates the importance of investing in a higher quality supply chain, despite the higher cost.

5.6.3 Societal Issues:

Societal issues were a repetitive theme with the 13 participants, and it was mentioned 163 times. Societal issues are any issues to do with the construction industry nature, such as work culture, political aspects and employee behaviour.

5.6.3.1 Work Cultural Issue

12 out of 13 participants condemned some of the practices that seem to create a negative work culture, this is the result of working reactively by only checking issues after the event happened as P12 stated, or the actual old quality mindset that needs to change (P7). Below are some points related to the wrong practices that construction projects currently have:

- ❖ Lack in capturing lessons/sharing the knowledge

4 participants mentioned the need to capture mistakes and issues in the form of lessons and share those lessons with others to avoid them and learn from them. P13 mentioned that he has conducted research to capture the lesson learnt aspect and he commented

"I interviewed a similar number of people, I think 10 or 12 people and interviewed of different parts of the organisation in different departments, and I bring it up and then I came to the conclusion which as you know, concludes our illusions, but concluded, that's we don't learn, just don't".

He also went to the extreme by arguing that human behaviour of being proud to accept a change prevents them from learning and changing their current mistakes

"Human native behaviours coming in, because if I'm the civil engineer, I want to say I cracked a hard nut. I don't want to say or somebody else did for me that's not this, it goes against my pride".

P12, however, stressed that the issue of learning lessons should be shared with project management to collect data and provide insight into repeatable issues

"We don't gather our data in a way that we're going to learn lessons from and/or we don't seek insight to learn a lesson"

while the actual current situation in this matter is

"Whereas at the moment we tend to only Learn a lesson. If we kind of went out to look for it".

He also provides an example of the way industry deals with close calls, if it has been fixed in the same day, no need to report it. Which ignores the lessons learnt a bit.

"If a defect is identified and can be corrected within the same shift, you do not have to raise a Non-conformance report and I'm arguing the case. Not interested in how quickly it can be repaired. If it happens, it happens … so the lack of really fast, intuitive, easy to operate, defect and snag reporting that would generate a near miss close call, safety observation type equivalent in the quality arena is a blocker to us learning lessons".

- ❖ Day-to-day work culture:

The actual day-to-day work process does add to the cultural issue as discussed by P12; this comes in the shape of not giving attention to *"the minutiae detailed culture is when you write a method statement or risk assessment. However, it says sort on site, or the foreman will do that. So we don't actually write our Management plans accurate enough, which means we don't actually monitor and measure the minutiae"*

the other one is

"too many of our leaders in the construction industry and in Costain are heroic leaders. They are spending all their time intervening, dealing with interventions. And not enough time leading to being successful tomorrow and they become drunk on the endorphins associated with that intervention".

P6 argues that

"Because the nature of construction is that. What you're doing isn't necessarily standard, is it?".

P7 indicates that

"much of the information that flows around the nuclear industry [construction phase of nuclear industry] is on paper"

And P11 agrees with that argument by stating

"I don't think we have done anything yet to overcome the traditional practices. I think we're still. Using the traditional practices, we've refined them. We're getting better at them, but I don't think we're doing anything new, and I don't think it's until there is this big step change that we talked about earlier that will force us to do something new".

As much as there is a responsibility on individuals to push out of the box to adopt new changes to enhance the day-to-day activities, there is even more responsibility on the project management's team to prepare a culture which cares about quality, lessons learnt, skilling staff, and to win over issues as stated by P4, P11 and P12. The current status is summarised by P13 as

"so we just managed to fight, not to lose, but we definitely not fighting to win."

❖ Resistance to digitalisation:

6 out of 13 participants discussed the reasons behind the lack of willingness to adopt digital to enhance the current construction culture to adopt technology; these reasons came in the shape of the client (in this case National Highways NH) not being in a good digital place as they still use old Information Technology tools. Also, the technology used by the client resulted in losing some of the documentation metadata when transforming them from one system to another, for example from Business Collaborator to SharePoint (P13). While P12 stressed the point of the age gap between the employees of old experienced non-digital minded engineers and the fresh graduate digital minded ones. This gap highlights the variation in skill levels when it comes to adopting and utilising digital tools in construction work

5.6.3.2 Political Issue

Political issues are problems related to the need to have policies (P7) created and pushed from the top of the organisation to the bottom to change current practices, adopt more quality control in current practices or adopt a more digital way of working. It was mentioned by 12 participants out of 13.

11 participants stressed the need of the client to provide financial support to train the supply chain to adopt digital. P12 argues that construction projects require a digital lead in addition to the current 3 heading a project (Contract Lead, Project Manager and Commercial Lead) with responsibility to champion the adoption of technology. P4 also supports this by going even further to argue the need to have a dedicated director to promote quality and he believes it is as important as safety in the organisation. P1 and P7 expressed the need to have a quality minded senior at the top level to push and enforce the quality process.

The mentality of performing the work right first time and working proactively was mentioned by P11 and P12. P4 and P11 argue that clients are required to lead on enforcing more quality at work instead of concentrating on completing the programme on time. P6 and P13 stressed the need to have seniors push to provide training and upskilling staff to use more technology.

P12 said

"and then occasionally you end up with on a bigger project a Chief Engineer who suddenly takes them all under his wing, and the Chief Engineer is undoubtedly a bookworm librarian, introverted, subservient top character, and he just becomes a patsy to the project manager, and the contract leader when they shout ball"

in a sign to the lead of the team who likes to have the work done in his own traditional way.

P5 argues the need to have a separate pot to sponsor innovation and avoid relying on projects to pay for it. Moreover, the need to change supply chain contracts to implement digital requirements by using digital tools and avoid paper-based handover was mentioned by P4. P2 explains the communication breakdown and the translation of the seniors' talks and policies to be lead in digital, this was mentioned here

"it actually disappears very quickly in the senior levels of management. And from senior management downwards. The application of digital tools is very sporadic and little understood, and so there is going back to this thing of translating. The day-to-day operations into a digital environment that hasn't been done".

P5 and P8 both noted the absence of standardisation and a shared understanding of collaboration in the process of delivering construction projects. This challenge arises due to the nature of the work. For instance, in joint venture projects managed by two or more contractors, each partner tends to promote their own working methods, which may not align with a high level of digital adoption.

5.6.3.3 Behavioural Issue

This theme discussed the attitude and behaviour of the workforce in resisting new ways of working. It was addressed by 12 participants out of 13 and mentioned 50 times in the 13 interviews.

7 participants mentioned the need to educate the workforce with the benefit of adopting digital to overcome the resistance of changing their way of working, for example one of them, (P4), stated

"the most pertinent barrier I can give you is humans as a whole. You know with fundamentally flawed in the sense that we can adapt to rapid change, especially in construction. You know there is a very strong behavioural issue within construction that prevents us from moving more rapidly in terms of innovation and development".

P12 stressed the need to educate the workforce to do a better job rather than learning new software applications when they move from one project to another.
P3 stressed the fact that the construction industry is slow in adopting digital. P8 agrees with that too

"we're going to incur losses because of poor change management".

Furthermore, P6 expressed

"I think that the most impactful thing we have done is around behaviours and getting people to understand how they impact on quality"

and therefore, the organisation needs to invest in behavioural management programmes for this sake. P12 expressed how the workforce only remembers bad things to do with the digital tool they used in the previous project and therefore want to try a new one in the new project and the cycle repeats itself in every new project. As a result, the workforce tends to fall back to their comfort zone of traditional ways of delivering projects using non-digital tools.

5.6.4 Communication and Collaboration Issues:

This theme discusses team communication and collaboration in construction projects, with respect to current practices and how it can be tackled. The theme of teams' communication and collaboration was mentioned by all 13 participants in 60 different places in the interviews.

7 of the participants talked about issues where construction projects need to improve the communication to and from different teams. Communication about changes and showing the benefit of adopting new ways of working digitally was also discussed by

P1, P3, P5, P10, P11 and P12. They all agree in giving the workforce the required training and asking them to be partners in providing ideas that could be implemented digitally so they may accept the adoption of a new digital way of delivering a construction project.

A recurring sub-theme among all participants was the importance of providing training and education to both team members and the supply chain regarding the advantages derived from the adoption of digital technologies in project delivery. Moreover, communicating the business case of adopting new ways of working digitally to the seniors as well as workforce individuals was mentioned by P6.

5.6.4.1 Reporting and Monitoring Need:

9 out of 13 participants talked about the need to have real-time reporting to enhance the decision making process and access information when needed. P12 argues for the need to have different reporting views per job level in projects. For example, the project manager does not need a real-time report while the on-site team does so as to watch and plan traffic management.

The lack of real-time reporting and monitoring in current practices may damage the organisational reputation as mentioned by P7 and P12, where the latter argues that having too many snags and defects and not being able to fix them before opening the project is costly and may have an impact on reputation.

5.6.5 Information System Design Specification Issue

This theme discussed the requirement to have a robust design for any digital solution that would help in the production construction process. It was mentioned by all 13 participants and appeared in 101 places within the interviews. To overcome the current in use, poorly-specified applications (P1 and P2), most of the participants provide a wish list for functionality to be designed in any new system such as GPS, user friendly, accessibility, connectivity, standardisation, scalability, performance, security, etc.

While P1, P8 and P13 expressed the need to have a proper standardisation of the user interface and data gathered with accessibility views depending on user profile, P5 mentioned the importance of having network connectivity. P2 and P3 also stressed the need for a mature framework with proper design, principles and guidance.

P12 mentioned the importance of having data insight in any supported digital tool. Furthermore, designing a future proof system with an understanding of its input and output and that they may change on either side, plus it could be scaled and adopted any future workload are important matters to P3 and P12.

5.6.5.1 Interoperability Issue

10 out of 13 participants stressed the need to have systems interoperability to enable exchanging data between different systems easily.

P2, P5, P7, P8, and P11 specifically highlighted the importance of designing an information system capable of integrating and digitally connecting with other systems, such as Primavera (program management tool) and BIM (3D design project), to support the current applications in use.

5.7 Interview Data for Solutions to the Issues Identified by Participants

The main themes derived from the interview data, highlight the crucial prerequisites within the construction industry that currently hinder a transition towards embracing a digital approach for project delivery are:

- More digitisation is required
- Better approach to design Information Technology (IT) systems is required
- Tackling current cultural issues
- Tackling behavioural issues
- Tackling political issues
- Better communication and collaboration are required
- Aim to save more in time and cost of construction projects
- Adopt better means in reporting and monitoring of the progress

The interviewees shared their own ideas on how to address the issues in the construction industry, which will be discussed next. Furthermore, the solutions proposed in the following section are linked to the issues raised in section 5.6, which discussed the current drawbacks affecting the construction industry.

5.7.1 Digitisation

The cost of creating new databases is enormous as National Highways (NH) used to create a database management system whenever they added a new asset type in their roads (D. McHugh, Technology Integration manager- Costain, personal communication, Nov 14, 2016).

Each stakeholder's need for information drives the specification of their asset management systems, resulting in multiple instances gathering data and driving activities differently (D. McHugh, Technology Integration manager- Costain, personal communication, Nov 14, 2016). He also added, construction projects necessitate an extensive volume of data, much of which lacks automatic correlation. As a result, numerous sets of information need to be prepared, integrated, and maintained. Regular updates and multiple reviews are imperative for most of these data and documents. The generation of these documents entails a multitude of activities, all of which require preparation, coordination, and tracking. Moreover, data is gathered following the execution of an activity on either an asset or a location. The volume of collected data and the extent of activity logs are determined by the quantity of assets within a project. These assets can be of various types, including point, linear, area, and volumetric assets. They are also defined in forms such as Geographic Information System (GIS) 2D and Building Information Modelling (BIM) 3D. Additionally, assets can exhibit hierarchical relationships, where a concrete foundation might serve as a parent to a column, which in turn acts as a parent to a beam, further linked to a sign/signal.

The main codes generated from the interview data in terms of the need for digitisation in the construction industry are:

- Construction projects need to adopt a more efficient way of working
- Construction Information systems need to consider more integration with other systems
- Construction Industry issues of lack of standardisation
- Construction Industry issues of better managing construction projects and adopting decision making process depends on real-time data
- Construction Industry need to apply more management of the quality delivered

Numerous interviewees emphasised the importance of transitioning to digital processes in the construction industry, citing various reasons. One specific interviewee, P3, highlighted the significance of how adopting a digital way of working would ***improve communication*** with stakeholders to promptly address issues. This involves raising awareness about obstacles within the process to ensure everyone remains informed and proactive in resolving challenges. Furthermore, P1 supports this viewpoint, as stated here:

> *"Better communication between the construction team, designers and senior management is needed around quality. More emphasis needs to be put on quality and not just on the quality of the products on site but the data quality, admin quality, etc. The quality of everything we do"*

The main focus of P3's discussion was on the motive for adopting digital technology, specifically to ***improve the handover process*** by digitising quality assurance documents. P3 emphasised the importance of identifying and addressing any obstacles in the process, thereby enhancing awareness among team members. Additionally, P3 highlighted the goal of ***involving stakeholders*** more effectively, with a particular emphasis on ***enhancing customer and client engagement***. Another key point made was the significance of being Building Information Modelling ***(BIM) compliant*** to satisfy clients and to maintain competitiveness in the market. Overall, P3 emphasised the necessity of digital enablement and communication in ***driving process improvement*** and staying relevant in the industry.

P4, P6 and P11 all share the importance of adopting the use of digital platforms in the construction industry as it provides ***better insight*** into the state of the asset at any point of time or when it is needed, i.e. when something happened and there is a need to intervene for a fix.

P6 stressed the need for adopting more digital in the build process to enable ***better planning*** for construction work:

“having information about the assets that's digital, allows you to be able to plan your construction better, because again, you have more information on the product”

On the other hand, P1 presented the rationale behind adopting digital processes in construction, centred around digitising the construction workflow. This approach is noted to ***enhance efficiency*** by facilitating better planning, operation, and maintenance of infrastructure. Moreover, it is pointed out that digitisation ***reduces risks*** by eliminating errors and waste through the integration of intricate processes. This shift also promotes a ***better grasp of the work and aids in cultural transformation***, as documents tailored to different levels of experience with Building Information Modelling (BIM) simplify this transition.

P1 also highlighted the benefits of conducting more ***comprehensive site surveys prior to the design stage*** and emphasised the value of ***managing mistakes and sharing lessons learned***, thereby holding individuals accountable for Total Quality Management (TQM). The idea of a ***unified source of truth*** was put forth, advocating for a streamlined process that integrates head office procedures and data into the digital solution for site-level documentation. This would ensure information is inputted only once and updated as necessary, contributing to the normalisation of TQM practices.

The importance of ***implementing a standardised approach*** to delivering construction projects through digital platforms was a key emphasis among multiple participants. P4 highlighted the necessity, stating,

"This is what we have to use as a business standardised across the business. There's too much variability and we end up reinventing the wheel on virtually every occasion […] I think there should be a standardised way of working"

Supporting this notion, P3 underscored the value of a standardised method not only for overseeing construction project delivery but also for comprehensively evaluating them. This includes considerations beyond financial aspects, encompassing time-related advantages and meeting agreed-upon deliverables. P3 also stressed the importance of providing stakeholders with access to information through a consistent format.

P1 echoed these sentiments, expressing the ***need for a standardised approach to working***. This includes both the production and tracking of progress, leading to increased efficiency and success. P1 mentioned the importance of recording work plan delays and their causes to gather data for better problem mitigation in the future. In summary, the participants highlighted the benefits of uniformity in project delivery and management processes facilitated by digital tools.

All 13 participants unanimously regarded the digitisation of the construction process as advantageous for numerous aspects of construction projects. These benefits included reductions in delivery time, improved quality control, enhanced project management, proactive approaches, and an elevated reputation. These advantages were collectively mentioned 168 times across the thirteen interviews.

The main outputs that were generated form the interview data in terms of the need for saving cost and time in construction projects were:

- Being Digital Built Britain (DBB) compliant resulted in saving cost through adopting digital systems
- Digitising construction process brings benefits of saving cost and time of the construction projects
- Participants' positive views on the Smart Delivery Platform (SDP) - which is an internal platform to connect data together in dashboards to generate reports from real-time data coming from CATS and other data sources - and the Construction Asset Tracking System (CATS) in terms of saving cost and time

5.7.2 Cost and Time Saving

One of the primary incentives for digitising the construction process is the aim to reduce costs and save time. This motivation was consistently highlighted by all interviewees. P2 specifically acknowledged the value of digital platforms in construction as a means to achieve cost and time savings, emphasising that:

“If you could get the behaviours right, if you could change the way we deliver a project to maximise the use of digital efficiencies, you would save 20% of time and cost on your project”.

P10 further underscores the importance of reducing current instances of wasted time and unnecessary costs in construction by stating:

“the amount of waste that you would save through an integrated data approach has got to be absolutely huge […] you wouldn't need as many people in terms of time and in terms of, you know you could go even right back to, you know licensing costs of software required to do these things […] and the systems and the people that you do have because they can focus on doing productive things like looking at the next scheme rather than wasting time trying to closeout an existing scheme”

P2 elaborates on the necessity of not merely replicating the construction process digitally, but rather implementing a transformative approach like platforms such as CATS. P2 highlights the importance of recognizing the system's functionalities as game-changing additions to construction projects, rather than just replacing paper-based forms. P2's explanation emphasises that current practices often involve a simple digitisation of existing paper forms. For instance, if someone is inspecting the work of another individual, the process might involve shifting from writing on paper to using a tablet. However, P2 suggests that such changes are not truly indicative of the substantial 50% savings potential that a game-changing approach could bring.

P7 highlighted the potential for cost savings within construction projects by re-evaluating current processes, suggesting that identifying unnecessary expenses can yield substantial savings. This is particularly evident when considering isolated processes like document management, where careful analysis of the entire cycle could uncover avoidable costs.

5.7.3 Tackling Societal Issues

This section explores what interviewees think regarding the issues related to societal aspects, and discusses how a digital system could contribute to the resolution of some of these matters.

Tackling cultural issues

P12 stated the need to have a quick and easy to use reporting mechanism such as a digitally operated one which would enable the learning of lessons from the mistakes happening in construction projects

> *"so the lack of really fast, intuitive, easy to operate, defect and snag reporting that would generate a near miss close call, safety observation type equivalent in the quality arena is a blocker to us learning lessons".*

P3 asserts the need to recognise the importance to change the current built process and to adopt a more digital one.

> *"I suppose the recognition that there is a change required is certainly one of the big steps. Because sometimes admitting that we need to do something is kind of the first step".*

P6 also explained the need to change the current practices into a more digital one by stating how proactive work enhances quality instead of reactively responding to defects and issues

> *"improves the culture so that everyone is focusing on the key. Things to do with quality to get things right first time … but if you look at the quality, the quality is an excellent matrix. That's what we tried to pull out within the quality matrix to show the proactive things as well as the reactive things that we need to focus on to get right first time and to deliver quality".*

P7 requests to adopt more digitally practice of doing construction work, he expresses how it would save time and change current way of working as mentioned here

> *"If we also have a better process which the one we have deployed recently where that information would come directly from the supply chain into the system directly rather than into a document controller and then the system. That would be one leg that we could cut out, if that digital system enabled people to work on that document simultaneously. You will*

compress all of those timelines considerably, and these things can sometimes take months to get through the system".

Tackling political issues

In Costain, the integration of digital technology is closely linked to the Operational Excellence Matrix (OEM) within the broader Leading Edge Strategy. This matrix serves as a benchmark against which construction projects' digital implementation is evaluated. P12 elaborated that the OEM score dictates the percentage of digital integration a project achieves. The company aims for high digital integration and actions to handle processes in-house, aligning with the Leading Edge Strategy. The OEM evaluation considers factors such as the number of processes digitised and the presence of detailed workflows and standard operating procedures in quality management plans.

P13 described the Operational Excellence Model as a critical factor contributing to the success of construction projects. This model addresses infrastructure and encompasses aspects like skills, behaviours, and other elements that are vital for success.

P8 shared insights on managing political challenges in construction projects by advocating for a common document management system. He suggested that the absence of such a system complicates collaboration with external partners who follow their own processes, implying that adopting a shared system could streamline communication and mitigate political obstacles.

Tackling behavioural issues

Educating the workforce about the usage and advantages of digital tools emerged as a key strategy for supporting their transition from traditional practices. This approach was consistently emphasised by all the interview participants.

Addressing resistance to change in behaviour, P6 discussed the implementation of behaviour management programs by contractors. These programs aim to counter reluctance by offering the necessary education and training, effectively demonstrating the value that digital adoption can bring to projects. P6's remarks underscore the significance of improving a cultural shift within the quality management sphere, with behaviour management programs fostering a change in mindset regarding performance and quality impact. This initiative is aimed at enlightening the workforce about the consequences of their actions on project quality.

> *"We've done a lot of work on sort of culture. Within quality I mean the behaviour management program that we operate that indirectly would have impacted on getting people to think differently about performance and about quality … I think that the most impactful thing we have done is around behaviours and getting people to understand how they impact on quality".*

5.7.4 Communication and Collaboration

P4 expresses his views on how reporting and data insight may save cost and aid planning

> *"I totally agree that information systems can definitely decrease cost based on the data and finding trends to prevent or to aid planning".*

P3 stated that Costain is good in advertising and pushing out how digital it is at the moment, and that it would like to be leading in this aspect

> *"The effective communication side of it, so there's certainly some steps which I think Costain is taking. And Costain, they are active in the digital twin build. You know they are pushing out a lot of information and advertising the work they're doing in that space".*

P5 mentioned the importance of sharing data between all stakeholders, and this is going to be a reality with BIM Level 3:

> *"L3 will mean the availability of digital models for all schemes".*

In a sign of collaborating on digital work with operators, P6 stressed the importance to include them in the digital journey and make them part of it so they accept it when it is ready as stated here

> *"train your operators so they can understand and not just understand it was [so] they can have a better input into it, because if you're involving*

them at the early stages where it's been digitised and they can visualise what the plant is and how the plants operate, they obviously can have some input into that. They know how best they would work to operate it. So, they would be able to input that to make it more efficient in terms of maintenance and even construction".

Communicating the experience of Highways Sector digital achievement to another sector such as Water or Rail might open doors into how they can follow Highways in being digital too as stated by P8

"but I suppose my point is this. It could. It could kind of cross sectors, couldn't it? The array rail sector experiences in digital data may well benefit highways environment or a water environment. If you were saying installing a pipeline like we are at the Strategic Pipeline Alliance. I guess at the moment that the strategic pipeline Alliance doesn't have access to digital data from other environments apart from maybe GIS data. So those are my, those are my thoughts"

5.7.5 Design Specification

P2 stated that CATS is compatible with different devices and platforms. It also has a couple of apps in Google Play for Android users,

"someone really needs to decide what platforms are we using, what devices are we using, you know, and I think we answered most of that week with CATS, we based it on a bring your own device. Philosophy, we made the decision that all of the front end. Um, operational Data capture could be done via mobile phone wherever possible, so we don't have to issue tablets to construction workers, so they would use their handheld device they already got with them in their pocket. So those sorts of decisions are fundamental".

P1 expressed the importance of adopting a single source of truth as a way of storing and using data in a nudge to how information systems might add any benefit to the construction process.

"standardising data and facilitating the single source of truth by housing the data in an enterprise data warehouse. Utilising the ETL process to integrate different systems data into one place".

Furthermore, P4 stressed

"the fact that paper can get lost"

is an indication of how easy paper-based reports might be lost in the process. However, benefits brought by data insight were discussed by the same participant to encourage a proactive way of working

"if you've got a suite of information, you can find correlations, trends and patterns to prevent those kinds of things from happening again".

Supporting the decision making process was one of the aspects that a single source of truth with data insight could offer to construction projects as mentioned by P6

"that certainly in terms of a single source of truth or information, is there you can interrogate information. You can see where things are, then decide what actions need to be taken".

5.8 Interviewees thoughts on what benefits digitalisation may offer

Expressing surprise at the current state of digital construction projects, P11 remarked on the persistence of digitising paperwork even while working on BIM initiatives. This duplication of effort was deemed counterproductive.

Additionally, P11 highlighted the potential of digital tools to empower asset owners with deeper insights into their network of assets. In the case of National Highways, standardisation through digital means was identified as a crucial step towards enhancing awareness and understanding of network assets.

P12 stressed the need to digitise as many processes as possible to meet the Operational Excellence Model (OEM) created by Costain

"how many of our plans and processes are planned to be digitised? What proportion of them are delivered in house? and that's the long and the

short of it. And we judge the percentages on whatever our OEM score says. And obviously we want to be as digital as possible, and we want to do as many in-house as possible. So that's bang in line with Leading Edge Strategy, so that's the long and the short of it, as much as possible and as much in-house as possible"

P10 touched upon the data driven way of working as a positive benefit from adopting digital as stated

"… connecting all of those activities together to make it easier to spot when we aren't being productive and how it impacts everything that happens after it, which we don't, you know, understanding that at the moment is very subjective and experience based. It's not data driven …"

Below are the main points that the participants stressed in order to benefit from any digital adoption in construction projects. These would benefit construction projects, contractors and clients.

Benefits of Integration

P10 illustrates the significance of integrated systems in enhancing project management and proactive work methods. Using the example of a delayed discovery of drainage defects, P10 highlights the benefits of early detection through integrated systems. This approach helps prevent latent defects, saving time, money, and ensuring safety. P10 emphasises that a BIM Level 3 approach, coupled with data-driven quality assessment, is powerful in ensuring quality throughout the project lifecycle. The current disjointed workflow lacks smooth transitions between activity outputs and inputs due to barriers, making integration crucial for effective quality assurance and project success.

Benefits of Better way of working

P13, while discussing the integration of digital tools and technology in infrastructure and construction, emphasises the benefits it offers to clients. By digitising with intent and maintaining separation of augmented reality, assets can be more safely managed, data can be recorded and collected efficiently. This progression contributes to creating richer, model-attached data that leads to improved maintenance optimization and interventions.

P11 expresses how adopting digital platforms in project delivery would significantly impact his role, as handover documentation would be streamlined as stated:

> *"so from my perspective, yes that would change my life significantly because the handover documentation would be done for me …"*

P2 underscores the significance of digitising the construction process in addressing the information processing challenges faced in current project delivery. P2 also highlights that proper information management and digitalization play a critical role in construction, with the actual construction becoming more efficient when supported by accurate information.

P6 explains that digitalization allows better planning in construction by providing more information about assets. This leads to improved visualisation, early visibility, and the potential for shorter project timelines.

P10 emphasises that digitising the construction process eliminates barriers between activities and enhances quality through proactive work. By measuring inputs and outputs in an integrated system, failures can be quickly identified and rectified, allowing for proactive quality management and minimising reactive rework.

Benefits of Standardisation

Developing a digitally standard way of controlling how the delivery of construction projects is made is something useful and financially rewarding as P3 argued

> *"A standardised method in place is useful for not only just controlling how delivery of construction projects is made. But also measuring them in terms of not just financial but from time benefits and the agreed deliveries is always useful […] it is beneficial for a company specifically in the bid process to have a standard in place and on a badge they get advertised because effectively that could be the difference between winning the bid and losing it …"*

P11 also agreed on the previous argument when stating *"contractors will be able to standardise their offering to the client. They know that the client needs a standard BIM model completed as part of handover, and as it's a standard model, all the contractors know what they need to do, so it almost makes a level playing field for the contractors."*

when he attempts to draw a scenario to support project's delivery through a standard digital platform. He also touched base on the supply chain by being digital compliant increasing their chance of winning more work

"it also helps eliminate the cowboy contractor that is just there to make a quick buck and do as little as possible because as soon as he's got to provide BIM models or CAD drawings then suddenly they can't get through the procurement process"

Benefits of Quality control

As P13 advocates for innovation in the quality management of construction projects, P3 recommends implementing a digital system within these projects to streamline the process. This adoption of digital systems for integrated data collection is deemed valuable, contributing to strategic quality management considerations. P3's perspective aligns with the idea that embracing digital tools can enhance overall project delivery quality.

While discussing the insufficient enforcement of quality standards in construction projects, P12 highlights the importance of tying senior project leaders' bonuses to activities that facilitate high quality. P12 asserts that the current approach lacks reinforcement for quality-enabling decisions and long-term considerations. P12 views Total Quality Management (TQM) and robust governance in TQM as an avenue to strengthen this aspect. P12 suggests that, especially in the context of extended projects like High Speed 2, it would be prudent for directors to primarily receive incentives and bonuses based on their contributions to enabling activities toward achieving better quality. This approach aligns with the nature of such projects, where results may take years to materialise and need to stand the test of time for even longer periods.

P10 in a note on the benefits in applying Total Quality Management, stated *"but also when an error does happen, you immediately know about it. And you put something in place, you know you, you, solve it there and then so that it doesn't have a knock on effect on the processes and the people involved in activities following …"*

P6 embraces digital use in the construction industry as it enables working right first time

"I suppose it makes it easier to think in terms of quality and it makes it easier for us to be quality compliance right first time if it more efficient"

P4 argues digitising construction enables better quality control of assets as stated

"You'd know that the condition of that asset you'd be able to explain when the next inspection is needed … You would also be able to identify in what priority that the any defects can be corrected based on their priority and severity"

Benefits of Better way of managing construction projects

Describing the benefits that digital adoption may bring to construction projects, P1 express the importance of reducing waste, cutting out the risk of error and adding efficiency to the delivery process

"it helps to cut out the risk of errors and reduces waste by integrating complex processes … it helps build, plan, operate and maintain the infrastructure more efficiently …"

While P13 supported the argument of digital deployment managing risk

"optimising the construction projects in a way that helps manage the risk […] you can build a digital first therefore minimise clashes, Or identify risks and therefore put in place solutions …".

P10 identified the fact that digital enhances the error proofing in construction projects

"… digital processes, you know, will very much allow or provide that error proofing environment because you can only input the information that the digital processes allow you to input in a certain way …"

Benefits of saving cost and time

P4 explains how important it is to have the mentality of doing the job right first time in construction as it would save quite an amount of money

> *"You're going to save X amount of millions of pounds by doing it right the first time and more people need to start embracing the right first time culture in every aspect, not just quality and safety. … ".*

Moreover, he asserts that digitising construction delivery would save time and cost of doing administration work as the data is collected and stored digitally

> *"you'd have that there straight away as the activities are completed, therefore you've mitigated the cost of someone doing that administration function later down the line … You've also mitigated the cost of keeping those engineers to do that paperwork later down the line. There's a whole host of management costs that you just need to factor in".*

P10 also supports this point but from the client's point of view

> *"I think benefits to Highways England are like there's got to be less cost, so in terms of the administrative burden that we currently have of collating an electronic, a digital, an asset information".*

He also linked the right behaviour of the workforce in adopting digital to the aim of saving on cost and time of construction project delivery

> *"If you could get the behaviours right, if you could change the way we deliver a project to maximise the use of digital efficiencies. You would save 20%. Of time and cost on your project … so making that step change towards a digital delivery. I'm absolutely sure I would make 20% saving now, that's not what the government is asking for, but until you save 20% you can't save 50% and that is the first step. The first full implementation of a digital driven construction project would save 20% on cost and time".*

Furthermore, P6 and P7 describe how digital would save time through giving an example of the current working process, P7 mentioned:

"one of our construction schedules, the contractor, placed a four week turnaround time for drawings to be reviewed and approved because of the machinations of the clients process and since we've introduced our process, then they're down to a couple of days, so we've taken potentially a month out of the process straight away just by implementing this digital solution".

P7 also highlighted the potential time-saving aspect when addressing defects within a project. In cases where an experienced team needs to travel to the site for investigation, P7 pointed out that a digital platform could provide access to necessary information remotely, eliminating the need for days of travel to diagnose and resolve the issue.

"ordinarily you would send a team of engineers out there alright, and it takes days. They've got to travel for days. We've got days to do that assessment, days to return and get the reporting and come up with a solution. If you can do all that by way of a digital platform and video or whatever else, there is a massive reduction on the engineer resource requirements at the time away from the project. Also brings the decision making time much closer to the point where it's needed […] So it's a big, big, big, big waste reduction".

On another point, P4 supports the argument of digitising the built process saving time when he tries to shed a light on issues that arise at the handover stage where some employees would have left the project for another project by then. If some of the built information is not stored, or documents are lost, then the only way to have the data is by contacting those people who have left. Therefore, digital would have stored all documents and data on spot and in the time of action as stated here

"The benefits of that, like I've mentioned at the start was, you know, you cut costs of administration tasks and things like that later down the line and trying to find documentation that you previously had you calling up previous staff and other employees that used to have that information but no longer do it. And you're just going around in circles trying to find this information, whereas if you had a digital platform you would have that information uploaded there and then, as tasks get completed".

He also confirms that digital use in construction projects saves cost and time through data availability and insight

> *"They can monitor effectively. Kind of implementing the LEAN process is to cut waste and cost on projects […] they use some of the previous data To prevent or cut down costs on, cut down times on the program to help cost".*

The argument from P7 to save in reworking was to adopt the mindset of doing the work right from the first time as stated

> *"strong quality culture. It not only gives you your compliance, but it gives you right first time and if you get you right first time it prevents rework. If it prevents rework, it doesn't hit your bottom line".*

Supports carbon footprint reduction

Furthermore, P7 embraced digital solutions, particularly for contractors, when they contribute to reduced carbon footprint and expenses while simultaneously offering greater flexibility and agility in operations. This perspective aligns with the broader trend of favouring environmentally conscious practices.

The issue of carbon footprint reduction was echoed by both P7 and P4, who noted that digital adoption can contribute to this cause by minimising paper usage and associated emissions tied to printing.

5.9 The Required Features of the Proposed Model

The construction industry lacks an application that helps keep track of an asset's build phase and provides support in delivering projects with an efficient handover process. This was discussed in sections 5.6.1 and 5.6.5 and stressed by P2

> *"The application of digital tools is very sporadic and little understood, and so there is going back to this thing of translating the day-to-day operations into a digital environment that hasn't been done […] But very often the processes that are used in the construction environment are not compatible with a software system requirement or in developing a user*

specification, because all of it is based upon manually managing the information management".

Therefore, there is a need for an application that solves these issues. Moreover, the application should also be able to integrate with other stakeholders' tools, especially BIM. It should be built on a research-based, best-practice, and robust model. The model's main goal is to be applied to the highways sector. However, other sectors such as water, rail and more could eventually benefit from the model as it will categorise assets with different types and dimensions, which will satisfy other sectors asset types too. Moreover, the model will contain a generic activity sub-model or engine that could satisfy any construction or maintenance job ticket in any industry.

Figure 17 shows the proposed solution of this research. This solution integrates to BIM and will help decrease the amount of reworking.

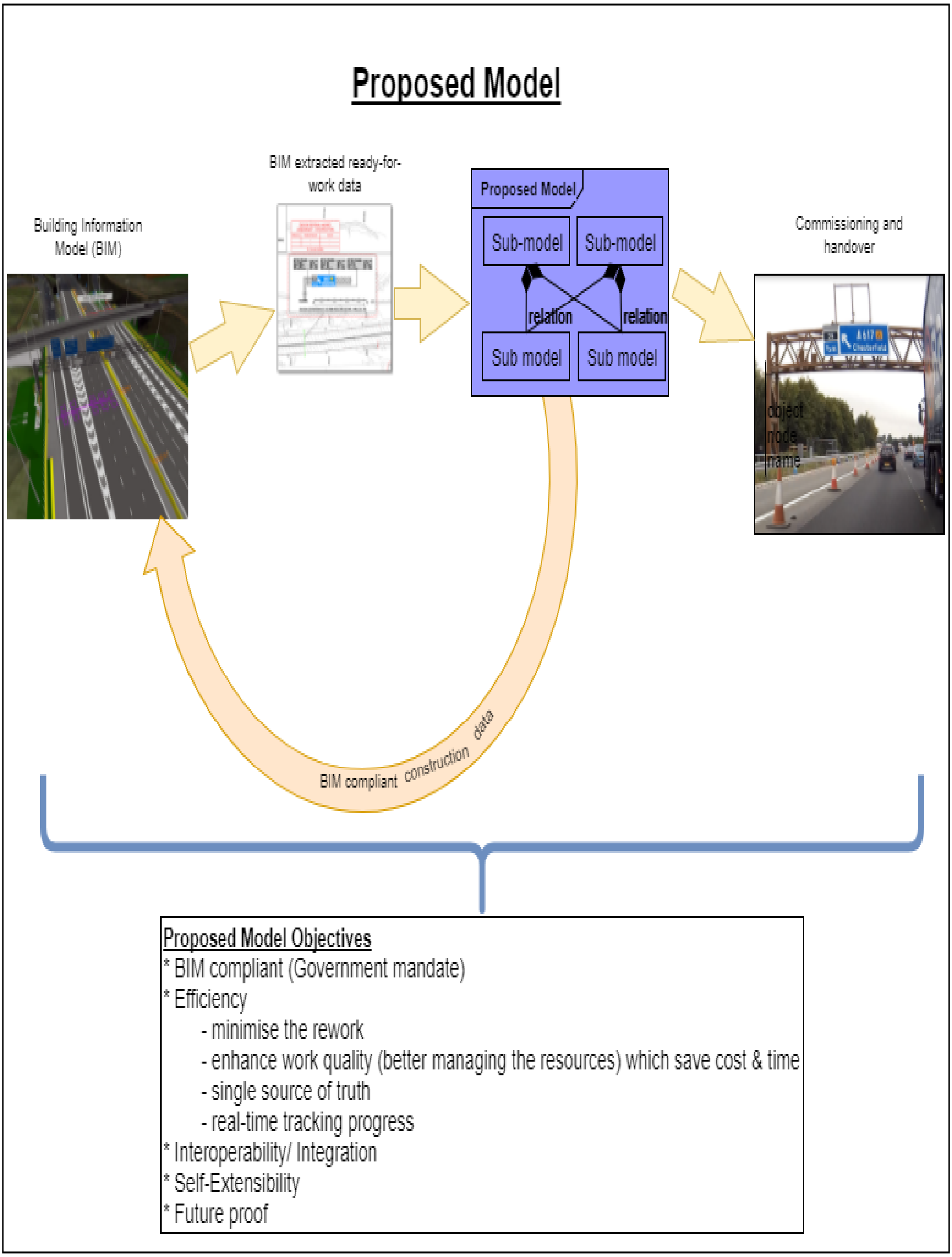


Figure 17: The proposed model

Figure 17 illustrates, as an example, the current process followed to convert design drawings in Building Information Modelling into a physical asset in a road and how the proposed digital model resulting in this project would help tackle issues mentioned by interviewees in section 5.6. This process encompasses the following:

- Initial BIM design is created by designers
- Once the design is approved by the client (National Highways in this case), asset information is extracted in many formats (Excel, paper drawings, PDF files, etc.)
- The proposed model (Construction Asset Tracking System (CATS) – see section 8.2) reads in the take-off (an exercise of reading all drawing and generating new Excel file with details of what are the assets to be built accompanied with their location)
    - CATS tracks and manages the build process and collects all relevant information that is required for the handover phase as well as BIM requirements.

Therefore, the following points are the features that the proposed model should have and which the existing solutions struggle to deliver – more on those solutions will be discussed in section 6.1.

- ***R1***: ***Data in Multiple Media***

As discussed in section 5.5.1, the data is supplied in multiple media, often paper-based, which is exceedingly hard to distribute, manage, retain and control. Version control is a significant challenge. Therefore, the proposed model will aim to transform the current practice of gathering building information from paper-based to raw data as much as possible.

This requirement is related to the issues of a need to digitise the build process discussed in sections 5.6.1 and Interoperability issue discussed in section 5.6.5.1. Many applications and tools are used in design and construction phases such as AutoCAD and TiLoS. Each one extracts data in many different formats. This requirement stresses the need to have a model that accepts entry data from different formats (i.e. csv, Excel, real-time entry) and extract them in the format required by the handover team, BIM and client platforms (Excel, links, application programming interface API).

- ***R2***: ***Asset Categorisation***

National Highways (NH) strategy is going towards adopting BIM 3D, it is a necessity to create a model that categorises all asset types that BIM and the National Highways (NH) databases are adopting. Assets come in different types i.e. civil, technology, structure, etc., and shapes, i.e. 1 dimension (point asset), 2 dimensions (linear asset), or 3 dimensions (road segment). In addition, asset categories should be future proof to accept any new asset type that may be adopted by the asset owners.

This requirement is linked to the lack of ability to host new asset types as discussed in section 5.5, because the cost of creating a new database for the asset owners is enormous when new assets are added to the site. Therefore, a model with single asset's structure that accepts and handles all assets from different categories is needed, i.e. the ducting assets used in technology and pipes related to drainage systems, both should be hosted in one single asset model not like what the current situation is when having ducts stored in Technology Pavement Management System (TPMS) and Pipes in Highways Agency Drainage Management System (HADMS).

- ***R3***: ***Construction Phase of Asset Life***

As many models and applications provide support in maintenance, there is no coherent model to express the need of tracking assets in construction, even though the amount of collected data at this stage is enormous. Collecting data at the time of construction prevents duplications and saves cost and time for the asset owner (McClure & Yuan, 2016).

The majority of sections 5.6.1 and 5.6.2.1 discussed the need to digitise the construction phase of an asset's life to save cost and time and deliver better in both the construction working process and project management.

- ***R4***: ***Integration with other stakeholder's systems (BIM-Compliant)***

The model must be BIM compliant as well as having the ability to perform interoperability / Integration with other associated systems, requirements by asset stakeholders, and what needs to be done to tackle issues of ad-hoc systems (Ehsan et al., 2011; Le & D. Jeong, 2016; McClure & Yuan, 2016).

This requirement is linked to the requirements to integrate to BIM and DBB that was discussed in sections 2.3, 2.4 and 5.6.5.1 as it bridges the gap between Building Information Modelling (BIM) and construction phase data. This requirement makes sure that data collected in construction is compliant for BIM and the asset owners' databases (in this case National Highways).

- ***R5*: *General Realistic Model***

Systems generally focus on the needs of the specifier, for example, client specified systems will understandably focus on capturing data that is useful to the client, but will not be suited to the needs of the constructor or maintainer. A new more realistic model is needed that is relevant to a wider group of stakeholders.

This requirement is attached to better way of managing construction projects that was explained in section 5.6.1.2, 5.6.1.5, 5.6.4 and 5.6.5 because of the enhancement that digital platform would offer not only to the client (NH in this case) but also to contractors and supply chain when undertaking construction work or managing construction projects. These enhancements could also come in the shape of better monitoring and reporting that positively affect the decision making process of construction projects.

5.10 Summary

The proposed model for construction industry data management and integration should address several key requirements identified through interviews and industry analysis. Firstly, it needs to effectively handle data in multiple formats, transitioning from paper-based to raw data for easier distribution and management. Secondly, it must categorise assets according to national strategies such as BIM adoption, ensuring future-proofing for new asset types. Thirdly, it should track assets during the construction phase to prevent duplication and save costs. Fourthly, the model must integrate with stakeholder systems, ensuring BIM compliance and interoperability. Lastly, it should be a realistic model that caters to the needs of various stakeholders in construction project management. To achieve this, the model should include core features such as asset, activity, and document models, appropriate data structures, and support for real-time data collection and sharing. By meeting these requirements, the model aims to enhance efficiency, interoperability, and usability across different platforms, ultimately transforming the construction industry's data management practices.

This chapter examines the challenges encountered by the construction industry in its current practices, considering both the existing methods of operation and the perspectives of the interviewees. The next chapter explores an existing model introduced to address the issues discussed in Chapter 3.

6.0 Existing Databases

Chapter 2 covered governmental requirements for strategies and plans that could enhance the construction industry, while Chapter 3 addressed the issues affecting the industry. This chapter will discuss the databases and models found in academic literature that were created to solve these drawbacks, as discussed in section 6.1. Section 6.2 focuses on highways control systems and databases.

6.1 Database structure relevant to infrastructure networks

This section will discuss some of the main applications and models related to infrastructure and construction industry that are in direct relationship with the research goal that aims to support the goal towards a digital construction industry build process.

6.1.1 Interlinking Life-Cycle Data Spaces (ILCDS)

The acceleration in technology has led to the highways sector changing from relying on paper based data to digital software tools. Even though the software provides improved efficiency, it also creates a challenge for systems and data integration. Moreover, failures in collecting and transferring data between all asset phases in an appropriate data structure can result in high operational costs.

The solution to these issues was proposed by Le & Jeong (2016) through a model that consists of abstract classes and their relationship among them. This model was developed using the Ontology Web Language (OWL) and Resource Description Framework (RDF) to describe the metadata of the model instances. The model mechanism consists of 3 parts: i) abstract data model, ii) data wrapper which restructures the data from the abstract level into a new format, and iii) data query.

1) The abstract data model consists of 3 domains (abstract classes including their attributes and relationships), which are: design product, construction event, and condition survey event. These domains were developed based on competence questions that the output result of this model should answer. The competence questions were based on a framework of pavement treatment that was developed by Zaghloul & Helali (2006). The domain of design product model concentrates on *Routes*. From the competence questions and other reference of LandXML 1.2

(developed by Landxml.org – which is an open standard that describes design data of civil projects in XML format, which used to transfer data from one software application to another), route was divided into *Pavement* and *Alignment*.

Furthermore, the model divided pavement into *PavementLayer* and included *Object* and *RoadElement* as they are attributes of real-world physical concepts. Other attributes and concepts were derived from the LandXML schema.

2) The construction event model was based on TransXML for the construction phase of data life-cycle. It does not include information from physical construction data e.g. asset completion status. It is limited to non-physical data, which consists of ConstructionType, Schedule, Cost, PayItem and Route.

3) The Condition Survey Model was built on a data structure that comes from the Highways Pavement Monitoring System of FHWA, which contains data related to survey events. The properties of this model are divided into two categories, one represents inventory data (Route, Direction and Milepost) and the other represents distress related data (Crack, Rutting).

Reflecting on the previous model of ILCDS's match to the research requirements (see section 5.9), this model is addressing the issues of paper-based documents, finding realistic solutions for the construction phase of asset life, and creating systems with interoperability. This model lacks the generic categorisation of asset types as it only deals with *Routes* and *Pavements*.

The model attempts to solve the issues, however, there is no proof to conclude that this model is the best-practice one over existing knowledge. Considering the previous approach, this research will assume that there are associations between assets, activities and documents, and it will investigate the infrastructure industries to discover the best representation for these associations.

6.1.2 Model Inventory of Roadway Elements (MIRE)

According to the USA Department of Transportation Federal Highway Administration (2010), MIRE is a data dictionary of roadway and traffic data which is important to

safety. Safety data also contains crash and driver history data. MIRE provides a structure of roadway inventory data that serves multiple users and tools. The MIRE listing includes 202 types of roadways elements, which are divided into three main categories: roadway segments, roadway alignment, and roadway junctions.
USA Highways applications use MIRE safety data for decision making process regarding not only design and operating roadways, but also helping in asset management and maintenance too.

MIRE is considered as a generic framework that hosts multiple types of assets in a single information system (McClure & Yuan, 2016). Although MIRE has safety data, MIRE itself does not include all the elements that provide help for all operational and design purposes. These data are stored in different databases such as Highway Performance Monitoring System (HPMS), Model Minimum Uniform Crash Criteria (MMUCC), SafetyAnalyst, and the Manual on Uniform Traffic Control Devices (MUTCD).

There are some shared elements between MIRE and the objectives of this research; for example, having a core asset record to represent a single source of data and asset categorisation. However, MIRE lacks in providing support in operational and design purposes. Another weakness of MIRE is that it does not provide a solution for capturing construction phase data***.***

6.1.3 Field data collection and documentation application

McClure & Yuan (2016) suggested that a mobile application that provides a means to collect construction inspection data on the build phase of the asset lifespan, would eliminate the duplication in asset inventory. While construction data is a key factor for asset management, it is very important to capture and record this data at the time of construction. Some asset types such as drainage are only visible during the construction phase and it is hard to collect this data when the road is open to traffic. Figure 18 shows the difference between the ideal data collection (brown line) and the data loss (dashed blue line) between asset lifespan at infrastructure projects. Some data is lost just because it is not collected at the right time, which creates an extra effort that can be eliminated if the data collection follows good practice.

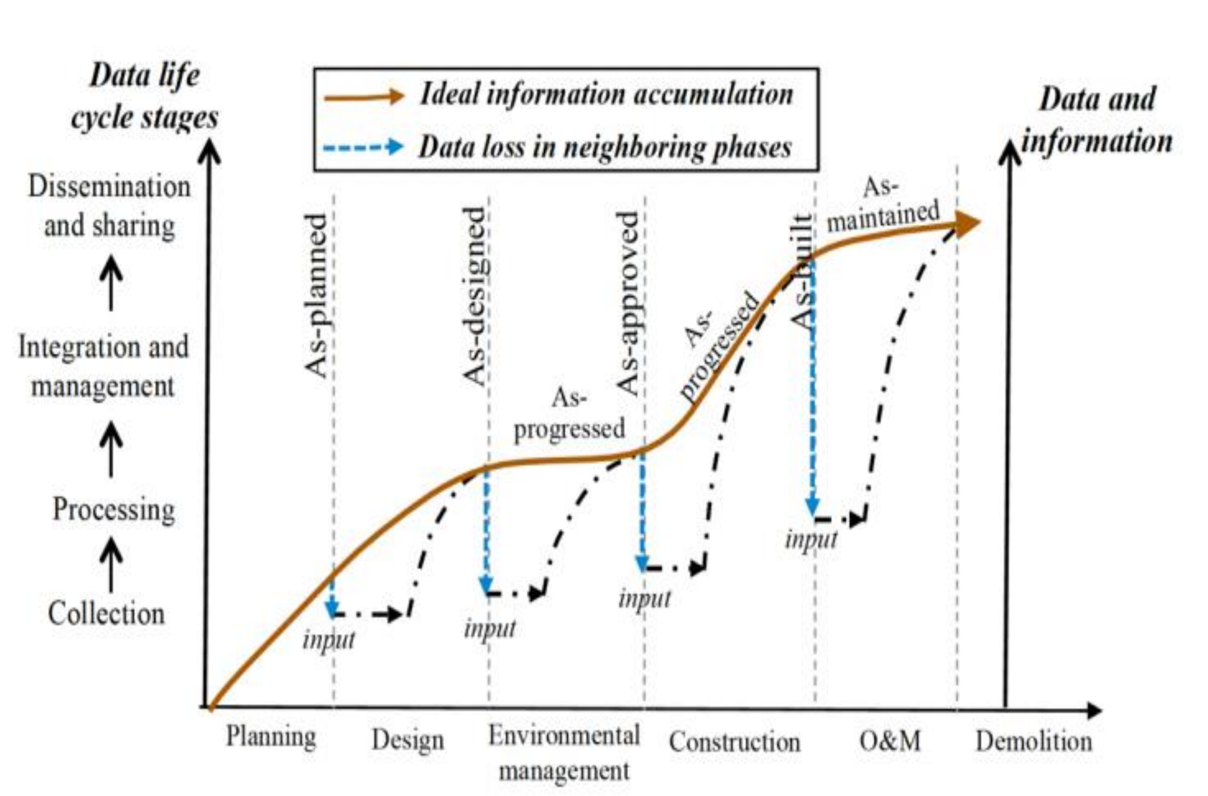


Figure 18: Data and asset lifecycle (McClure & Yuan, 2016)

The idea behind this mobile application is to create a link between assets on the design drawings to their correspondents in the asset management databases through work activities which are called “Pay Items”. This application focuses on the data flow between the construction and the O&M phases. Figure 19 shows the entity-relationship framework model that links assets from planning, construction, work management system, and pay items. This framework enables the flow of construction data into asset management systems.

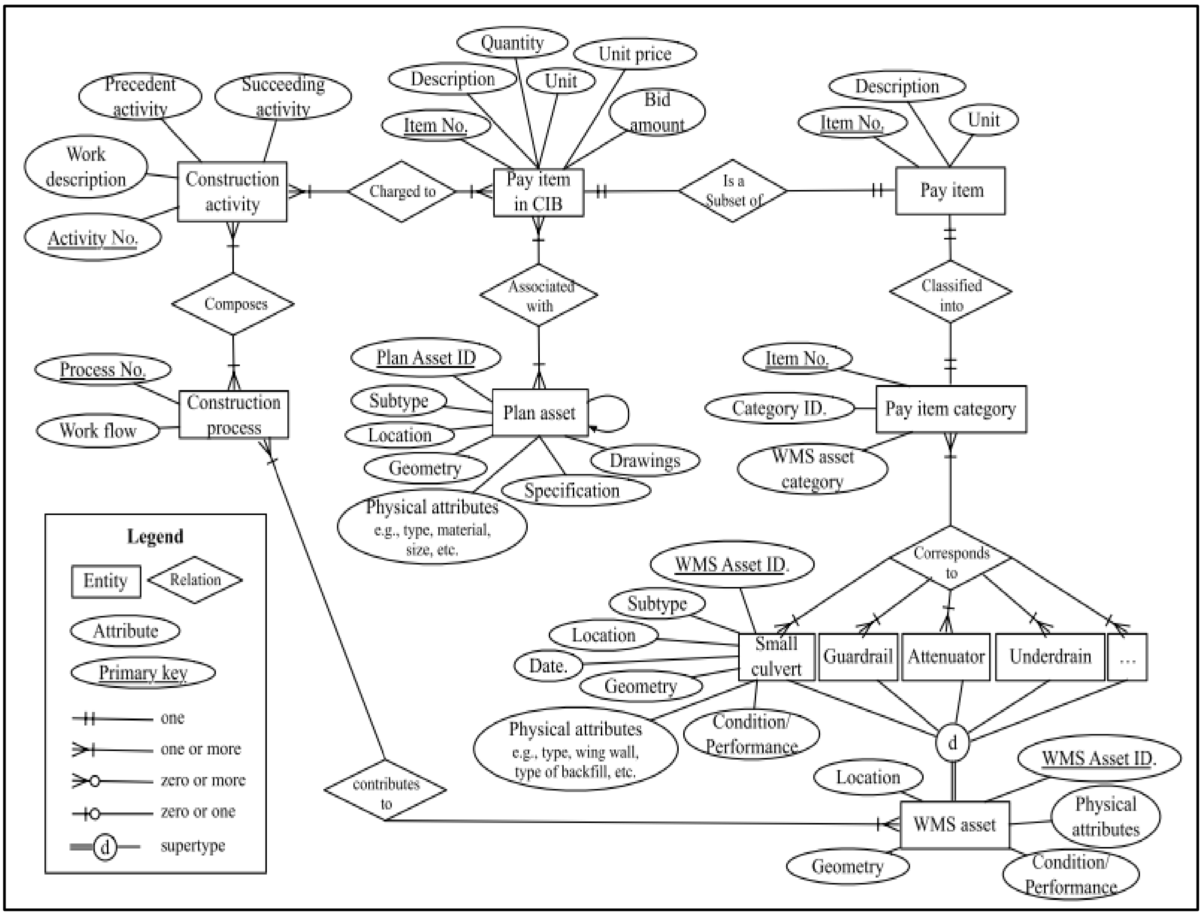


Figure 19: Construction Model of Field data collection and documentation application (McClure & Yuan, 2016)

This model relates to the issues of documents coming in different formats, having an attempt to categorise assets, dealing with the construction phase of asset lifespan, and creating a link between the design and construction phases. This research agrees with the previous model that construction activities need to be modelled in a way that connects design phase with construction one. However, it is not so clear how assets with different types are modelled, or how such a model could be integrated with current and future applications i.e. BIM. Moreover, there is no evidence showing where the authors produced this model from.

6.1.4 Dorset's Highways Asset Management Plan (HAMP)

Munslow (2011) reports that Dorset County Council has developed a framework to manage local and motorway assets. They have structured assets into 11 asset groups (Figure 20). This structure concentrates on combining finance and data to promote decision making, producing a balance between financial risk and the customer need to provide the best service. The framework runs locally and did not include the broader aspect of NH's asset management structure.

1.0 Carriageways, Footways & Cycle-ways
2.0 Verges, Hedges, Trees & Landscaped Areas
3.0 Road Signs, Markings, Studs, Bollards & Pedestrian Railing
4.0 Street Furniture
5.0 Drainage
6.0 Structures
7.0 Street Lighting
8.0 Traffic Control and Information Systems – ITS
9.0 On-Street Parking Facilities
10.0 Public Rights of Way & Private Streets
11.0 Depots, Chipping Landings & Winter Maintenance Plant

Figure 20: Dorset's Asset Group (Munslow, 2011)

The HAMP model discusses the taxonomy of assets in groups and subgroups. It was created to run locally based on the needs of Dorset Council.

6.1.5 Road Asset Management system (RAMs)

The Road Asset Management system (RAMs) for National Highways Authority (NHA) of Pakistan was created to collect and to provide accurate data to decision making tools of the Highways Development and Management model (HDM-4). Ehsan et al. (2011) discusses the points that require enhancement in RAMs in order to improve the efficiency and to provide effective measures to help in the decision making process. Their study shows that RAMs lack the integration with other systems and data accessibility. Moreover, it does not have a database that refers to location such as Geographical Information Modelling (GIS), which creates a difficulty in understanding the whole situation of the assets.

The RAMs model was created to categorise assets in a realistic way to be able to deal with integration between stored data and the tool of HDM-4 as mentioned earlier.

6.1.6 Water Pipeline Database

Landers (2008) stated that budget-constrained pipeline owners frequently ignore their pipeline networks until an emergency occurs rather than putting in place methodical, cost-efficient asset management procedures. Pipeline owners need information on the state of the pipes and the numerous elements affecting pipe performance in order to solve this problem. There is presently no national database that allows municipalities and other organisations to compare data and pipeline management practices, despite the fact that certain owners are starting to collect such data for their particular systems.

The major goal of the project is to advance a method to running and maintaining the water and wastewater pipes across the United State of America that puts emphasis on extending the life of current assets.

Researchers working on water pipeline databases are developing a unique data model to standardise the data into a common format given that incoming information is available in a variety of forms. For the purpose of streamlining database searches, they are also creating a standardised coding scheme. The main objective of the research is to develop prediction models that provide thorough insights into pipe performance under particular circumstances by using the data in the database.

6.1.7 Water Infrastructure Knowledge Database

A web-based water-infrastructure database named WATERiD has been developed by Jung et al. (2014) to make it easier for people to share their knowledge and experience about infrastructure sustainability. As a knowledge repository including condition assessment, renewal engineering, subsurface utility engineering, models and tools, and best management practises for utilities, WATERiD's main objective is to serve as a resource for these fields. WATERiD takes a big step towards closing the knowledge gap that presently exists between accessible technologies and those often used by capturing real-world utility experiences through technological case studies. Utilities may find practices to improve their current asset-management strategies and aid in creating more successful asset-management programmes by using management-practice case studies.

The essential elements making up the data structure of WATERiD are: (1) review data; (2) metadata; (3) basic taxonomy; and (4) enhanced taxonomy. While metadata contains important information, review data contains the comments and feedback obtained during reviews. The basic taxonomy and the extended taxonomy are the two halves of the taxonomy. Both parts strive to organise documents and profiles into hierarchical structures in order to fully reflect all WATERiD aspects while avoiding needless complexity. Based on the many types of infrastructure systems, the basic taxonomy arranges material. The enlarged taxonomy, on the other hand, provides more in-depth classifications, encompassing technology and strategic asset management elements.

6.2 Highways Databases

In the USA, the agency responsible for transport is called the Federal Highway Administration Agency (FHWA). The FHWA is a division of the Department of Transport (DOT). It provides support through the Federal Aid Highway and Federal Lands Highway programmes. The support takes the shape of helping states to design, build and maintain the main roads financially and technically (FHWA, 2016).

In this section, there is a discussion related to how data used in the operational phase of assets could impact on asset management.

6.2.1 National Bridge Inventory (NBI)

The National Bridge Inventory (NBI) was created by the USA's Federal Highway Administration (FHWA) to record data on the status of structures in roads in the USA. (FHWA, 1995) mentioned that, by having a complete inventory, they will be able to create an accurate report of bridges to the governmental bodies. The NBI contains information about the inspection and rating given by inspectors. The NBI component includes:

- Asset information such as the structure's unique identifier, location, and the type of the routes carried out on and/or under the structure.
- Bridge specific information, which could be a bridge type and classification, bridge geometric data, and information about the operational conditions.

On the 1st August 2007, Minneapolis, Minnesota, USA, witnessed the consequences of a drawback in the FWHA NBI data representation when the 8-lane bridge of I-35W

Mississippi River Bridge (formally known as Bridge 9340) collapsed. The bridge was inspected in 2006 and 2007. Both inspections found problems of cracking and fatigue. In 2006 NBI classified the bridge as "Structurally deficient" and in possible need of replacement. It was found that many records within the NBI were inaccurate or out of date. Therefore, NBI recommended the bridge to be replaced only by 2020 as stated in Hopes Dim in Minneapolis for Survivors (2007).

NBI model and its lack of prediction because of the insufficient bridge structure representation, played a major role in the inaccurate interpretation of the actual status of the bridge.

Moreover, the insufficient structure information could be carried over from the construction stage to the O&M phase. When field engineers are only required to record data of "Pass/Not Pass" without detailed information about testing results to O&M, any future O&M decision making process may be affected (McClure & Yuan, 2016).

6.2.2 UK highways

Highways England (HE) has a group of core databases to track and store information on their assets.

HE has four main asset management systems that are used to inform the decision makers of what exists on roads, the condition they are in, as well as keeping asset status up-to-date with the maintenance work. These systems are: Highways Agency Pavements Management System (HAPMS), Highways Agency Drainage Management System (HADDMS), Highways Agency Geotechnical Management System (HAGDMS), and Structures Management Information System (SMIS), and Technology Pavements Management System (TPMS). All previous databases integrate with the 2D Geographical Information System GIS (HAGIS) for displaying purposes and Environmental Information System (ENVIS) to provide environmental details for the road network. Moreover, all management systems hold standard information on the road inventory, network surveys and scheme specific surveys. HE's databases log details about road assets; these assets include drainage, lighting, signs and signals, earthworks, safety barriers, and pavement. HAGIS is used to display asset location combined with the data stored against it (Miller et al., 2012). Miller et al. (2012) also reported that most asset management systems were very technical, which created a gap between the system users and the decision makers within HE.

6.2.3 Control systems

Control systems are very important in the construction industry as they improve the communication process between stakeholders and increase work efficiency by replacing hard copies with digital documents. One of the solutions for control systems is Electronic Document Management (EDM) systems which provide a means to access all the files associated with a given project, while at the same time maintaining the security of the documents. In EDM, all documents and information throughout the project life-cycle is stored in one place and the data are always kept up-to-date.

For any proposed solution to be compliant with construction project's work and process, would involve a large number of documents, e.g. design drawings that are reviewed multiple times, thus resulting in a number of versions being created, all of which must be shared and be readily accessible by all stakeholders. Therefore, the model which is proposed in this research - CATS - should integrate and work collaboratively with these control systems.

Turkan, Guo, & Jahren (2015) discussed four main EDM platforms that are used to manage documents in the American Department of Transport (DOT). These platforms are Interchange, ProjectWise, New York State DOT EDM system, and Doc Express.

Interchange

Interchange was developed by Microsoft SharePoint and it is used by Utah DOT state. One of Interchange's main features is that it grants privileges for different users on different project stages. Its users can submit their documents and design models to the same platform. It also provides a task management platform for users. The stored design models can be reviewed on specific dates and the reviewers submit their review before the due dates.

ProjectWise

The ProjectWise platform was developed by Bentley Inc. and is used by Michigan DOT. ProjectWise provides a means to keep the documents up-to-date through delaying the payments to the contractors and subcontractors if the documents have not been uploaded by the designated due date. It has rules to store the documents through its format, folder structures, and user authorizations.

New York State DOT-EDM system

New York State DOT uses their own EDM system which is also built on the ProjectWise platform. New York State DOT has their DataSource supporting database implemented into the system. The system does provide privileges to access the data to ensure security and the data are kept up to date. Moreover, only data owners are allowed to determine which documents to keep and which ones to remove.

Doc Express

The Doc Express platform, crafted by Info Tech Inc., promotes the shift towards paperless contracting by offering a secure platform specially designed for managing construction administration documents. Contractors can efficiently handle their contracts and associated papers. They have the flexibility to arrange and review their contracts as per their preference and can also opt to get timely notifications in real-time.

6.2.4 Building Information Modelling (BIM) & Geographical Information system (GIS)

The UK government created Construction Strategy 2025 which mainly concentrated on leveraging the use of BIM in all infrastructure phases. This includes the asset locations which are represented in the GIS in different shapes, point and linear assets as was discussed in section 2.4.

In GIS, the idea is to have a massive dataset that could cover the entire city or country in a simple 2D graphical representation with lines, points and regions. This dataset could give the possibility to ask a query across the whole country. This means if a little bit of the pavement has failed somewhere near London, we could compare certain parameters such as weather condition, and temperature when the pavement was laid. Therefore, if another pavement were laid in the same conditions somewhere near Leeds, then the system should trigger a flag to warn that the pavement near Leeds is liable to fail.

Building Information Modelling (BIM) is described by HM Government (2012, page 3) as *“a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets”.*

The BIM team lead by Mouchel Ltd as a designer partner with Costain in M1 Smart Motorway Project J28-35, is building a very graphically complex model, which is heavy on computer resources – 3D snippets. The existing assets’ location as well as the newly built ones will be hard-coded into the model. This BIM system is going to link with NH databases to gather asset information.

The purposes for creating BIM are to achieve project higher efficiency, better communication, and to provide support in the handover process (Teall, 2014). However, the idea of having the entire complexity of the NH database all in one 3D model perhaps will take a couple of decades before the computer power is available that could handle the graphical complexity along with the massive amount of data all in one go. Therefore, the idea of creating a 3D model for the whole road network in a similar way to GIS offers, is going to take a while before it sees the light of day (Vallance, 2015). From the NH perspective, the information attached to BIM could have the ability to be gathered into groups and subgroups depending on the purpose the data is to be used for, i.e. ‘drainage’ information as a subgroup could be duplicated in another subgroup of ‘structure’ if the purpose of the main group is ‘fault management’ (Teall, 2014).

The first attempt of using BIM on projects was in 2013 at the M25 Widening project. At that early stage, BIM was used for clash detection and design review purposes. Moreover, NH is encouraging their projects’ contractors to implement BIM within supply chain and is allowing them to develop their own BIM compliant tools which shall accept information from BIM model and provide it with relevant construction data as NH is eager to make use of BIM tools within the sector in all levels (Teall, 2014).

- One single source of truth

A database is only as good as the quality of the data it contains. 3D BIM will be reading the data from NH databases. Moreover, Teall (2014) stated that BIM will be updated with the construction data such as as-build information during the project life. This data will become later the handover information to NH when the project comes to end.

- Problem

On motorway networks, things are changing daily through the maintenance operations, and if something changes in real time, the database which holds its information should be updated too. BIM snippets have an issue with this update, because each snippet has its own hard-coded data. Therefore, the snippets must be updated with the changes too. Thus, if the databases were updated alone, the snippet will hold up-to-date data attached to wrong location, which will reduce the model effectiveness by time,

> *"The model will be a snapshot in time at the time it was finished, and over the next five years of maintenance, a lot of things may be different to what it actually showing." (Vallance, 2015).*

The idea of creating a fancy 3D BIM model is great. However, it could be a number of years before we have a powerful computer which could handle a 3D model the size of a whole city or motorway roads. To make BIM work as it should, a robust and definite procedure that updates all software and databases with the new data is required, which is a big difficulty (Vallance, 2015).

- How BIM should work

The standard civil Building Information Model (BIM) updates the model once the data has changed, e.g. if a door height of 3.5 metre has changed to 2.5 metre in the database, then the model will automatically change up to the new value. This happens because the civil model reads the information directly from the database. This feature does not exist within Highways BIM as assets are hard-coded to the model, which means that assets are directly written into the model with a location, which makes them become a permanent part of the model and cannot be easily changed. Therefore, if any asset location has changed for any reason, a new hard-coded asset must be created at the new location and attached with the relevant information within the database.

HE is driving BIM towards replicating the behaviour of the standard BIM. However, considering the technology and resources of computers up to the time of this research, BIM stands as a suitable platform for civil buildings as the two-way updating of the database can take place with relative ease. This is not the case for highways due to the regularity at which maintenance and managing of motorways happens (Vallance, 2015).

6.2.5 Integrated Asset Management Information System (IAM-IS) & Asset Data Management Manual (ADMM)

This section will discuss National Highways proposal of Integrated Asset Management Information System (IAM-IS) and its relationships with Asset Data Management Manual (ADMM) (the format that controls the data stored in IAM-IS) and Construction Operations Building Information Exchange (COBie). COBie is a standard format for building information in Excel templates which is used by IAM-IS to read information from BIM.

The idea of IAMS is not new. Highways started a programme to create such a system and replace the ad-hoc existing Highways databases and the management systems attached to them. The main purpose of the IAM-IS system is to provide integration to the NH asset management systems and databases, and to accept information from BIM (Teall, 2014). In 2012, Miller et al. (2012) mentioned that the National Highways – then known as Highways England - was expected to introduce IAMS in the following year. When the researcher interviewed the Costain Performance Manager and Highways BIM Programme Lead, it was stated that the new IAM-IS is expected to be fully launched in 2020 (Bennett, 2015).

IAM-IS is the system repository that stores data. It is planned to remove the legacy systems and migrate the data into the IAM-IS platform. IAM-IS will be the centre repository for all data for Highways England (HE). It will also be used for workforce management.

Basically, NH wants to be much more controlling with intelligence as most of previous projects and contracts happened through supply chain contractor’s proposals.

Therefore, NH created the idea of IAM-IS to gather data and use an intelligent system to assist in work management, commercial controls, intelligent forms, etc.

Regarding IAM-IS history, Bennett (2015) stated that the IAM-IS framework was developed 8 years ago (in 2007-2008) and it was allocated to contractors 5 years ago to start creating it. Essentially, specifications of as old as 8 years would definitely struggle to fit with nowadays technology asset types, e.g. technologies of signs, signal, RADAR, etc. is not structured at ADMM or IAM-IS.

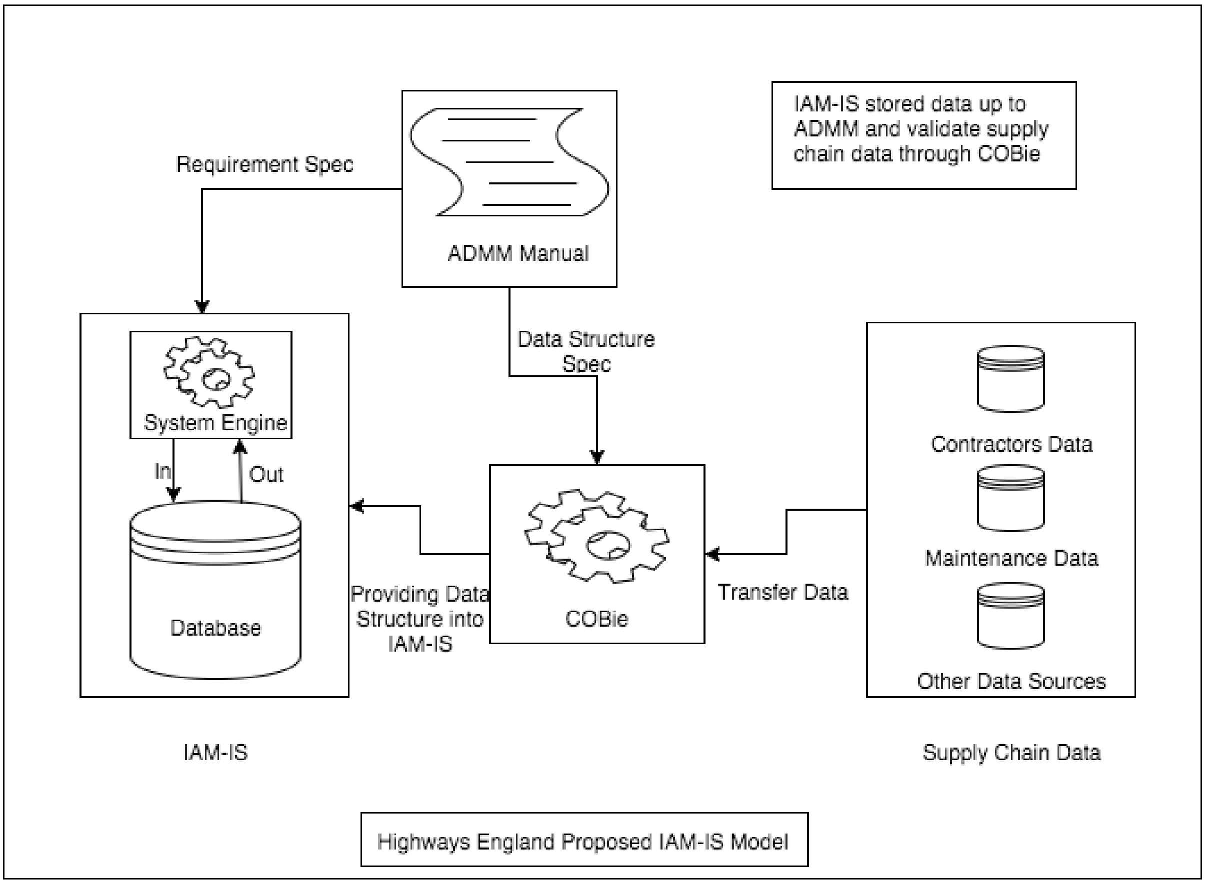


Figure 21: IAM-IS Model

ADMM is the rulebook or manual of IAM-IS that determines how things should be stored in IAM-IS. So ADMM is the written paper documents and IAM-IS is the system repository. Beside standardising the structure and the metadata of the asset, ADMM also describes the Hierarchy relationship between assets as mentioned in (HIGHWAYS AGENCY, 2014).

Figure 21 shows the data flow from supply chain databases to IAM-IS. This figure is what NH planned to have by 2020. The data is transferred from supply chain databases i.e. Costain as contractor to IAM-IS through ADMM Manual which controls the asset data structure. This data must fit the COBie and IAM-IS data structure.

6.3 Summary

This chapter discussed the existing models found in the literature as well as Highways databases which were initially created to address the issues of data loss, reworking, and saving in construction's projects cost and time as mentioned din section 3.2. Next chapter will discuss the insight conducted into the database models mentioned in this chapter and what are the core models, objectives, and system factors that they included in their structure to help the construction industry adopt digital platforms to enable better ways of working.

7.0 An Insight into Existing Models

This chapter will discuss the features, which are important to have in the proposed model, that were found in the academic literature in section 6.1. Section 6.2 considers the features raised in the interviews that are important to have in the proposed model.

7.1 Features Found in Previous Models of the Existing Databases

In order to create a robust research analysis, it is important to identify the features that other researchers have investigated.

7.1.1 Features of the Core System Model

Those are the models shared among the applications identified in the literature review and discussed in section 6.1. The core models consist of:

7.1.1.1 Asset Model

This model was discussed by Landers (2008), Le & Jeong (2016), McClure & Yuan (2016), and Munslow (2011). It has the role of modelling all assets with their different categories, i.e. point, linear, area and volumetric assets. It also has the metadata – structure - of the asset types with their interrelationship.

7.1.1.2 Activity Model

The importance of activities was mentioned by Kostic (2003), Le & Jeong (2016), McClure & Yuan (2016), and Munslow (2011). Most of the models mentioned in the literature review modelled activities to capture the actual work tasks. Work activities generate cost or job invoices. The difference between any O&M activity and construction activity is that in the construction phase, the activities are leading the work in real-time by assigning a job ticket to an engineer on site, rather than being tracked back or reported sometime after the job is done. This way of pre-assigning activities ensures the work is completed within the time frame and all follow-up job tickets are ready to launch on time. Moreover, in the current work pattern, even if the contractors have their system in place to track activities, most of which are paper-based, sometimes, they still have the issue of doing the same job more than once, e.g. in the construction industry, engineers may dig a hole for a chamber somewhere in the site, after that, the quality control engineers go to the site to check the hole features such as location and depth. They could find that the location of the chamber is not being placed in the right location as the designers set in the last-updated programme or design drawings. Therefore, the construction engineers will have to fill it back and re-dig the hole somewhere else (Sean Allen & David McHugh, Personal Communication, 2016). This issue will lead to the need for an up-to-date document model.

7.1.1.3 Documentation model

The documentation model was mentioned by Le & Jeong (2016), Turkan et al. (2015), McClure & Yuan (2016), and Jung et al. (2014). Previous models proposed solutions to keep documents under control by replacing paper-based documents with electronic versions. They emphasise the importance of mapping documents to activities to keep track of all the documents generated by the activities. They also made a link between design drawings and construction activities (McClure & Yuan, 2016).

7.1.1.4 Groups and Sub-groups

As the core model consists of row data, it was recommended by Highways Agency (2014), Teall (2014), Munslow (2011), and Jung et al. (2014) to create groups and subgroups between them as it will provide the flexibility to manage the same data in different occasions, e.g. 'drainage' information as a sub group could be duplicated sin another subgroup of 'structure' if the purpose of the main group is 'fault management' (Teall, 2014).

7.1.1.5 Location

On the other hand, location importance was mentioned by Tor & Shahidehpour (2006), Dolezilek (2001), Le & Jeong (2016), U.S. Department of Transportation Federal Highway Administration (2010), Munslow (2011), Ehsan et al. (2011), and Jung et al. (2014). The location model should be aligned with current and future tools such as GIS and BIM.

7.1.1.6 Metadata and Interrelationships

As long as we are discussing the core model themes of asset, activity, and document, it is important to mention the main features that shape these models. The data structure or the metadata as well as data interrelationships importance was discussed in Tor & Shahidehpour (2006), Le & Jeong (2016), U.S. Department of Transportation.

Federal Highway Administration (2010), Munslow (2011), Jung et al. (2014), HIGHWAYS AGENCY (2014), Le & Jeong (2016), and McClure & Yuan (2016). These features set the shape of the data that will be stored within the model. If the data is crude and misrepresented, without explaining interrelationships between them, the model will have unexpected outcomes. The model will also run the risk of becoming another ad-hoc solution that is only capable of dealing with the specific issues for a specific industry, which is precisely the drawback found within current models. Therefore, there is a need to create a model with more abstract features that represent all asset types, activity types, and document types with the ability to create associations between these data.

7.1.2 Features of this study's objectives:

The proposed model for the construction industry's digital transformation must address several key requirements, which were also found in the models mentioned in this section. These requirements include efficiently handling data in various formats for better distribution, management, and interoperability among different applications, as well as asset categorization to accommodate all types and shapes, ensuring future-proofing and avoiding the need for multiple databases. Additionally, the model needs to provide a coherent approach to track assets during construction, preventing duplication of efforts and saving costs and time. Moreover, it must be BIM compliant and capable of integrating with other stakeholder systems to ensure effective data sharing and compliance. Finally, the model should offer a more realistic approach, catering to a wider group of stakeholders beyond just the client, enhancing project management, monitoring, and reporting capabilities throughout the construction process.

7.1.2.1 Efficiency in cost & time

This research tries to build a model which is able to achieve better efficiency in cost and time, is able to integrate with other systems and tools in the industry, have the ability for self-extensibility, and is future proof. Authors Brown & Spare (2004), Dolezilek & Ayers (2001), Ehsan et al. (2011), Hanley & Clayton (2008), Jung et al. (2014), Kostic (2003), Landers (2008), Le & Jeong (2016) McClure & Yuan (2016), and Munslow (2011) mentioned the importance of efficiency in systems. Teall (2014) suggests that he aims to achieve an 18-20% saving in projects and needs them to be completed in half the time previously required.

7.1.2.2 Integration

Moreover, integration is one of the main features that Ehsan et al. (2011), Hanley & Clayton (2008), Le & Jeong (2016), McClure & Yuan (2016), and Tor & Shahidehpour (2006) discussed in their solutions. As HE and other sectors such as the water sector are leading towards adopting Building Information Modelling (BIM), it is very important for the proposed model to be able to be compliant with the new and future applications or tools. Therefore, considering the previous solutions mentioned in the literature and their impact in solving specific issues in specific situations, it is important for this research to take a different approach to integrate with other solutions.

7.1.2.3 Expandability and Flexibility

Expandability and flexibility mean that if any asset type appears in the future that is not catered for within this model; then only minimal changes will have to be made to the model's internal structure and data flow in order to accept, read and catalogue the new asset type. This was discussed in Tor & Shahidehpour (2006).

7.1.2.4 Future Proof

The acceleration of Information Technology applications is developing quickly. This development has an enormous amount of data. Therefore, the proposed model shall be able to store and analyse enormous amounts of data to help with current and future asset improvement. This improvement could be on the ability of the asset to be resilient against unexpected events such as extreme weather conditions, or for the asset to be able to adopt the required changes in construction or maintenance in the future (Ellis et al, 2016). Future proofing was mentioned in Tor & Shahidehpour (2006), and Munslow (2011).

7.1.3 Features of system factors and user influences

Features related to the applications concerning the way they will be used includes system usage, real-time data, and ability to share data with stakeholders were shared across the applications identified in the literature review and discussed in section 6.1.

System usage is accomplished by constructing a core model with sufficient features of data structure and interrelationships. However, to achieve these objectives, there must be some elements that mediate this relationship. System accessibility in real-time within different platforms such as desktop computers and mobile devices influence the relationship between the model and the objectives. Dolezilek & Ayers (2001), Le & Jeong (2016), McClure & Yuan (2016), and Tor & Shahidehpour (2006) mentioned the importance of real-time data in systems.

Table 4: Existing Applications and the relation with the Proposed Model Features – Research gaps

Feature\Application	Interlinking Life-Cycle Data Spaces	MIRE	Field data collection	HAMP	RAMs	Water Pipeline Database	Water Infrastructure Knowledge Database
Features of the Core Asset Model							
Asset model	✓		✓	✓	✓	✓	
Activity Model	✓		✓	✓			
Document Model	✓		✓				✓
Data Structure	✓	✓		✓			
Data interrelationships – hierarchy	✓		✓				✓
Groups and subgroups				✓			✓
Location	✓	✓		✓			✓
The Features of research objectives							
Efficiency in cost & time	✓		✓	✓	✓	✓	✓
Interoperability/ Integration	✓		✓		✓		
Self-Extensibility							
Future proof				✓			

The Features of system factors							
Usage (Accessibility, Different platforms, user behaviour)			✓			✓	
Real-time Data	✓		✓				
Data Sharing	✓	✓	✓				✓

Previous models and applications share the objectives and research requirements of this study without combining the objectives in one coherent solution that aims to digitise the build process in the construction phase. This research will take a different approach to include all the research objectives and to find one coherent solution to the research requirements. It will learn from the literature mentioned earlier and will be heading towards combining the solutions together to come up with simple, best-practice, and accepted by industry models.

The "Interlinking Life-Cycle Data Spaces" and "Field Data Collection app" models play a significant role in modelling activities. However, their solutions were designed to address specific issues in particular asset life-cycle stages. This research will examine these models but will adopt a different approach by developing generalised activity models suitable for all asset life-cycle stages and purposes.

Most of the solutions mentioned in section 6.1 infer the need to integrate systems. However, the solutions to this issue were to provide specific asset representations to be able to create connections with specific tools such BIM. This research is looking to investigate integrations with generic solutions that could fit with most of current and future applications of different industries.

Table 4 shows the relationship between the existing applications and solutions in this research field, and its proposed features. This table shows that beside the existing solutions that dealt with ad-hoc issues, they did not provide the coherent platform that the industry needs. This coherent model will be discussed in this research.

Finally, after studying previous solutions, section 8.2 discusses the model proposed by this research that learnt from the previous models/attempts and addresses the drawbacks they suffer which include integration, alignment with government strategy, being BIM compliant, dealing with different types of assets, conforming to clients' databases, and delivering the research requirements and objectives discussed in section 5.9.

7.2 Features Found in the Interview Data

This section discusses the main findings from the interviews reported in Chapter 5 regarding the main issues with the traditional management of highways construction projects.

Features	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Features of Core Asset Model													
Asset Model		✓	✓	✓		✓		✓		✓	✓	✓	✓
Activity model	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Documentation model	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓
Data Structure	✓	✓		✓	✓							✓	✓
Data interrelationships – hierarchy		✓	✓								✓		
Groups and subgroups		✓											
Location model		✓	✓	✓	✓	✓		✓			✓	✓	✓
Features of System Objectives													
Efficiency in cost & time	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Interoperability/ Integration	✓	✓	✓	✓		✓	✓	✓			✓	✓	✓
Self-Extensibility	✓	✓			✓								
Future proof		✓		✓					✓		✓		
Features of System Factors													
Usage (Accessibility,	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓

Different platforms, user behaviour)													
Real-time Data	✓	✓	✓			✓		✓		✓	✓	✓	
Data Sharing	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	

Table 5: Core Model mentioned in interviews

The features in table 5 are categorised into 3 groups, one called Core Model which includes all aspects of the data models and the structure of the databases which includes the best of the existing models discussed in section 6.1 and confirms to ADMM (see section 6.2.5). The second called System Objectives which was discussed in section 7.1 and is aligned with this research objectives in section 5.9. And the third is System Factors related to the usage and user attitude, this feature was mentioned in the literature as well as the interview data mentioned in section 3.2, 3.9, 5.3, and 5.6. Furthermore, the left column in Table 5 represents the features that were repeated within the software applications found in the literature journals which was discussed in section 6.1.

Table 5 clearly shows that the proposed model, which includes Assets, Activities, Documentation, and Locations (see section 8.2.3), was consistently mentioned by the interviewees. This observation is supported by Table 6 in section 8.3, which also highlights the frequent appearance of the core model across various literature journals, as discussed in section 7.1. A tick in Table 5 indicates that the participant in the top row directly mentioned the feature next to the tick box in the left column during the interview.

7.3 Summary

This chapter discussed insight that was conducted in the existing models and tools found in literature. The insight is used to find out what are the core models, objectives, and system factors that they include in their structure to help the construction industry adopt digital platforms to enable better ways of working.

The next chapter will discuss the Construction Asset Tracking System (CATS) model and how it compares to the models mentioned in this chapter.

8.0 The Model (CATS)

This chapter will discuss the Construction Asset Tracking System (CATS) model that was designed and developed to support the construction build phase. It starts with the Agile and scrum methodologies of the software lifecycle that was used to create CATS is discussed in section 8.1. Section 8.2 then describes the model called CATS in detail to enhance the construction project's build and handover process and to solve some issues found in the existing models such as integration to Building Information Model (BIM). A comparison between CATS and other applications found in the literature is discussed in section 8.3. The assessment of CATS in comparison to the data from the interviews will be discussed in section 9.3.

8.1 Agile Methods

Deuff & Cosquer (2013) stressed that a new method of software development was introduced in 1980 as a result of major research into the reasons for the failure in software development projects related to late delivery, overestimated budget, and producing software which does not meet the customer need. However, it was not widely adopted until 2001 when a group of experts in software development created what is called the Agile Manifesto[4].

Deuff & Cosquer (2013, page6) define agile as:

> *"the agile methods are iterative and incremental development models which are intended to cater as fully as possible for the needs expressed by the commissioners (the clients behind the development of the product), providing the opportunity to regularly evaluate the product, and offering a high degree of reactivity in relation to their requirements. They offer the flexibility to apply to the product any adaptations which appear necessary to be made during the course of the development phase. This is due to the fact that they respect the four fundamental values of the agile manifesto: the team […], the product […], collaboration […], acceptance of change […]",*

[4] http://agilemanifesto.org/

They also divided software development projects into 3 phases: design, development, and validation & evaluation. These phases should be iterative which means there is always possibilities for modification in any of the phases if the project requires. The method of agile that allows for iterative and incremental development in the development phases is called the *Scrum* method.

8.1.1 Scrum

The relevance of this section to the research project is tied with CATS development that is discussed in more details in section 8.1.3.

Scrum is a framework with an iterative process to develop one or more features related to the product. This process is repeated over a fixed period of time – usually 2 or 4 weeks – and is known as Sprints. All activities and lifespan of sprints are exactly the same. A group of sprints compose a development phase of a product which is called a *Release*. To summarise, a Scrum method consists of many releases, each release composed of many sprints. See figure 22 below.

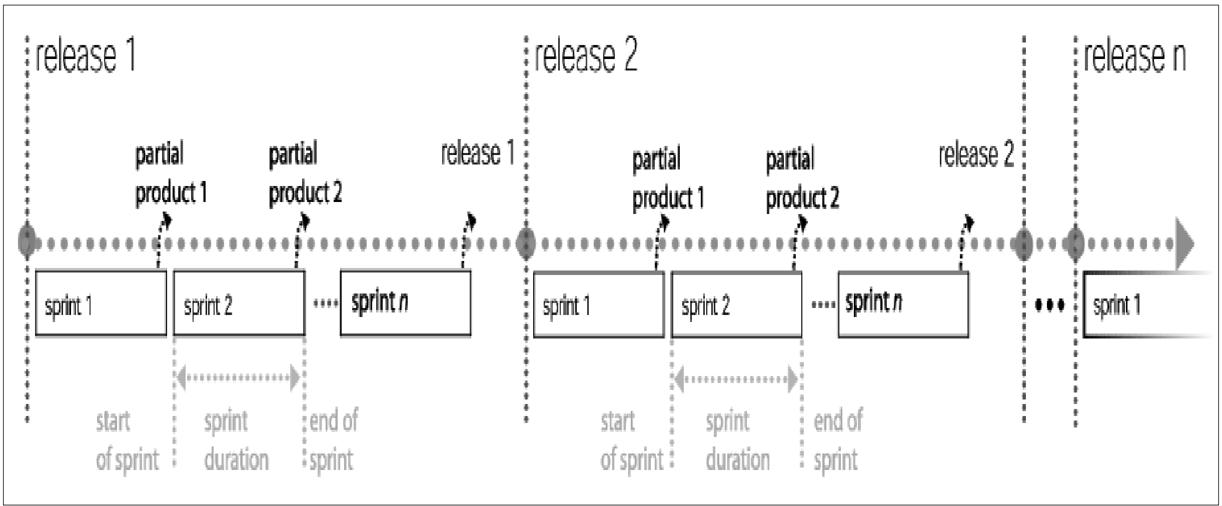


Figure 22: Iterative process of the agile method, Scrum, based on sprints of fixed duration (Deuff & Cosquer, 2013)

8.1.2 Scrum Method Elements

The Scrum method requires 3 elements to shape the development process roles in teams, artefacts and ceremonies. The roles come in 3 shapes as follows:

- Product Owner: Such as the client, the stakeholder with vision of the product.
- Scrum Master: The member of the team who helps the team adopt and apply the scrum methods and unblock the issues the team face.
- Development Team: The team who develops and produces the product.

Scrum artefacts are divided into 2 sections as reference points to the activities needed for a product development:

- Product Backlog: High level items explain the main functionality required in a product.
- Sprint Backlog: A specific item or task planned and allocated to the current sprint that is required to be completed during the current iteration and assigned to team members at the beginning of the sprint.

Scrum ceremonies come in the following shapes (see figure 23):

- Release Planning meeting: Consists of reviewing the backlog items and prioritising the ones required to be included in the coming release.
- Sprint Planning meeting: It happens at the beginning of each sprint and consists of breaking down the backlog items into small tasks and assigning them to team members to be completed within the sprint time.
- Daily Scrum meeting: A window, usually 15 minutes, for the team members to share what they have completed since the last daily scrum meeting and what they are planning to do in the current day. This meeting enables the team to evaluate their work progress and to provide help and support others where needed.
- Sprint Review: It happens at the end of the sprint between the product owner and the development team to discuss the sprint progress in comparison to the vision from the product owner and what may be added to the next sprint if any modifications and/or update is required.
- Sprint Retrospective: Placed at the end of the sprint between the development team and concentrates on evaluating the progress of the current sprint, and how it affects the release if it entails any delays.

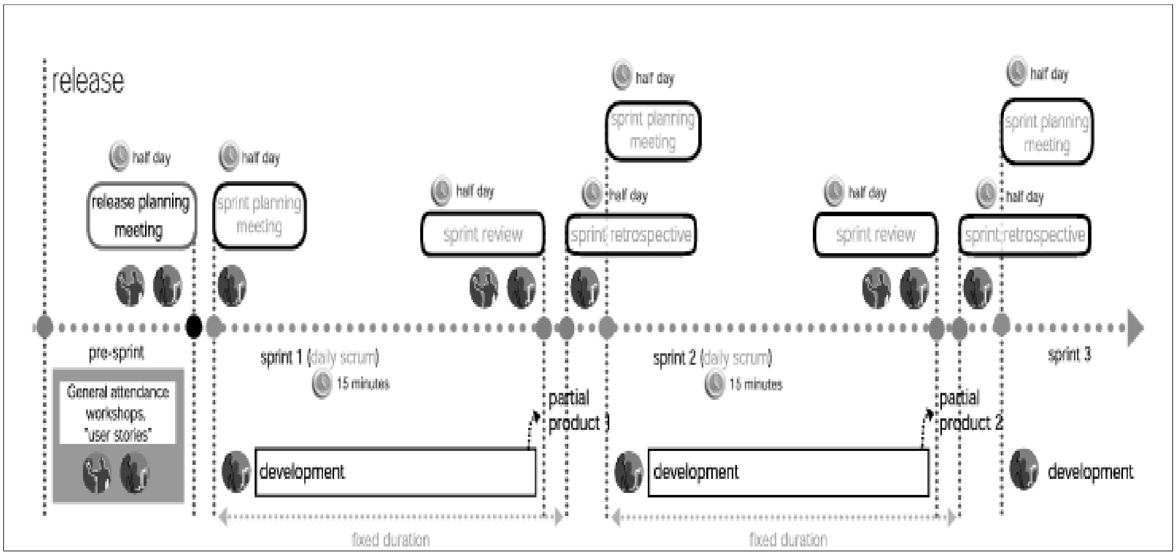


Figure 23: Scrum Agile Method (Deuff & Cosquer, 2013, p. 13)

8.1.3 CATS Development

Considering the previous-mentioned description, it is valuable to delve into the developmental process of the Construction Asset Tracking System (CATS). As illustrated in Figure 24 below, CATS adhered to the Agile Scrum methodology throughout its creation. The construction of the CATS model transpired in three distinct phases:

1. **Analysis and Design**: During this initial phase, the researcher devoted substantial time to peruse governmental documentation pertaining to the structure of databases. An example of this documentation is the Asset Data Management Manual (ADMM), accessible at the link here: ADMM Documentation[5].The purpose of this phase was to gain insights into the underlying rationale for the project, considering documentation, literature, and governmental policies. Moreover, prior attempts at constructing systems to digitise the construction process were examined to ascertain if they aligned with the government's objectives. It was established that these attempts did not fulfil the government's vision, as discussed in section 8.3. An extensive exploration of the structure of National Highways databases was undertaken to establish the foundation of CATS' integration model,

[5]https://nationalhighways.co.uk/suppliers/design-standards-and-specifications/admm-and-other-management-and-maintenance-guides/#:~:text=The%20ADMM%20contains%20the%20asset,corporate%20and%20asset%20management%20objectives

enabling seamless data import and export in line with their databases. This involved crafting models for Assets, Locations, and Documentation within CATS.

2. **Development**: The development phase embraced the iterative Scrum approach in crafting the core model and the system itself. This stage encompassed building the database, designing the Graphical User Interface (GUI), and implementing security and environmental factors. Collaboration within a team environment was pivotal, as the researcher created the model structure and GUI while engaging with experts in the construction process, the Technology Integration Manager, and the Handover Manager.

3. **Validation and Evaluation**: This final phase revolved around the deployment of releases at the culmination of each cycle. After each release, the output was reviewed and discussed with the team and users. Feedback from users was incorporated into subsequent releases. The researcher also compiled a presentation of CATS, featuring videos and screenshots showcasing live data at M1SM T2 for research purposes and internal dissemination within Costain.

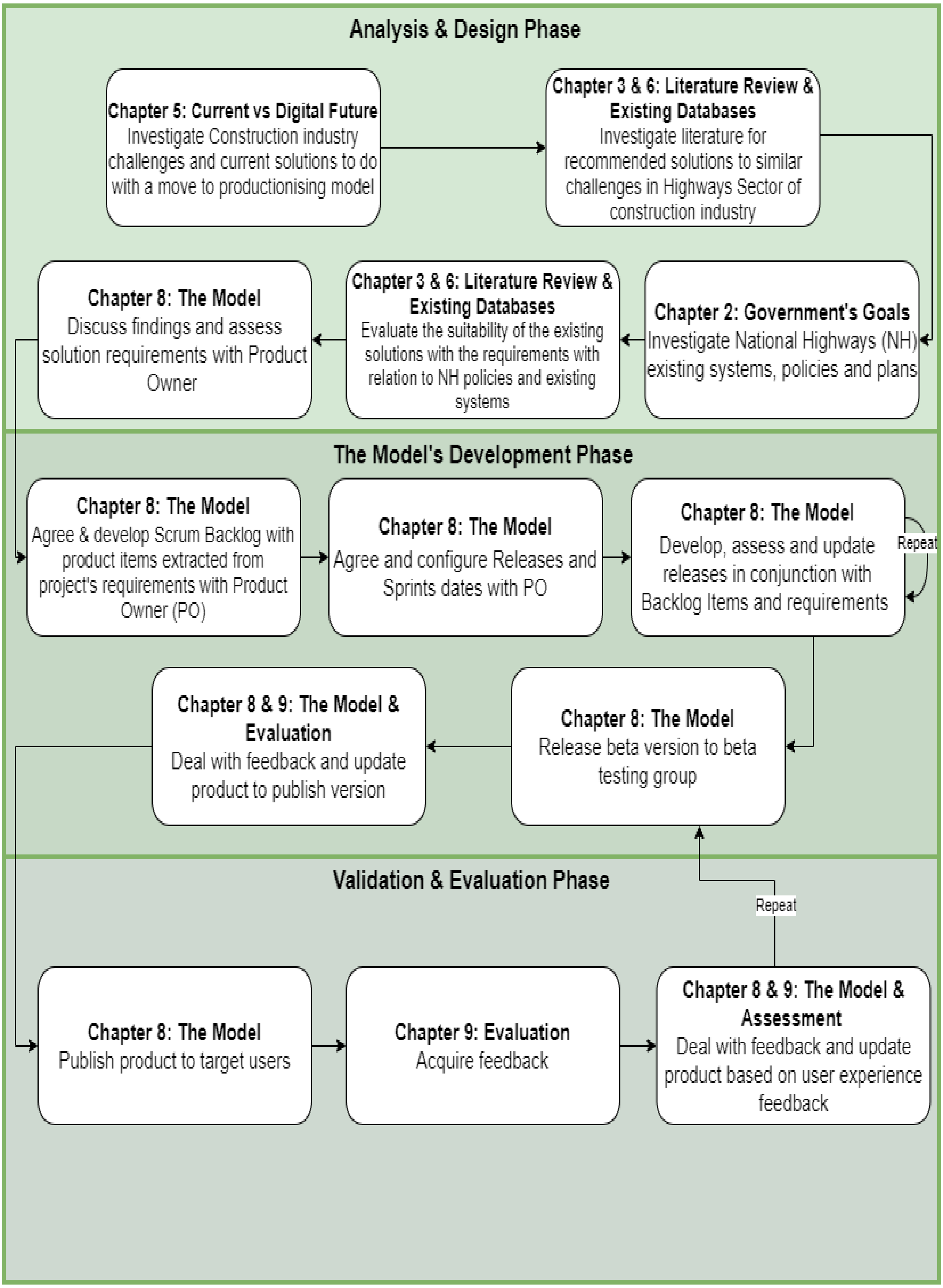


Figure 24: CATS Development Process

In essence, CATS' development hinged on meticulous analysis, agile development cycles, and iterative refinement to create a system that aligned with both governmental aspirations and practical user needs.

8.1.4 User Testing Method

User testing is a method used to test releases and to evaluate the usability of the product. The test follows the product requirements of the platforms (Windows, MacOS, etc.) and device types (Desktop, Mobile phones, tablets, etc.). Testing products also helps in capturing user experience as well as feedback on the product use (Deuff & Cosquer, 2013).

8.2 Construction Asset Tracking System (CATS)

The previous sections discussed the models and the databases of existing Information systems identified from academic papers and information from National Highways.

This section provides an overview of an information system resulting from my work at Costain and a research project. It explores the genesis of the Construction Asset Tracking System (CATS), its purpose, and my contributions. Beginning in 2014 as a System Engineer at Costain, I aimed to leverage IT to streamline processes. As I delved into project intricacies, I recognised a need for an innovative solution to manage construction lifecycles and asset delivery. This led to CATS, which aimed to enhance project management, asset tracking, and collaboration. With careful planning and technical expertise, I played a key role in shaping CATS, designing its architecture to suit construction complexities, incorporating features like milestone tracking and asset management.

8.2.1 Overview

Construction Asset Tracking System (CATS) is a platform that was built on top of a database to enable construction projects to manage construction in a more digital way. It provides a perspective of managing the progress of the construction by creating and tracking the status of the activities and assets digitally. It also provides real-time data access to monitor the progress.

CATS was initially created to enhance the handover process between Costain's construction projects and National Highways (NH) by collating the data and storing it at the time of construction to be used in handover when required. This is mainly related to Stage Gate Assessment Review 6, which discusses the building phase and what follows from testing, commissioning and handover (see section 5.2.5).

CATS is divided into 5 main sections; Work, Safety, Quality, Management and Reports that will be discussed at section 8.2.6. Each one of these sections enhance one part of the project management, figure 25 shows the main screen of CATS

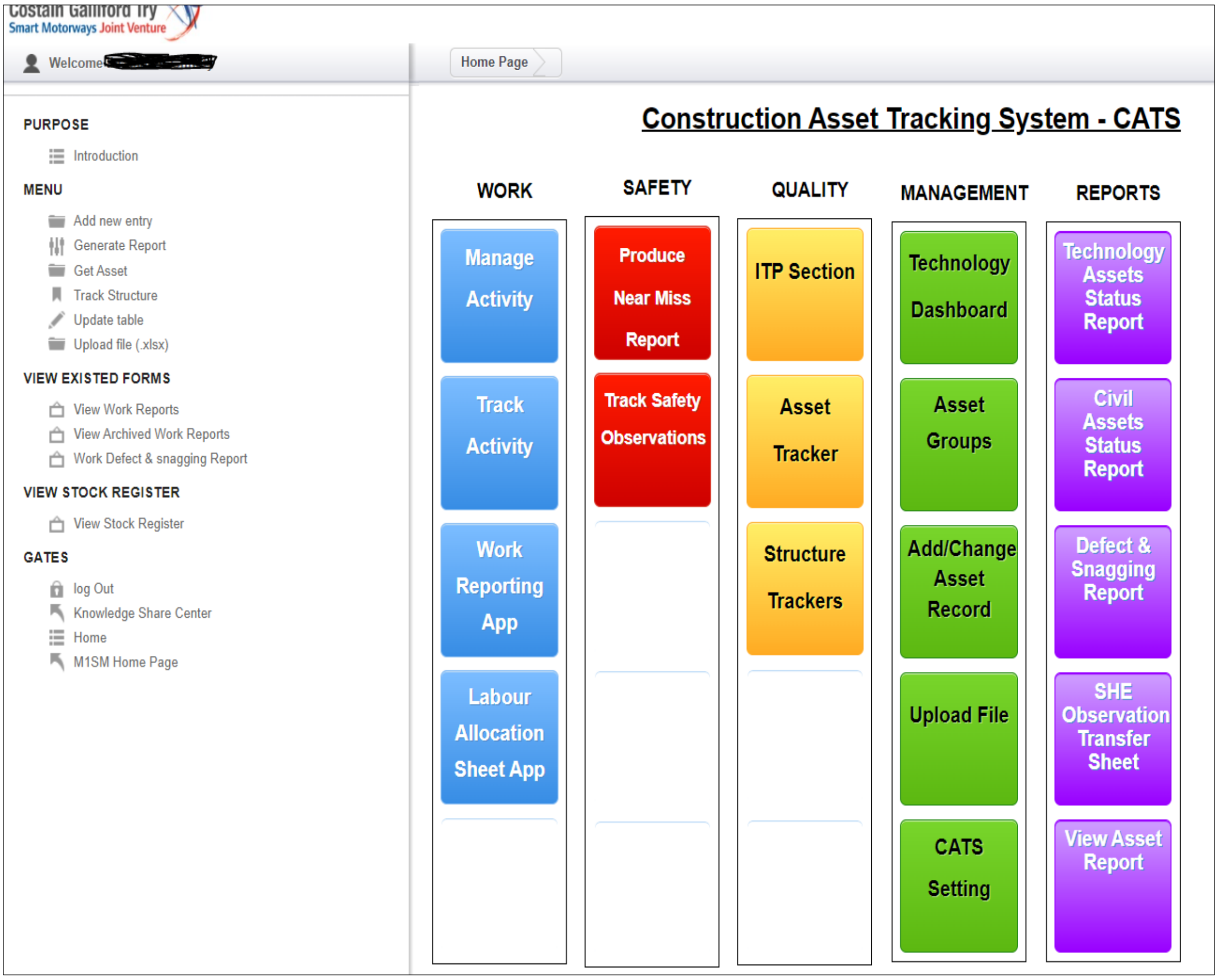


Figure 25: CATS main screen

Within the "Upload File" button under "Management" (see figure 26), functionality is provided to upload Microsoft Excel files containing a specific format of assets. This file should be exported from the design model BIM. The file should contain the details of the assets categories and location as a start (these details already existed in the design drawings). CATS then manages and tracks the progress of the constructions, testing and handover by extracting the information where required. CATS also links asset records with all required activities to install, test and commission the asset. It also has an email engine which alerts the accountable parties to perform their job when their planned work approaches. For example, when a subcontractor digs a trench for a light post column to be installed in an area, and reports the trench as ready to be tested, CATS contacts the relevant Integration Quality Verification Team IQVT manager to approve the quality of the work before the next step of pouring concrete starts. Once approval is registered for the task, the IQVT user who approved it, along with their electronic signature, is automatically captured. Once this is completed, the next step in the installation activities begins.

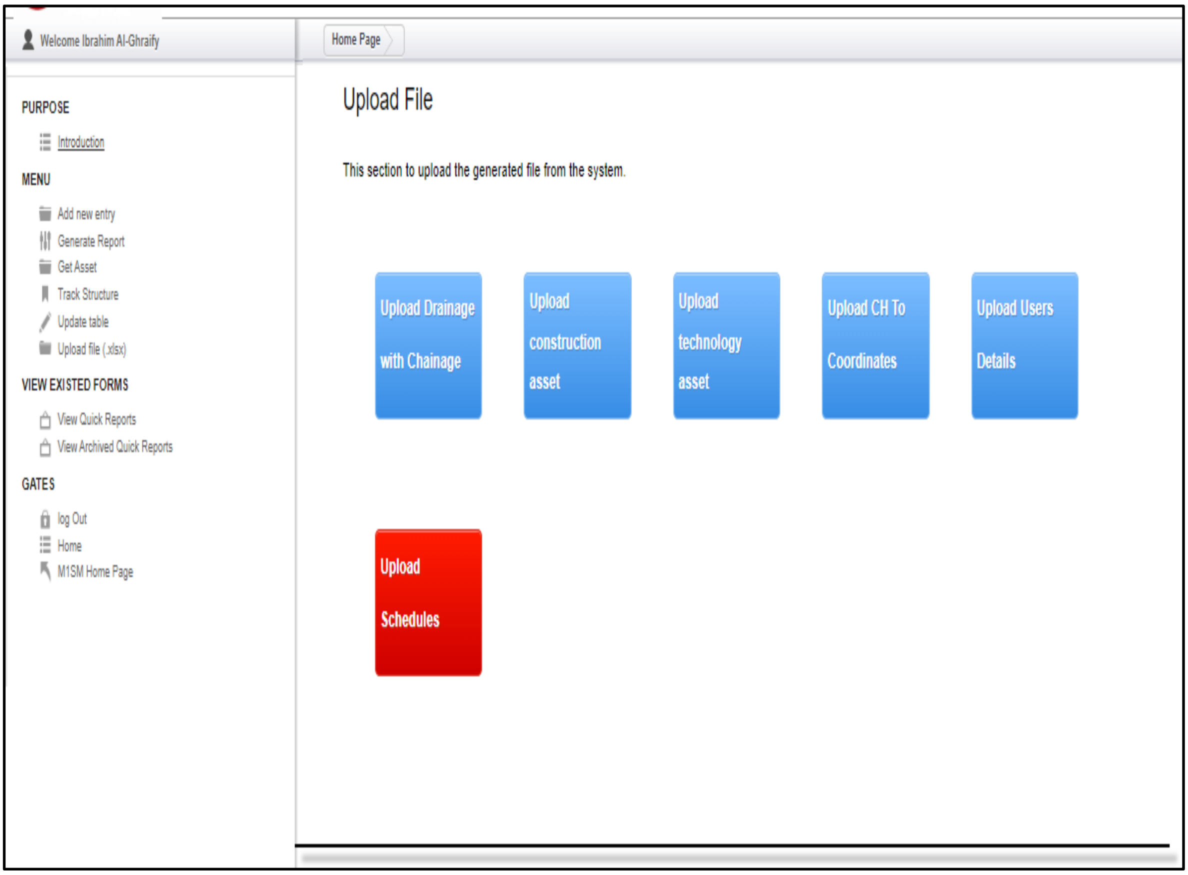


Figure 26: CATS upload files functionality

8.2.2 Development Methodology

CATS was developed by myself using Agile methodology for the benefit of Costain within the UK main road of M1 Smart Motorway project in the area of junction 23A to junction 25. The main and direct contact was the Technology Integration Manager in the project.

Agile methodology as stated by Dingsøyr et al. (2012) is a method that shapes the software development and concentrates on the direct involvement and the collaboration between the development team and the customers in all the development phases. In the case of CATS, the planning stage took place in collaboration with the Technology Integration Manager and the package manager, as well as colleagues working on site to use it when released. Since Agile methodology concentrates on productivity, the plan was to release functionality one by one and not wait until the end of the development to release CATS as a whole. There were always requests to the team to enhance user experience and add new functionality, which were added to the backlog to be discussed with the main client and planned into a To-Do-List if approved.

8.2.3 Database Model

The database is the place where the collected data is stored. Each database has tables and relationships between them. Each table has properties. The main properties of a table are having a Primary Key (PK) or Foreign Key (FK). Any PK must be unique and must have a value, but the foreign key (FK) may lack a value and need not be unique, as it serves to reference the primary key (PK) in a different table.

The CATS database models were created to easily align and integrate with the National Highways' (NH) databases. Asset properties and features in CATS were built to mirror what the main NH's databases are, i.e. National Highways Pavements Management System (HAPMS), Highways Agency Drainage Management System (HADDMS), Highways Agency Geotechnical Management System (HAGDMS), and Structures Management Information System (SMIS), and Technology Pavements Management System (TPMS).

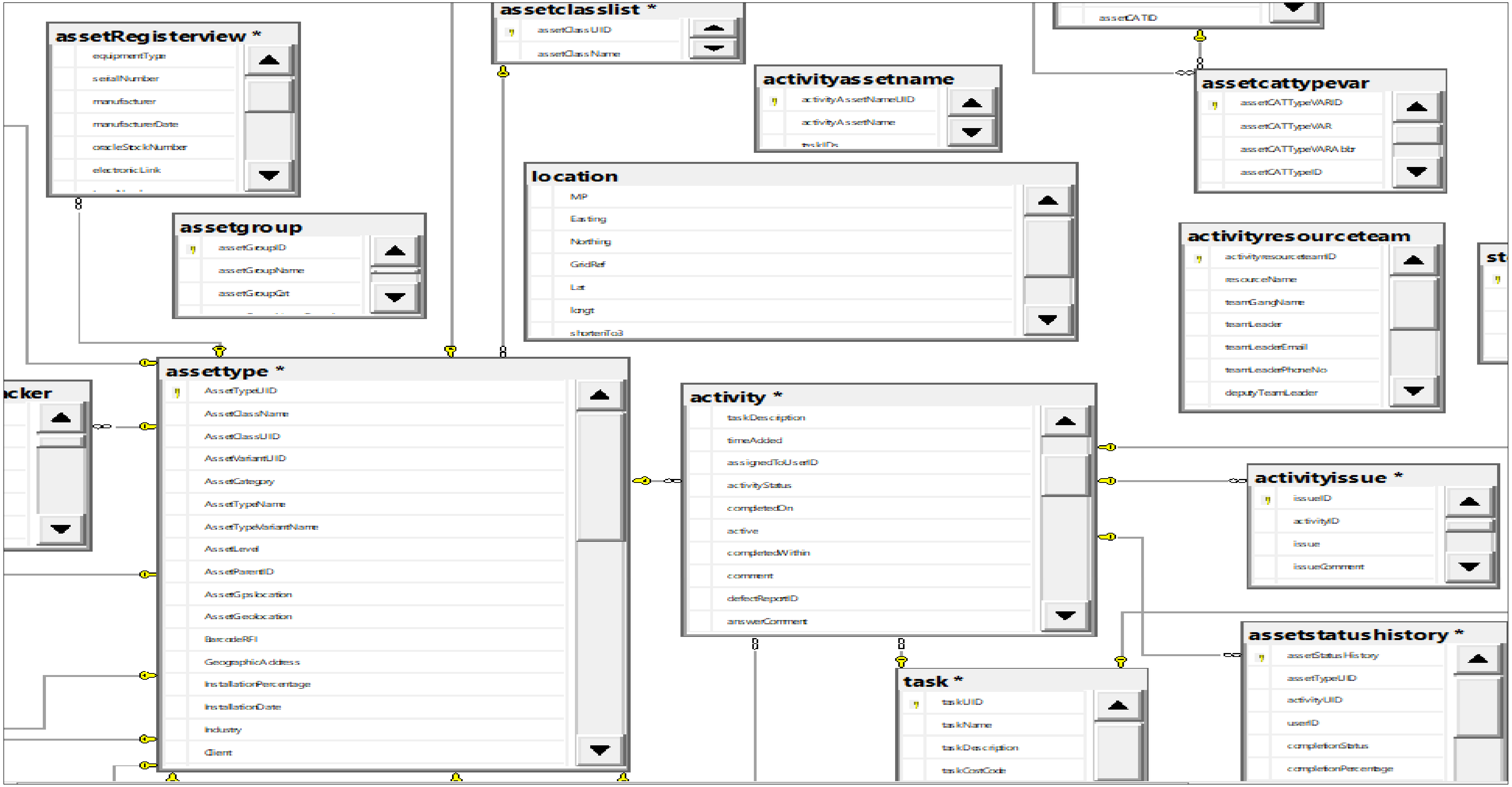


Figure 27: CATS Core Model of Asset, Activity and Location

The database model was built in a hierarchical way to enable future proofing by accepting any new assets appearing in the future. Figure 27 shows the relationship between the core models of CATS including Asset, Activity, and Location tables with the relationship between theme and other supporter tables such as assetgroup, assetclasslist and task.

Asset Model

This model was discussed by Landers (2008), Le & Jeong (2016), McClure & Yuan (2016), and Munslow (2011). It has the role of modelling all assets with their different categories, i.e. point, linear, and area assets. It also has the metadata –structure - of the asset types with their interrelationship.

The Client Reference of Asset Model

The structure of the Asset model is derived from the Asset Data Management Manual (ADMM). The ADMM serves as the rulebook or manual for the Information Asset Management - Information System (IAM-IS), governing the storage methodology within IAM-IS. In this context, ADMM represents the written documentation, while IAM-IS functions as the system repository. Beyond standardising asset structure and metadata, the ADMM also outlines the hierarchical relationships between assets, as noted in the work by the Highways Agency (2014).

The data flows from the supply chain and stakeholders into IAM-IS. However, as of the time of writing the thesis, this live data flow is not yet mandated. The handover process continues to rely on BIM Level 2 (Hall, 2023). The data is projected to move from supply chain databases, such as those of contractors like Costain, into IAM-IS. This movement is guided by the validation of ADMM Manual and must also adhere to the COBie metadata structure, which is built upon the foundations of ADMM.

The Interviews Reference of Asset Model

Many interviewees mentioned the importance of adopting asset models in any proposed digital platform that intends to digitise or productionise construction built processes. P4 for example asserts the need to have assets metadata in the model to minimise human error *“it should all be a Set. I like to call it metadata whereby you know like we use for business collaborator”*

<u>Assets’ hierarchy</u>

The asset model was built as follows:

- The higher level of the hierarchy is the asset class (assetclasslist)
- Asset class child is a category of the asset (assetcategory)
- Asset category has a child of asset type (assetcattype)
- The child of the asset type is asset variant (assetcattypevar)
- The table where all assets are hold to be used in the CATS system is called asset type(assetstatus) and is shown in figure 28

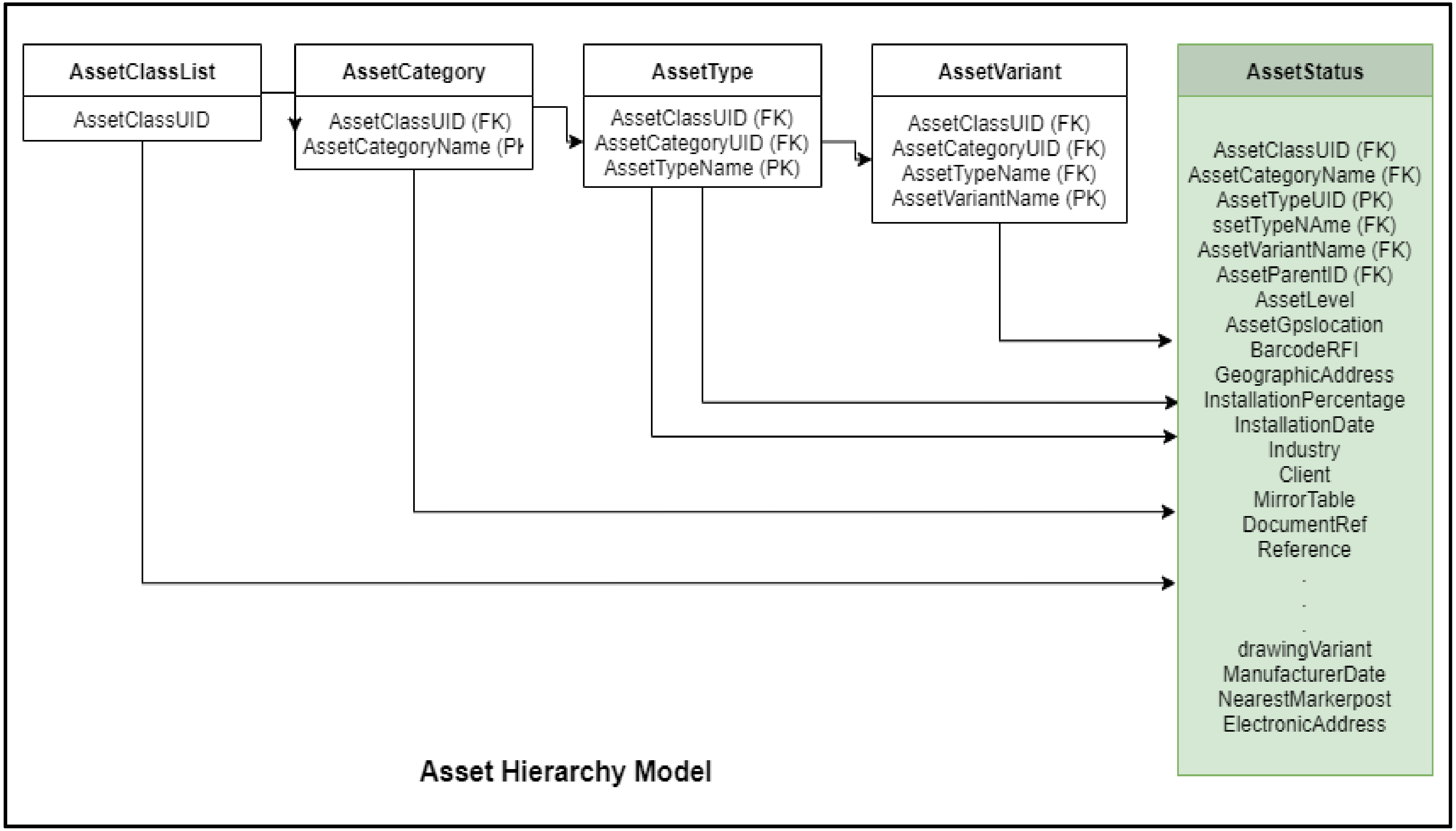


Figure 28: Asset model

By enforcing this hierarchy, it means each asset must have a category, type and variant, and each asset category must belong to a class (see Figure 29).

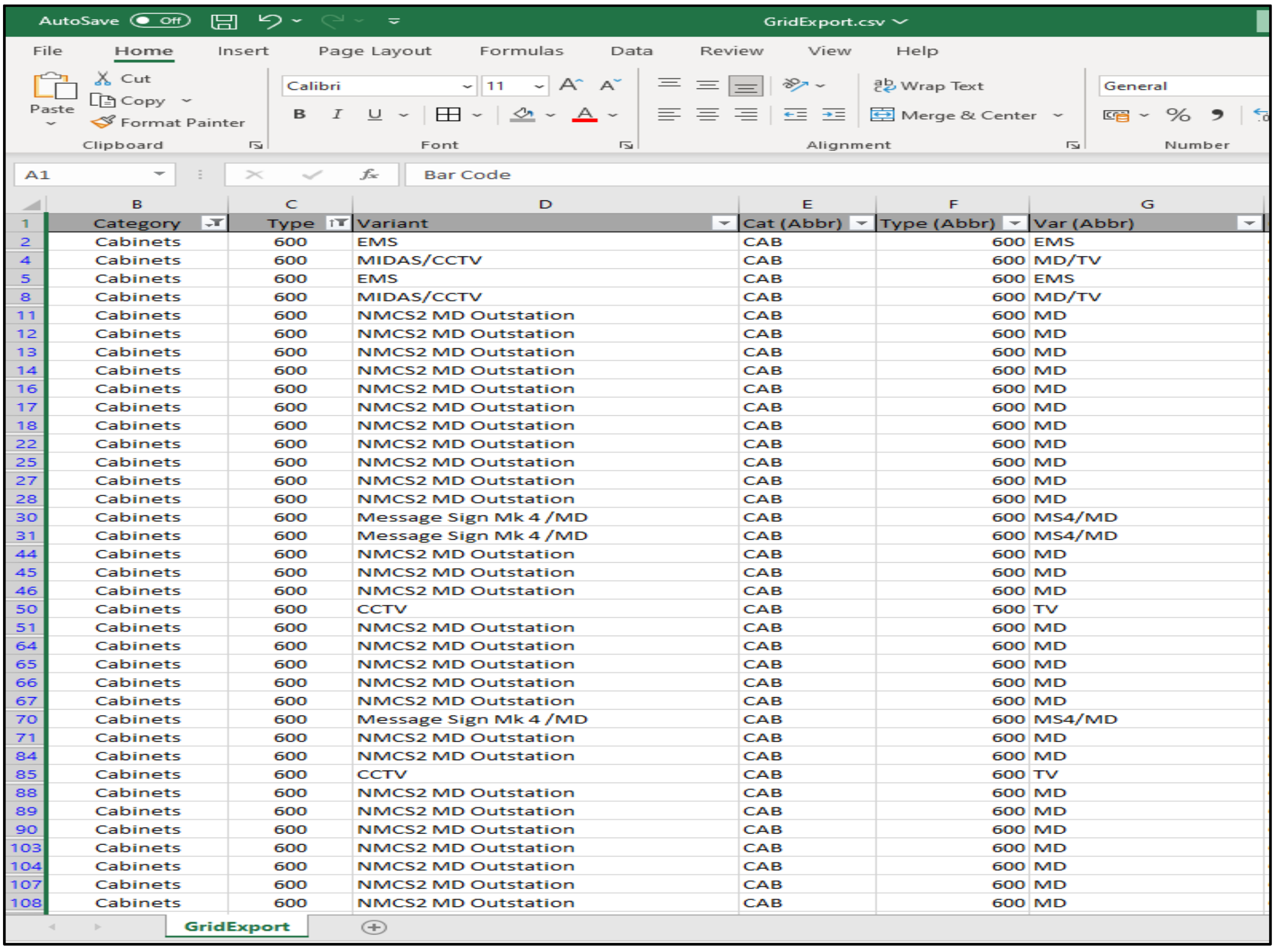
Item Description	Oracle Stock Number	Category	Type	Variant
4 Lane Gantry	N/A	Structures - Portal Gantries	4 Lane	Active Traffic Management Gantry
5 Lane Gantry	N/A	Structures - Portal Gantries	5 Lane	Active Traffic Management Gantry
8 Lane Gantry	N/A	Structures - Portal Gantries	8 Lane	Active Traffic Management Gantry
AMI (Non Enforcement) Version 2 Colas	AMI-0128-1-CLS	Signal	Indicator	AMI Non-Enforcement
AMI (Non Enforcement) Version 2 Techspan	AMI-0128-1-TSS	Signal	Indicator	AMI Non-Enforcement
AMI (Non Enforcement) Version 2 VMS	AMI-0128-1-VMS	Signal	Indicator	AMI Non-Enforcement
AMI CMU (Non Enforcement) Version 2 Colas	AMI-0130-1-CLS	Outstations	NMCS2	Cable Marshalling Unit
ALM V2 Colas	MS4-0599-2-CLS	Outstations	NMCS2	ALM Sensor
ALM V2 Techspan	MS4-0623-2-TSS	Outstations	NMCS2	ALM Sensor
ALM V2 VMS	AMI-0131-2-VMS	Outstations	NMCS2	ALM Sensor
Cabinet 600 MK6	CABINET-0200-1-000	Cabinets	600 MK6	Various
Cabinet 609D	CABINET-0022-1-000	Cabinets	609	Various
CCTV 2nd Gen Camera (IR Enhancement)	CCTV-0278-2-SSL	Closed Circuit TV	2nd Generation	Camera - Issue D with IR enhancement
CCTV 2nd Gen Base Unit (IR Enhancement)	CCTV-0272-1-SSL	Closed Circuit TV	2nd Generation	CCTV Base Unit Issue D with IR enhancement
CCTV 2nd Gen Pan/Tilt Unit (IR Enhancement)	CCTV-0259-2-SSL	Closed Circuit TV	2nd Generation	CCTV Pan/Tilt Unit Issue D with IR enhancement
CCTV Mast	N/A	Structures - Posts	MAST - CCTV	Fixed - Verge
ERT 354 Housing	ERT-0089-1-GAI	Telephone	Telephone Motorway	354 Housing
ERT 354 Barrier	ERT-0119-2-GAI	Telephone	Telephone Motorway	354 Barrier
ERT 354 Barrier-GSM	ERT-0122-2-GAI	Telephone	Telephone Motorway	354 Barrier-GSM
ERT 354 Beacon	ERT-0124-2-GAI	Telephone	Telephone Motorway	354 Beacon
ERT 354 Pod	ERT-0101-2-GAI	Telephone	Telephone	354 Pod
MIDAS IP Outstation Peek	MIDAS-0034-1-PTS	Outstations	NMCS2	NMCS2 MD Outstation IP Enabled
MIDAS IP Outstation Siemans	MIDAS-0034-1-SPC	Outstations	NMCS2	NMCS2 MD Outstation IP Enabled
MS1 94xx Signal	MS1-0003-1-CLS	Signal	Indicatoe	94XX
MS3 3x18 V2 Techspan	MS3-0002-1-TSS	Message Sign	Motorway Signal MK 3	3x18 V2
MS3 3x18 V2 VMS	MS3-0002-1-VMS	Message Sign	Motorway Signal MK 3	3x18 V2
MS3 3x18 Cantilever Structure	N/A	Structures - Cantilevers	Motorway Signal MK 3	MS3 Cantilever
MS4 Cantilever	MS4-0625-1-TSS	Message Sign	Motorway Signal MK 4	Cantilever V2
MS4 Cantilever Structure	N/A	Structures - Cantilevers	Motorway Signal MK 4	MS4 Cantilever
MS4 Portal Gantry	MS4-0625-1-TSS	Message Sign	Motorway Signal MK 4	Portal Gantry V2
Post 75E - Standard Length	INDICATOR-0001-1-000	Structures - Posts	Post 75 - Signal	Entry Slip
Post 75E - Extra Long	INDICATOR-0002-1-000	Structures - Posts	Post 75Ext - Signal	Entry Slip
RADAR Sensor	N/A	MIDAS	MIDAS	Above Ground Detector
RADAR Surge Cab	N/A	Cabinets	Other	Pole Mount Surge Cabinet
RADAR Interface Rack	N/A	Outstations	Stand Alone	Above Ground Detector Interface for MIDAS
RADAR Mast	N/A	Structures - Posts	MAST - Above Ground Detector	Traffic Monitoring Detector - Radar

Figure 29: TPMS category of technology asset

For example, a cabinet representation in CATS's AssetType comes in the following shape:

- It begins as an asset belong to a class of Technology
- Which has a category of Cabinet
- Which has the type of cabinet 600
- Which in turns has a variant of Electrical Interface (EI) as shown below

This way of categorisation came from the TPMS database that NH is using, see data export example from TPMS in figure 30 below.



	Category	Type	Variant	Cat (Abbr)	Type (Abbr)	Var (Abbr)
2	Cabinets	600	EMS	CAB	600	EMS
4	Cabinets	600	MIDAS/CCTV	CAB	600	MD/TV
5	Cabinets	600	EMS	CAB	600	EMS
8	Cabinets	600	MIDAS/CCTV	CAB	600	MD/TV
11	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
12	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
13	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
14	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
16	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
17	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
18	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
22	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
25	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
27	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
28	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
30	Cabinets	600	Message Sign Mk 4 /MD	CAB	600	MS4/MD
31	Cabinets	600	Message Sign Mk 4 /MD	CAB	600	MS4/MD
44	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
45	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
46	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
50	Cabinets	600	CCTV	CAB	600	TV
51	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
64	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
65	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
66	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
67	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
70	Cabinets	600	Message Sign Mk 4 /MD	CAB	600	MS4/MD
71	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
84	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
85	Cabinets	600	CCTV	CAB	600	TV
88	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
89	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
90	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
103	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
104	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
107	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD
108	Cabinets	600	NMCS2 MD Outstation	CAB	600	MD

Figure 30: an example of grid export from TPMS database showing asset hierarchy

An example of a 609 cabinet which is only used as a power or electrical interface cabinet is shown in figure 31

Figure 31: A 609 Cabinet

An example of A 600 cabinet which is used to host controllers to all highways signals and signs is in figure 32.

Figure 32: A 600 Cabinet

Both figures 31 and 32 represent Technology cabinets that exist on the side of motorway roads. However, both cabinets are different in shape, price, some of the installation tasks and the technical tools that they host inside. CATS distinguishes between them both in these perspectives.

The AssetType table has all the properties and features that are required by the handover team to submit to the client at the completion stage of the project. These properties are collected in the construction time and kept safe and backed up. When the project handover phase arrives, the data can be extracted in Excel format and can be converted to any other format afterward. Example of these asset properties are, EMN (Existed/Modified/New), Scheme, DocumentRef, Reference, Link, Junction, GeographicAddress, AssetGeolocation, BarcodeRFI, SerialNumber and many more that are required by TPMS database.

Activity Model

The importance of activities was mentioned by Kostic (2003), Le & Jeong (2016), McClure & Yuan (2016), and Munslow (2011). Most of the models mentioned in the literature review modelled activities to capture the actual work tasks. Work activities generate cost or job invoices.

The difference between any O&M activity and construction activity is that in the construction phase, the activities are leading the work in real-time by assigning a job ticket to an engineer on site, rather than being tracked back or reported sometime after the job is done. This way of pre-assigning activities ensures the work is completed within the time frame and all follow-up job tickets are ready to launch on time.

Moreover, in the current work pattern, even if the contractors have their system in place to track activities - most of which are paper-based - sometimes they still have the issue of doing the same job more than once, e.g. in the construction industry, engineers may dig a hole for a chamber somewhere in the site, after that, the quality control engineers go to the site to check the hole features such as location and depth. They could find that the location of the chamber is not being placed in the right location as the designers set in the last-updated programme or design drawings. Therefore, the construction engineers will have to fill it back and re-dig the hole somewhere else

(Sean Allen & David McHugh, Personal Communication, 2016). This issue will lead to the need for an up-to-date document model.

The Activity Model is the base to any task and process in CATS, it is included in Inspection and Test Plans (ITP), Defects tasks and Asset construction activities. Activities are also linked with each other in a hierarchical parent-child relationship, the same as with assets.

A single activity is defined in CATS as a task that is assigned to someone to do it. This task can be performed on an asset or location. The Activity table has a link between task, asset type, quick report, and users. It also has more properties to do with timeAdded, activityStatus, completedOn, activityRank, carriageway, link, etc. Figure 33 shows the link between the activity table in CATS and other support tables linked to it.

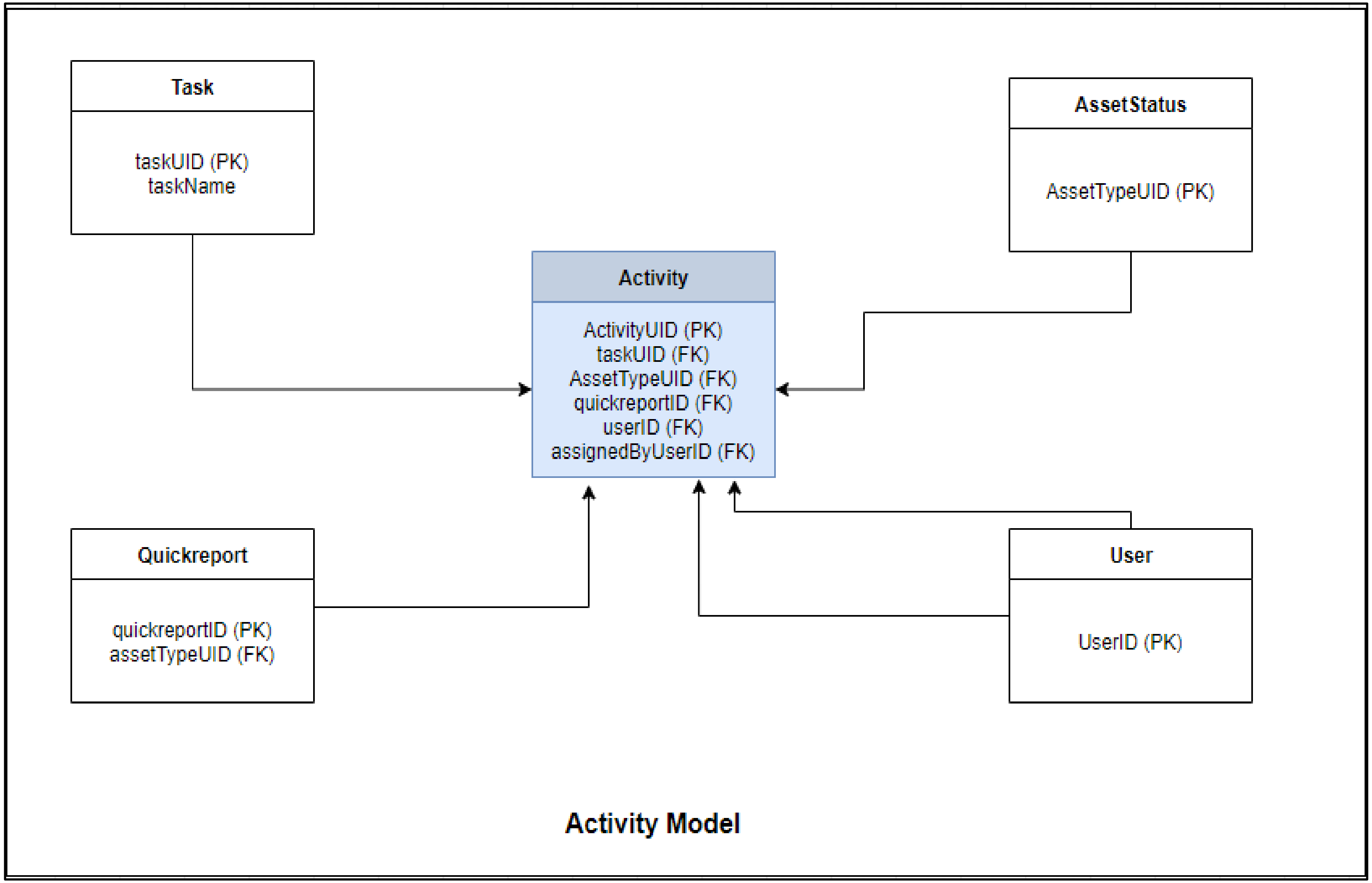


Figure 33: Activity Model

Location Model

The importance of categorising asset location was mentioned by Tor & Shahidehpour (2006), Dolezilek (2001), Le & Jeong (2016), U.S. Department of Transportation. Federal Highway Administration (2010), Munslow (2011), Ehsan et al. (2011), and Jung et al. (2014). Also, the location model should be aligned with current and future tools such as GIS and BIM.

The location model holds all possible location representations of an asset, activity or document. This location definition includes

- Markerpost (MP which is a marker used on Highways that approximately measure 100 metre)
- Easting-Northing (Coordinate used to determine a location by vertical lines and horizontal lines, northing compares to equator while easting compares to the false easting)
- GridRef (a specific location reference to apposition by determining the vertical and horizontal grid lines of the point)
- Latitude-Longitude (Coordinates used for specific location to determine how far it is from the equator)
- Chainage (a special metric used by highways).

Since most of these location references come from NH databases, CATS can be integrated well with these when required at the time of handover. CATS uses these coordinates to locate assets or activities, as well as to map documentation to a specific location or an asset.

Document Model

Summarising the model related to document model that was found in section 6.1, the document model was mentioned by Le & Jeong (2016), Turkan et al. (2015), McClure & Yuan (2016), and Jung et al. (2014). Previous models proposed solutions to keep documents under control by replacing paper-based documents with electronic versions. They emphasise the importance of mapping documents to activities to keep track of all the documents generated by the activities. They also made a link between design drawings and construction activities (McClure & Yuan, 2016).

To link documents with their related assets, a document database was created to easily represent data in the “Design Finder” map and to provide links to assets by mapping the GPS locations of the documents and the assets. See the asset details section for more information.

8.2.4 Integrate to BIM

A key aspect of CATS is its seamless integration with the Building Information Model (BIM), achieved by sharing certain asset and location characteristics that BIM employs as primary identifiers for assets and their positions. When CATS initiates asset construction at a designated location, it generates various interpretations of that central location using a range of location system standards. For instance, CATS comprehends the Easting-Northing standard and can transform it into the Latitude-Longitude standard where needed.

This integration enables CATS to align with well-established location standards that BIM employs to pinpoint asset locations. Consequently, CATS can correlate its asset data with the specific location in question, providing a distinct link accompanied by a unique asset identification number. This linkage allows BIM to effortlessly retrieve comprehensive information related to asset installation tasks and activities. Furthermore, CATS offers BIM access to test results belonging to the assets, quality reports (including defect or snag reports), and the historical resolution process for such issues.

8.2.5 Integrate with Highways Databases

CATS incorporates the concept of a "Mirror Database" for its assets. This means that each asset possesses an associated mirror database, which is intended to be extracted during the handover phase. To illustrate this, consider the case of a cabinet asset; it undergoes mirroring into a TPMS (Technology Pavement Management System) database. This mirroring process facilitates the direct synchronisation of all cabinet asset properties into TPMS, eliminating the need for manual editing.

Another instance pertains to chambers, which can be classified into two types: those employed for drainage purposes, containing water from drains to aid drainage system maintenance, and those used in technology to interconnect ducts and cables. Chambers assigned to drainage functions possess a mirror database in HADMS (Highways Agency Drainage Management System), while those accommodating cables are associated with the mirror database of TPMS

8.2.6 Functionality

This section gives an overview of the main functionality of CATS and how it enhances the process of construction projects.

- Secure by enforcing credentials

CATS has secure login functionality that enforces authentication to the system. This authentication adds a level of security which preserves data confidentiality.

- Asset Details

CATS has a dedicated page to provide direct access to the asset's details and properties. This page allows users to view the details of the asset and update them when required (see figure 34).

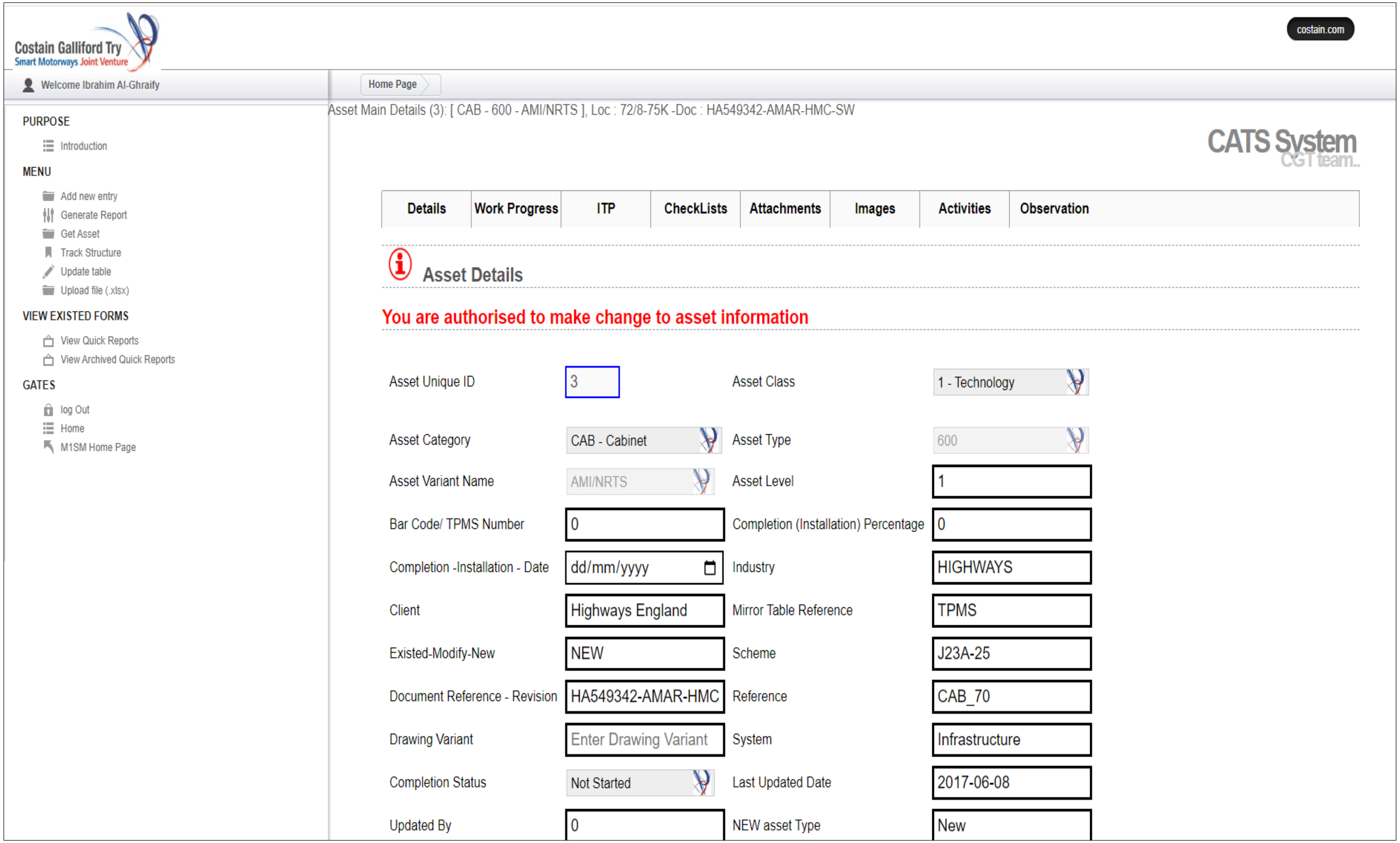


Figure 34: CATS asset details page

The tab bar in the asset details page links all linked information to that specific asset as follows:

- **Details**: Which Shows details of the asset and those who are authorised can make updates. Figure 35.

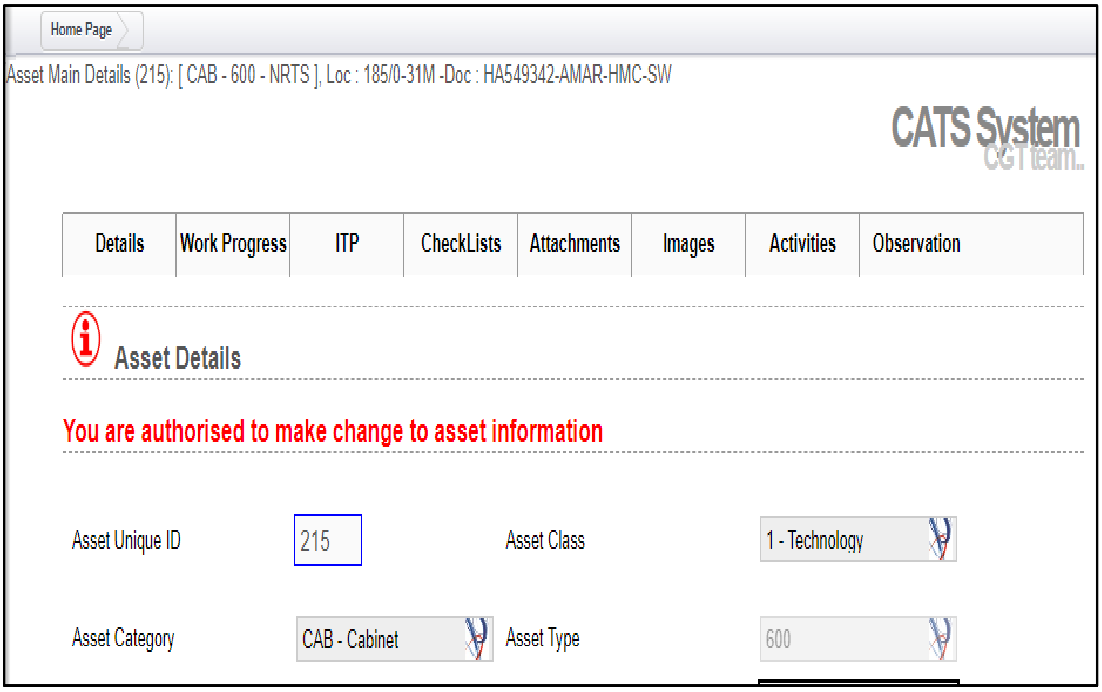


Figure 35: CATS - Asset's details page

- **Work Progress**: Provides information regarding the installation status of the asset. See figure 36.

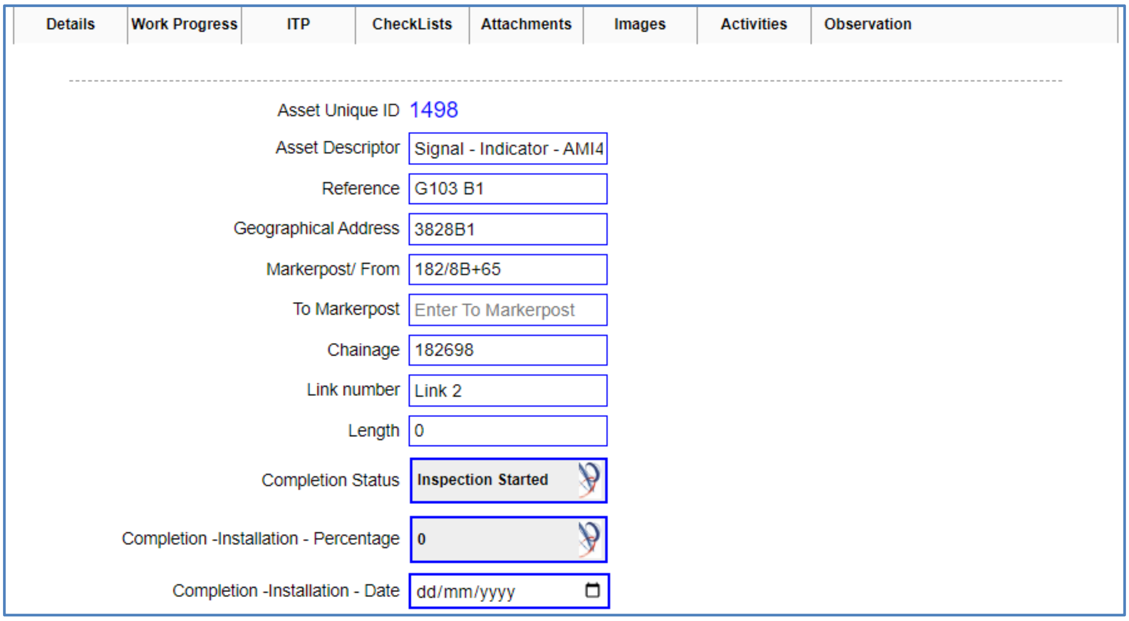


Figure 36: CATS - asset's work progress page

- **ITP**: Inspection and Test plan (ITP) form for a specific asset, the ITP is used to control the quality and the tasks of installing an asset and is used to report to the National Highways (NH) about the steps of how the assets was built and what quality and safety measures was taken in the installation process. see figure 37.

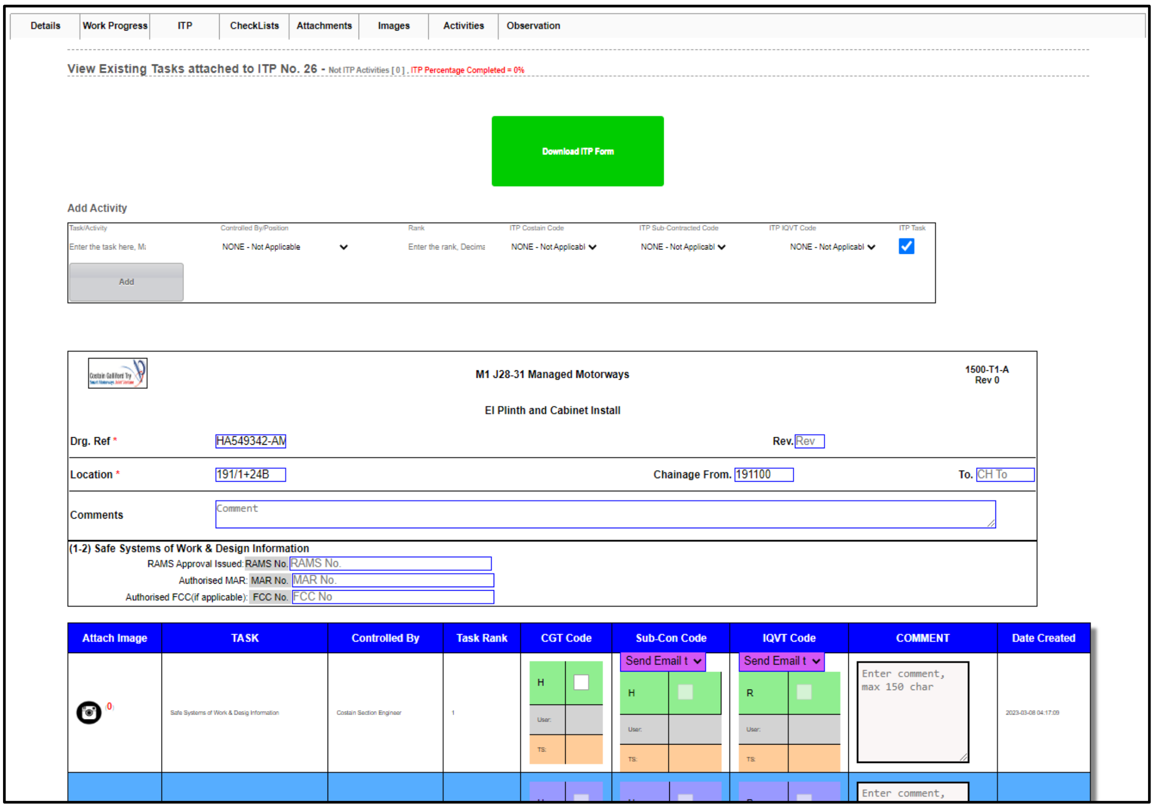


Figure 37: CATS – asset's ITP page

- Checklists: which is a window to all activities and tasks for an asset, this has direct links to all activities on all status, special attributes to the asset and the defect reports related to these specific assets if there is any. See figure 38.

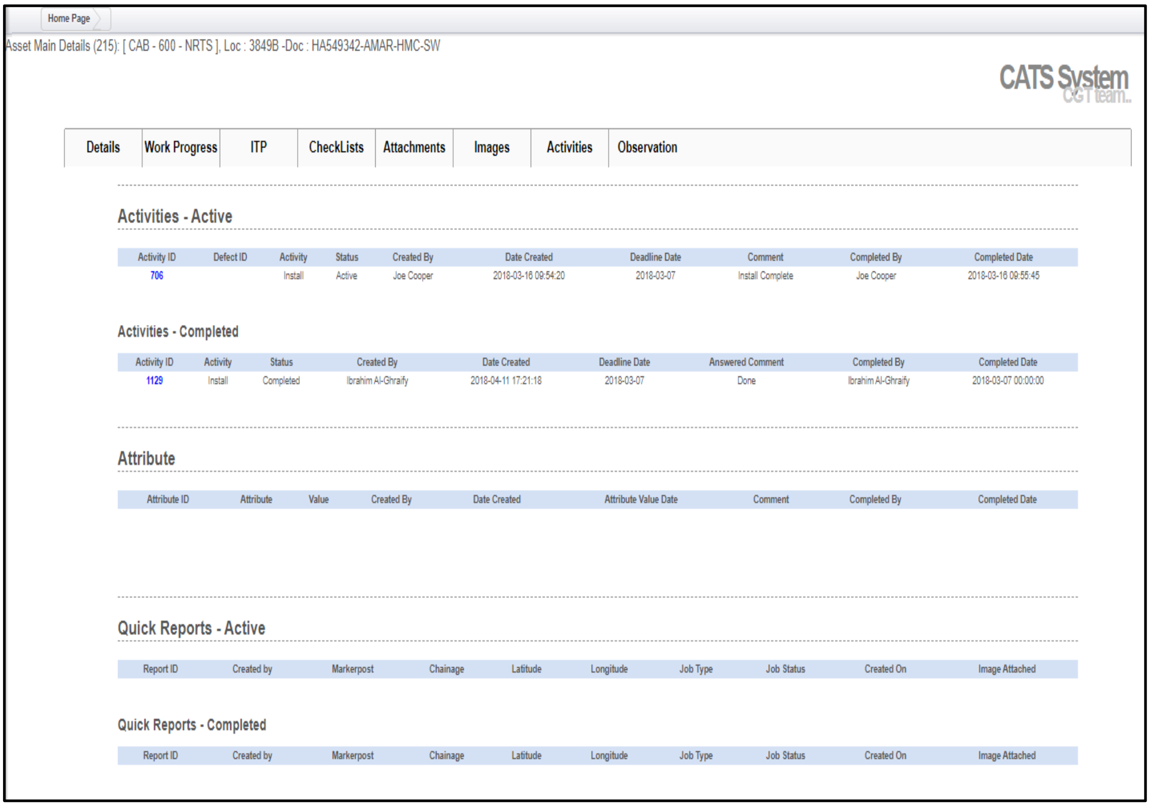


Figure 38: CATS - asset's checklist page

- Attachments: This page allows the user to upload and link any attachments related to the asset as shown in figure 39 below.

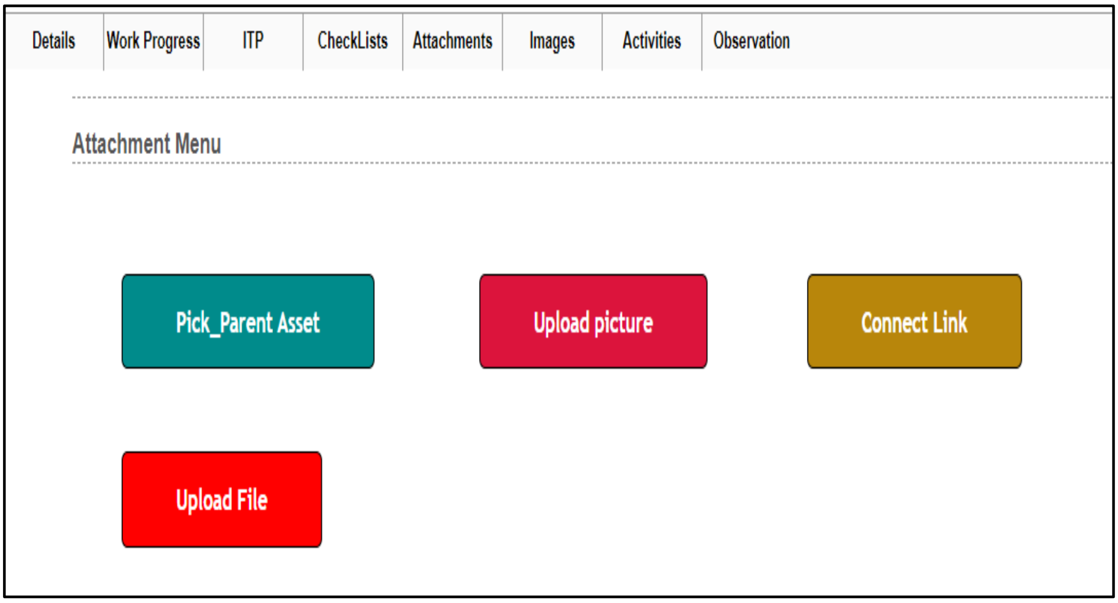


Figure 39: CATS - asset's attachment page

- Images: a page to show all uploaded images related to the asset

- Activities: a page to enable the user to create any new activity required at any time related to the asset. For example, this can be how the asset's installation status is moved from stage to another until it is 100% complete. It may also be used when there are special circumstances that require an extra activity to be performed because the type of the ground is harder or softer than the adjacent area, or if there are gas pipes or electricity cables under the ground and require extra activities to work around that specific area for these assets only.

- Observation: This page allows the user to create a defect or snagging report or observation to go with the installed asset, see figure 40 below.

Figure 40: CATS: asset's work observation

- Map View

As well as the asset details page, CATS provides access to map views which understands 2 types of assets: point assets and linear assets. Each asset has a different colour code change depending on the build status that the asset is in at the time of the view. When clicking on any asset on the map, a popup window opens with details about the chosen asset and the activities linked to it with the completion status of these activities. All activities and the asset are clickable to navigate the user into more details of the chosen clickable link.

- Point Asset Map

The CATS map functionality understands and represents the point type of assets, such as cabinets, cameras and signals as shown in the figure 41 below.

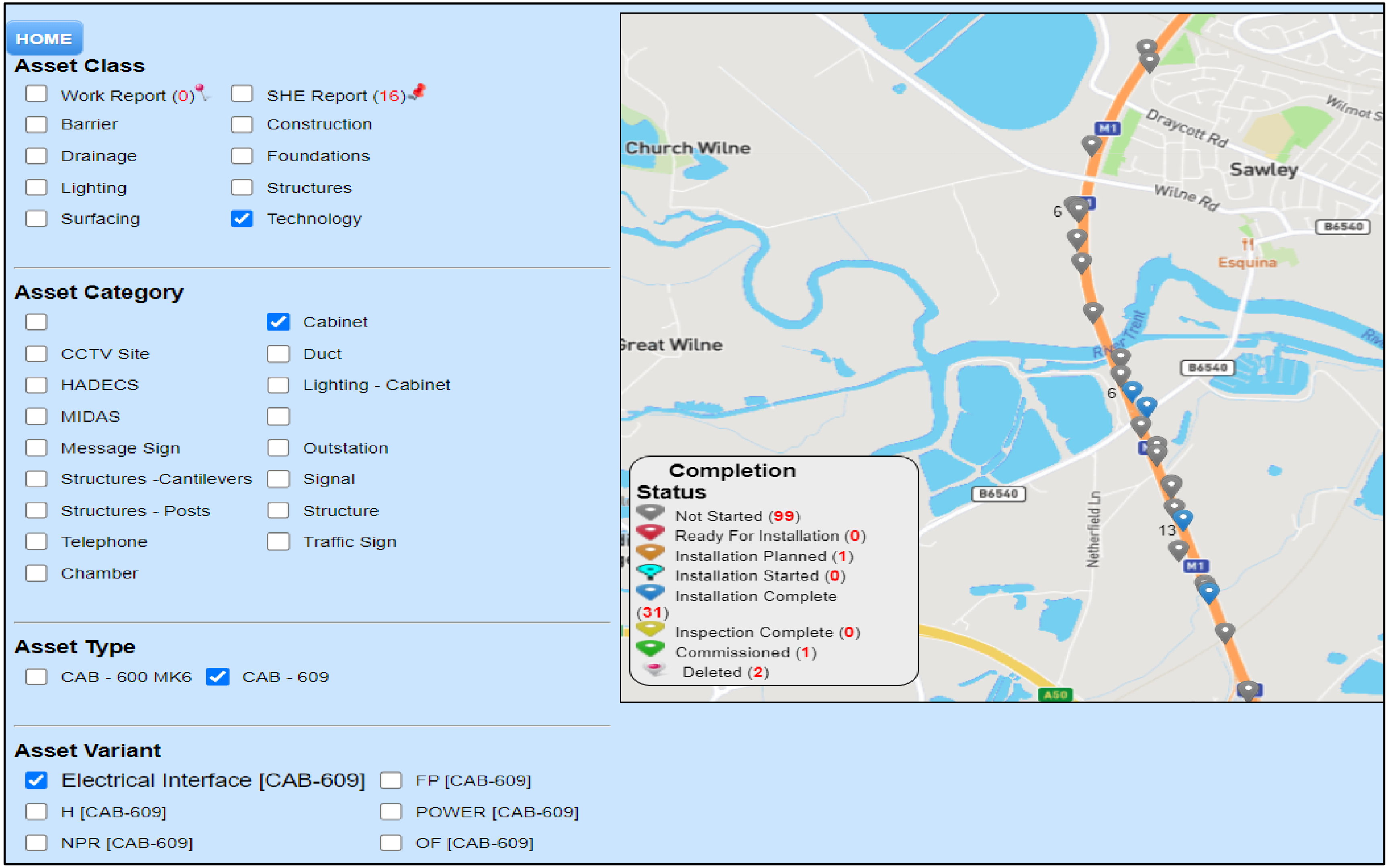


Figure 41: CATS map - point assets

- Linear Asset Map

CATS also has a map's functionality to represent linear type of assets which has start and end points as shown below a picture of ducting assets. See figure 42.

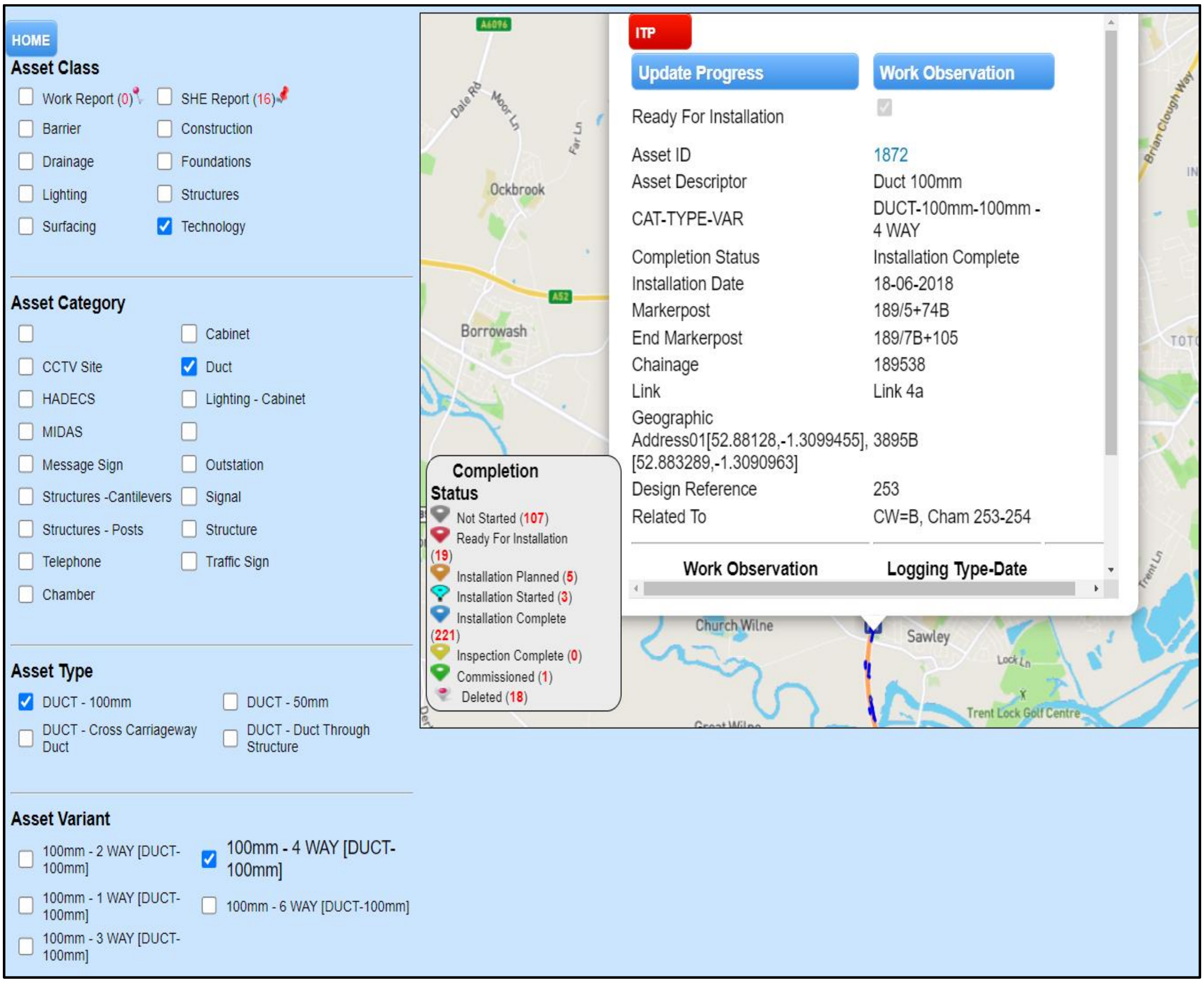


Figure 42: CATS map - linear assets

- Document Map (Design Finder)

Direct link to the last updated drawing documents hosted in the construction project's document control software in use such as Business Collaborator (BC) or ProjectWise. See figure 43.

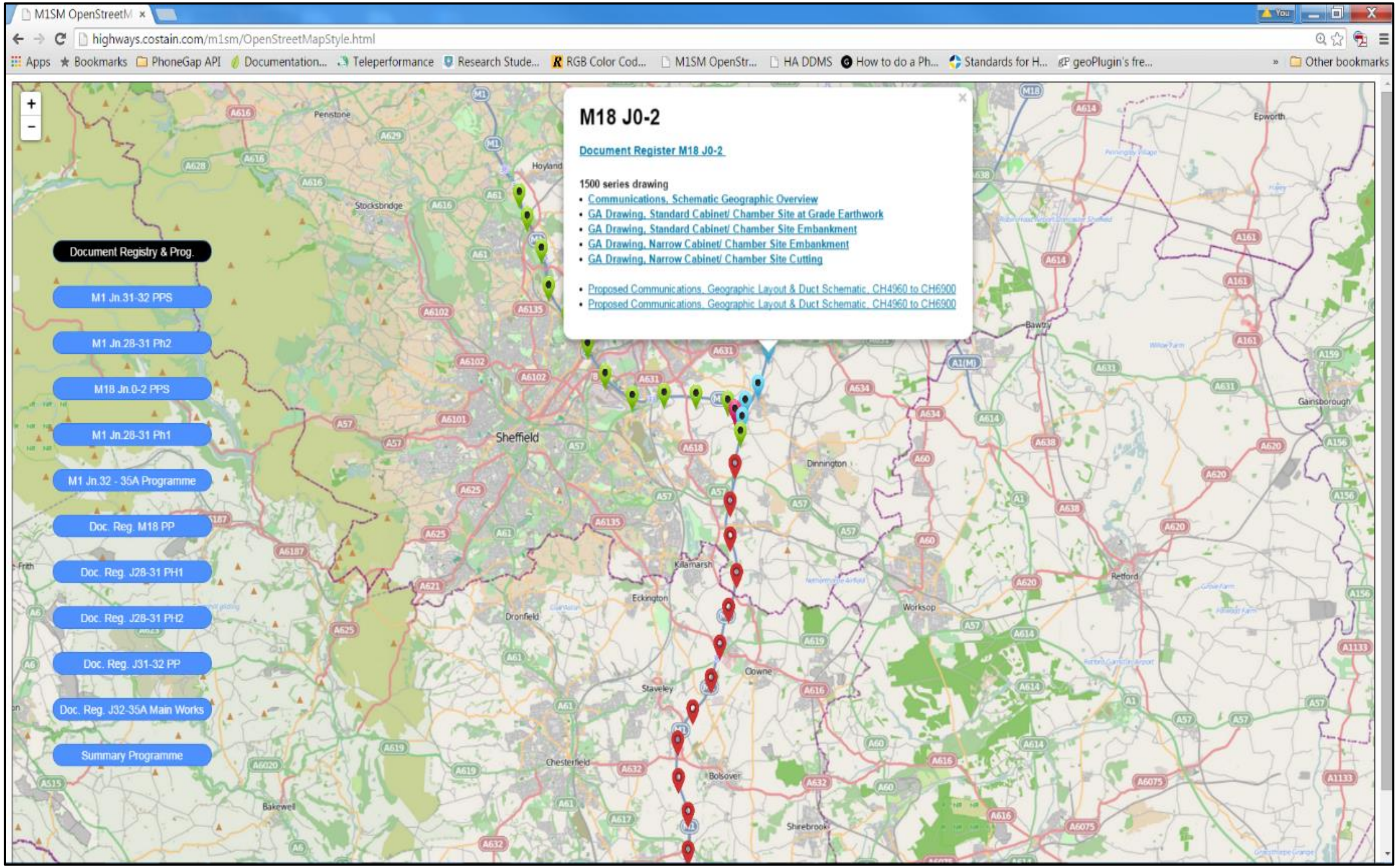


Figure 43: CATS: map - Design Finder for always up-to-date documents

▪ SHE Map: Safety Health and Environment Map

CATS provides a whole process in the shape of a sub-system called (CATS-SHE) to report, manage, update and track hazards and safety observations (see figure 44). It includes:

- An online database system that shows active and archived reports
- A map that shows all the reports and their locations with link for more information per individual report
- An app to report and track the observations, the app works on Desktop – HTML, Android store and Microsoft store

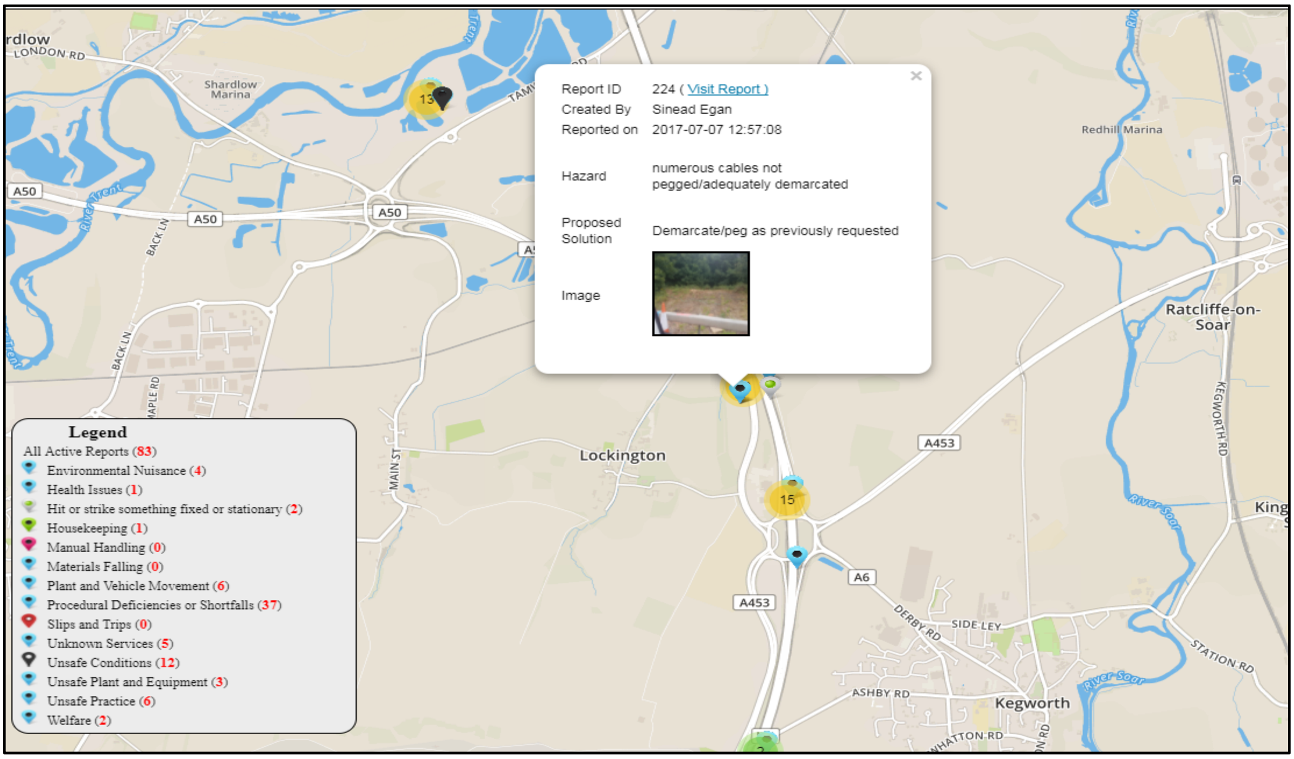


Figure 44: CATS-SHE map for hazards and safety observations

- Defect & Snagging report

Snagging and defects are major attributes in any building and therefore it is the main part of CATS. Because of the flexible activity model, CATS can link tasks and activities to assets from the type of defects and allocate to the observation tab in the asset details to be looked at and fixed before the handover phase. See an example of defects list view in figure 45 below.

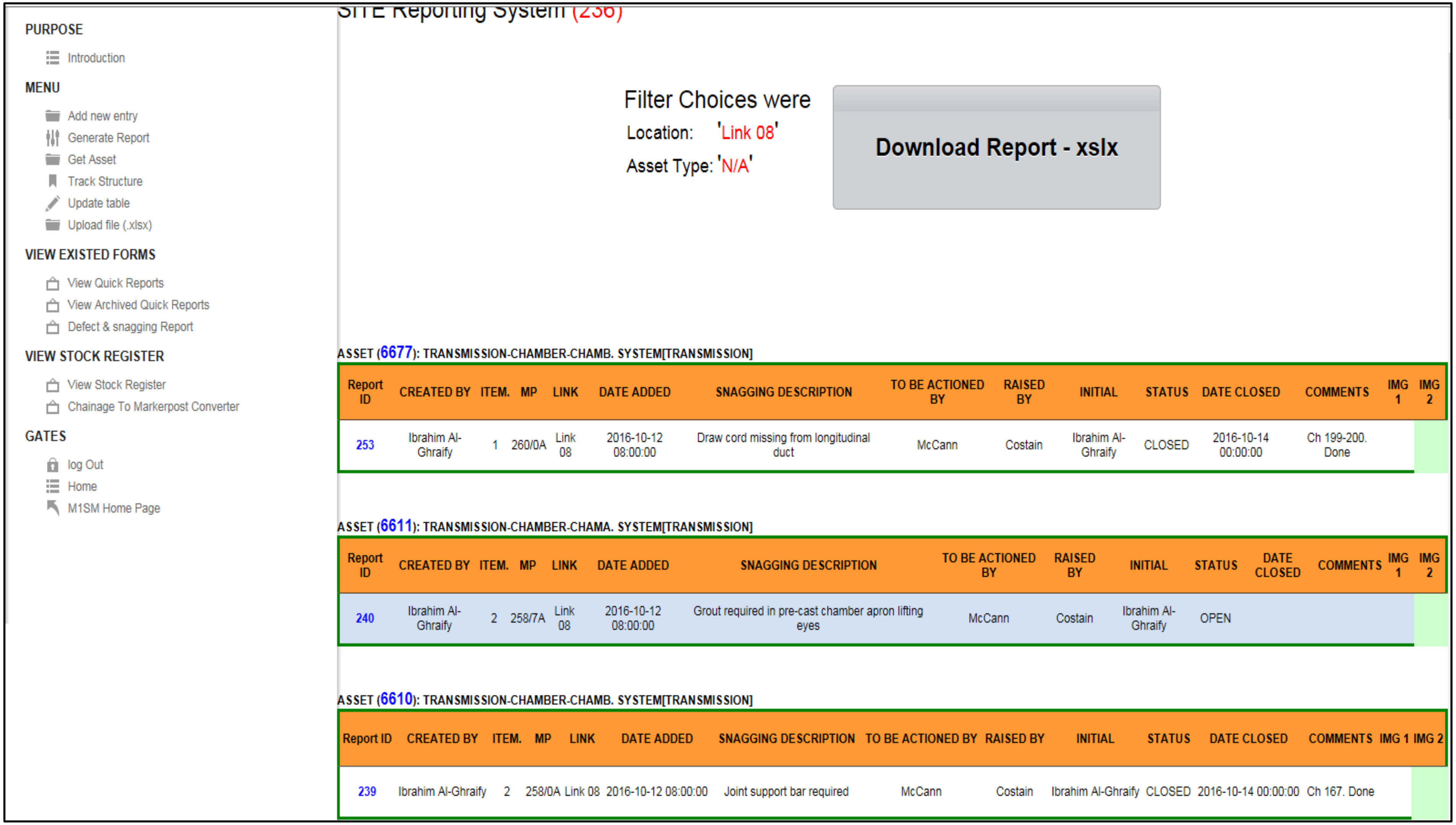


Figure 45: CATS: defects list view

- Tracking and managing defects

CATS has a special process to report, manage and track defects and snagging as shown below. CATS provides the functionality to report a defect, update its details while keeping a history of updates, assign an action owner, close the report and request further details if required. All this data is linked to the assets and is provided to the handover team when required to be communicated to the client. See an example of a defect report page in figure 46 below.

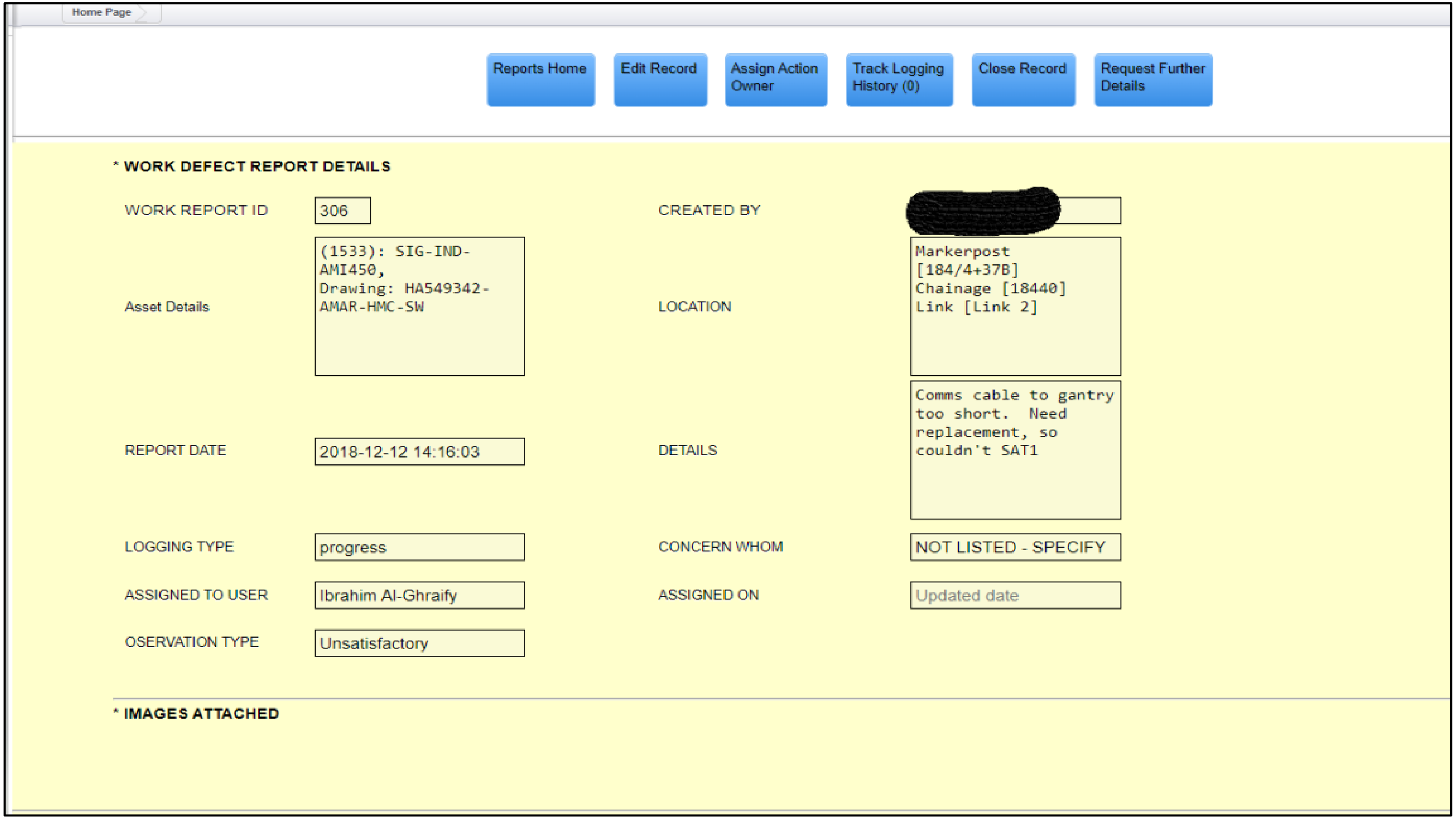


Figure 46: CATS defect report page

- Dashboard to quickly view the Defects progress

CATS provides a quick dashboard specific to the defects divided by how the working sites are divided – usually by links, and a link is a segment of road between 2 junctions or a junction and a service in the motorway. The colour code of green and red refers to red-active reports still to be progressed and green means defects are completed successfully. See figure 47 below.

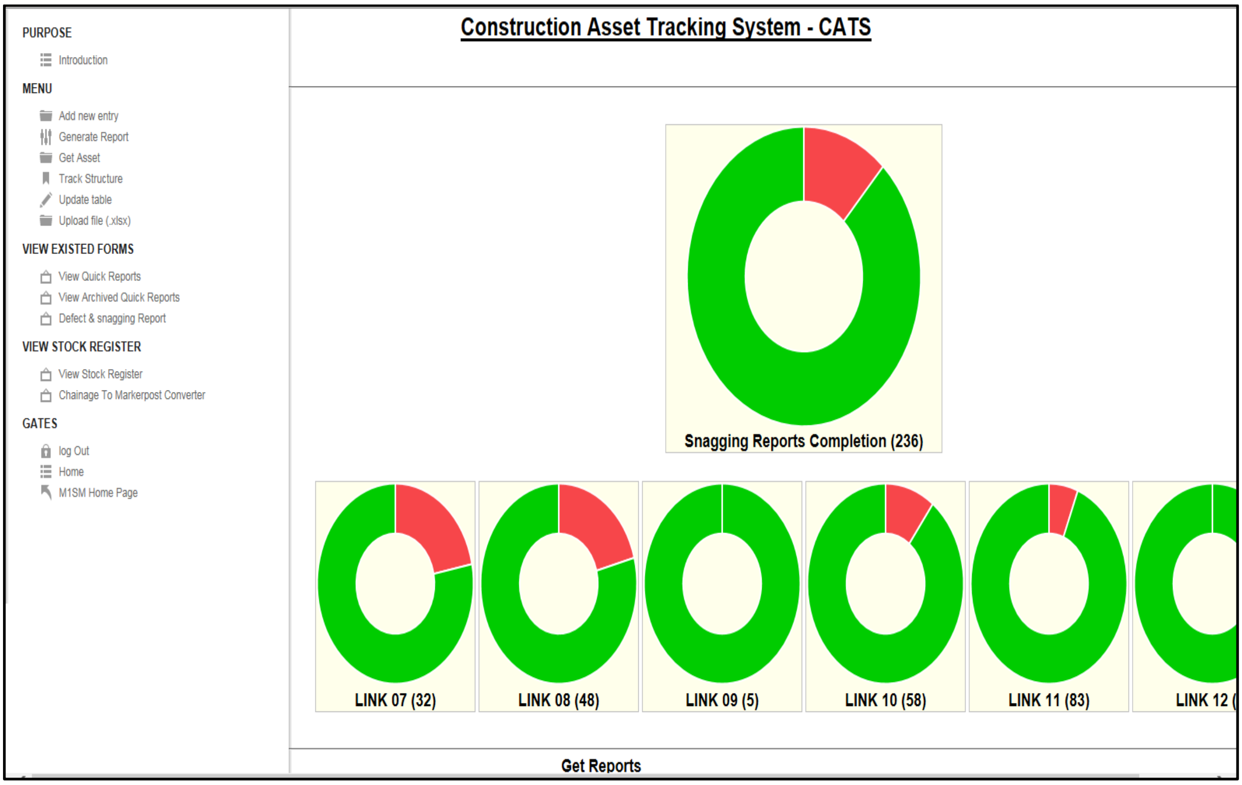
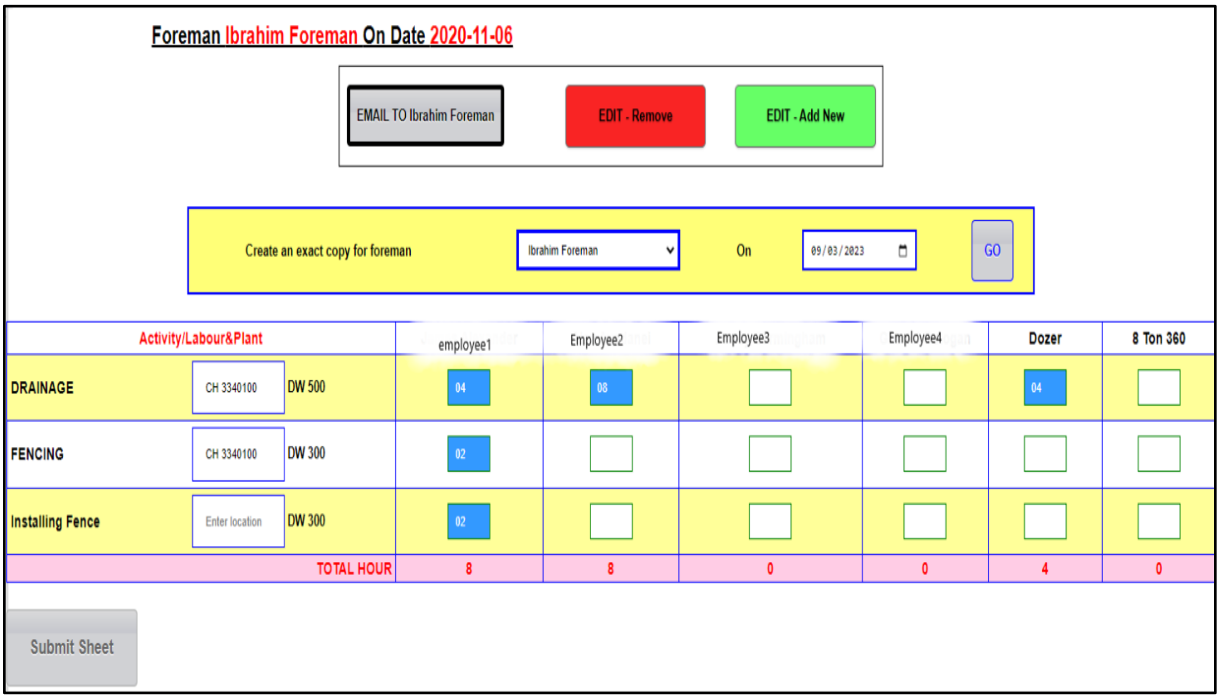


Figure 47: CATS - defects dashboard

- Labour Allocation Sheet

The Labour Allocation Sheet is a form that is created by a foreman who manages a group of workers (called a gang) allocated to a specific work in a specific location using a specific tool for a specific number of hours. All this information is then passed to the accountants authorised to make a payment to the subcontractor where the gang member belongs to. Labour Allocation Sheets also help in planning what tool is needed at any location within the project, and if any tool is needed where to find it and who is managing it. See figure 48 below with an example of digital labour allocation sheet form.



Foreman Ibrahim Foreman On Date 2020-11-06

EMAIL TO Ibrahim Foreman | EDIT - Remove | EDIT - Add New

Create an exact copy for foreman | Ibrahim Foreman | On | 09/03/2023 | GO

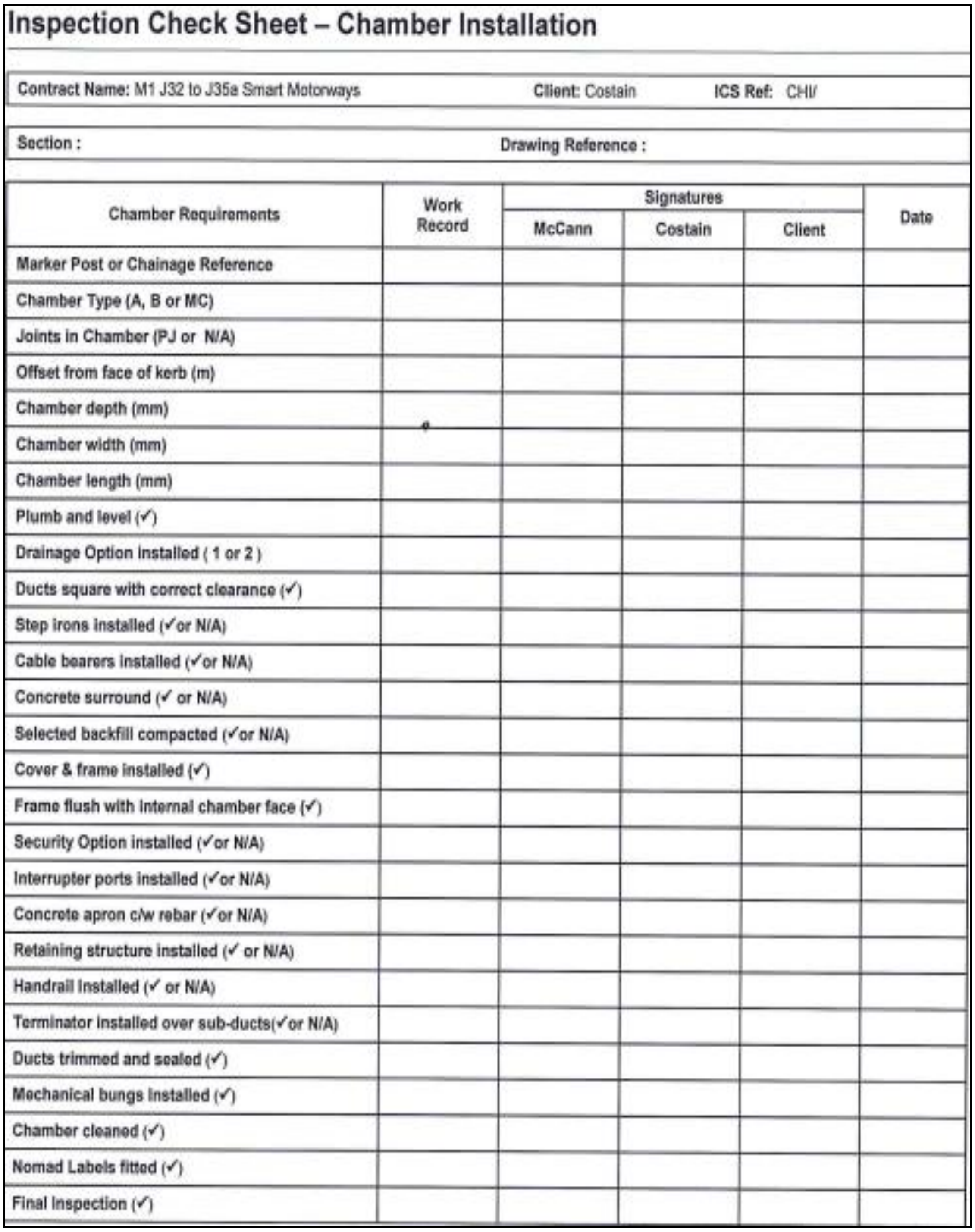
Activity/Labour&Plant			employee1	Employee2	Employee3	Employee4	Dozer	8 Ton 360
DRAINAGE	CH 3340100	DW 500	04	08			04	
FENCING	CH 3340100	DW 300	02					
Installing Fence	Enter location	DW 300	02					
		TOTAL HOUR	8	8	0	0	4	0

Submit Sheet

Figure 48: CATS – digital labour allocation sheet form

- Asset Inspection and Test Plan (ITP)

Every asset type has an Inspection and Test Plan linked to it. This is a group of activities set together to control the installation and to make sure safety and quality are being included into the installation. Each task within the plan could have 1-3 signatures from the subcontractor, contractor and the quality manager. Depending on if it has a hold point, it requires all 3 signatures after completion or not. See an ITP example in figure 49 below.



Inspection Check Sheet – Chamber Installation

Contract Name: M1 J32 to J35a Smart Motorways | Client: Costain | ICS Ref: CHI/

Section : | Drawing Reference :

Chamber Requirements	Work Record	Signatures			Date
		McCann	Costain	Client	
Marker Post or Chainage Reference					
Chamber Type (A, B or MC)					
Joints in Chamber (PJ or N/A)					
Offset from face of kerb (m)					
Chamber depth (mm)					
Chamber width (mm)					
Chamber length (mm)					
Plumb and level (✓)					
Drainage Option installed (1 or 2)					
Ducts square with correct clearance (✓)					
Step irons installed (✓or N/A)					
Cable bearers installed (✓or N/A)					
Concrete surround (✓ or N/A)					
Selected backfill compacted (✓or N/A)					
Cover & frame installed (✓)					
Frame flush with internal chamber face (✓)					
Security Option installed (✓or N/A)					
Interrupter ports installed (✓or N/A)					
Concrete apron c/w rebar (✓or N/A)					
Retaining structure installed (✓ or N/A)					
Handrail installed (✓ or N/A)					
Terminator installed over sub-ducts(✓or N/A)					
Ducts trimmed and sealed (✓)					
Mechanical bungs installed (✓)					
Chamber cleaned (✓)					
Nomad Labels fitted (✓)					
Final Inspection (✓)					

Figure 49: Chamber ITP paper form used in M1SM project

CATS digitises the form with an engine to control the move from one task to the next depending on the task importance and if it requires a signature from all accountable parties or not. Accountable parties are being contacted by email notifications once the task is completed and a signature is required. See figure 50 for an ITP form in CATS.

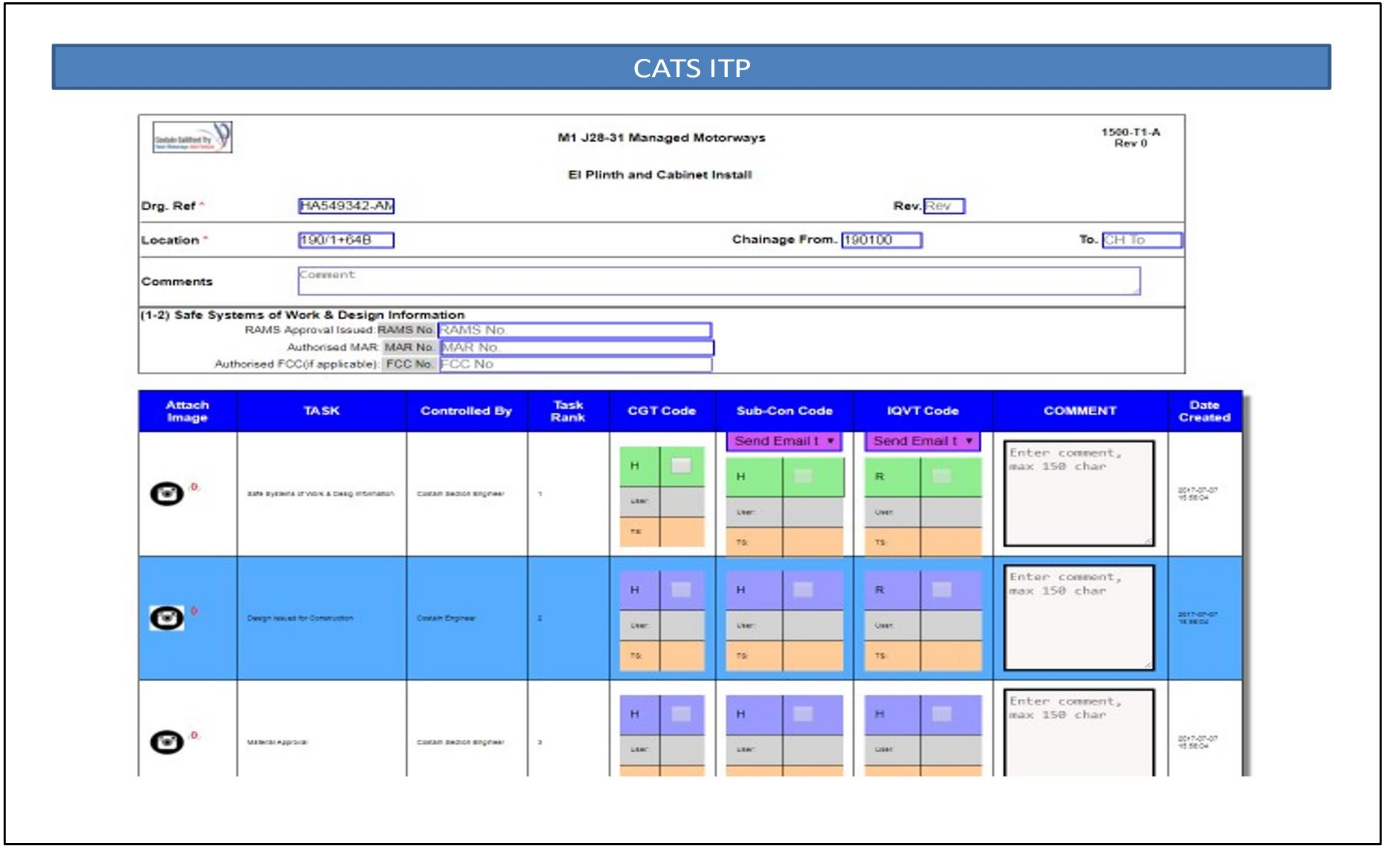


Figure 50: CATS - digital ITP form

8.2.7 CATS Dashboard and Reporting

CATS has an interactive dashboard (figure 51), which provides a visual representation of the status for each asset type. This is colour coded to indicate the status of the completed and still in progress assets. When clicking on any of the bars, it filters out all assets in the database to show the ones chosen with the ability to export the filtered assets in Microsoft Excel format.

Figure 51: CATS asset dashboard

8.3 Application Features identified from literature

In section 7.1, we discussed the common features of the existing applications found in academic literature. Those features were categorised in core asset models, research objectives, and system factors features.

This section will discuss how CATS satisfies these features.

8.3.1 Core System Model

This includes the following

- **Asset model and Meta-data**

This feature was fulfilled by an asset model enhanced with metadata that confirms to the client's (National Highways) databases and being BIM compliant. To make sure that the CATS asset model has the right metadata, a thorough investigation of Asset Database Management Manual (ADMM) was done before creating CATS asset tables.

- **Activity model**

A thorough understanding of the construction process and documents involved in the construction build process was investigated to come out with activities and tasks models. This includes Inspection and Test Plans (ITP), Non-Conformance Reports (NCR), etc.

- **Document model**

Reading and understanding design, management, and programme documents was vital to understand the day-to-day job of the construction projects. This practice has resulted in a design finder map that links location on the working site with the right documents stored in Common Data Environment (CDE)

- **Group and sub-group**

Understanding the ADMM classifications of different asset types shaped the hierarchical relationship between assets in CATS. For example, concrete *foundation* is a parent of a *column,* which is a parent of a *beam,* that is a parent of a *sign/signal.* Also, tasks related to a specific asset type in any location on the site, can be attached to the same asset type but in a different location. This increases CATS automation of assigning which group does the asset belong to and assigning common tasks to it with ability to change and modify it where required.

- **Location**

Assets come in different types and must be installed in different locations, with examples of types being point, linear, area and volumetric assets. Therefore, it is vital to model the representations of an asset's location for CATS to work/integrate with other systems smoothly, especially at the time of handover where location is required to fit the clients' databases.

8.3.2 Features of this study objectives:

Study objectives were delivered by CATS in the sections of: Efficiency in cost & time, Interoperability/ Integration, Self-Extensibility, and Future proof.

- **Efficiency in cost & time**

Digitising the built process, offering a way to report defects and snags in the time of action, and supporting handover process provided extra efficiency in saving cost and time. This is clear in the interviewees' comments in section 5.7.1 and 5.7.2.

- **Integration**

CATS provides a simple and easy way to input data into the system by uploading Excel files and updating the data either manually or by uploading files with updated asset data. CATS also simplifies the output data by providing a map to quickly understand the progress of the work. Furthermore, CATS enables users to export an Excel file which allows the manual update of the file if needed before uploading it to the client's databases.

- **Expandability, Flexibility and Future Proof**

CATS provides a flexibility in the asset model that enables any type of assets to be easily included and represented in CATS. This future proofing comes in the shape of attaching a property to any assets that can add any features to any assets that are not common or already exist. These properties of the assets are included with the assets when it is exported to enable better integration. This is also the case when the activities model has been created, as any activity can have one or many tasks which are treated as properties of the activities.

8.3.3 System usage and user influences

Features of the software systems related to the way they have been used which includes system usage, real-time data, and ability to share data with stakeholders has been included in CATS. It offers accessibilities from different platforms like Windows and Mobile apps to provide real-time data input. This data is then analysed and viewed live for better real-time reporting.

Table 6 below shows how CATS fulfilled the features of the core mode, the features of research objectives, and the features of system factors that were set after investigating the government's manuals and reports as well as the existing models discussed in section 6.1. Table 6 highlights in the last column how CATS is a coherent model by fulfilling all the features that are set as requirements throughout this study in section 5.9 and 7.1.

Feature\Application	Interlinking Life-Cycle Data Spaces	MIRE	Field data collection	HAMP	RAMs	Water Pipeline Database	Water Infrastructure Knowledge Database	CATS
Features of the Core Asset Model								
Asset model	✓		✓	✓	✓	✓		✓
Activity Model	✓		✓	✓				✓
Document Model	✓		✓				✓	✓
Data Structure	✓	✓		✓				✓
Data interrelationships – hierarchy	✓		✓				✓	✓
Groups and subgroups				✓			✓	✓
Location	✓	✓		✓			✓	✓
Features of research objectives								
Efficiency in cost & time	✓		✓	✓	✓	✓	✓	✓
Interoperability/ Integration	✓		✓		✓			✓
Self-Extensibility								✓
Future proof				✓				✓
Features of system factors								
Usage (Accessibility, Different platforms, user behaviour)			✓			✓		✓
Real-time Data	✓		✓					✓
Data Sharing	✓	✓	✓				✓	✓

Table 6: Existing Applications and the relation with the Proposed Model Features – Research gaps

8.4 Summary

This chapter discussed the software methodology of Agile that was followed in creating the software platform of CATS accompanied with the functionality and screenshots.

9.0 Evaluation of CATS by Interviewees

9.1 Introduction

Chapter 1 discusses the research motivation, while Chapter 2 explores the government's objectives outlined in their plans and strategies for the construction industry. Chapter 3 conducts a literature review of the challenges encountered by the construction industry. Data collection and methodology are discussed in Chapter 4, followed by an explanation of the current situation and the interviewees' views on the issues and proposed solutions of these issues in Chapter 5. Chapter 8 introduces the CATS model developed as a solution for digitising the construction industry, aiming to meet governmental requirements and the interviewees' wish list of features to address current industry practices.

In this chapter, the interviewees reflect on how CATS addresses the problems they encounter in managing construction (Section 9.2). Section 9.3 discusses the interviewees' overall thoughts on CATS, how it could be improved, and what should be done next. In Section 9.4, industry recognition of CATS will be discussed before summarising the chapter in Section 9.5..

9.2 Evaluation by Interviewees of How CATS helps in Dealing with the Problems

This section discusses what the interviewees think about CATS and how it helps answer their views on major problems. All the interviewees saw a clear need for CATS or a similar tool. For example, P1 emphasised how important it was for contractors when she said

> *"If we don't implement something like these systems, we will get left behind and won't become 'digital by default'. Schemes will cost more and overrun etc."*

Moreover, Participant P3 in the interview data emphasises the necessity of achieving BIM compliance to maintain a presence in the market and collaborate with the client, specifically National Highways (NH). P3 highlights that an essential aspect of improving processes is to raise awareness about any obstacles within the workflow, enabling stakeholders to understand the ongoing developments

9.2.1 Digitising Built Process

Commenting on the new digital way stemming from the project, P11 noted that

> *"contractors will be able to standardise their offering to the client".*

This point was also suggested by P3 as he stated that having a

> *"standardised method in place is useful for not only just controlling how delivery of construction projects is made. But also measuring them in terms of not just financial but from time benefits and the agreed deliveries is always useful".*

Regarding the point of how CATS would provide better ways of working and managing construction projects, P12 expressed his positive views on CATS by saying

> *"I'm a big fan of that. … I'm very keen on what you just demonstrated there on creating vanilla, um plans and activities and then you can just add those to all of your events and then you can take your way through them all, and I think that's particularly important because sometimes you're doing things individually per asset and you're working way through your workflow and on other occasions we might be working on one work activity across multiple assets".*

He also added

> *"the ability to modify your work string"*

when he expressed his views on how future proof the systems should be and this is what CATS has as functionality features of adding tasks to any chain of activities whenever required. Moreover, P6 added that

> *"and making decisions based on where you are against that plan"*

This means that managing projects digitally enables a better decision making process, allowing it to be quicker and more accurate.

It is important to explore how the CATS map interface, along with the color-coded system (refer to the Map View in section 8.2.6), facilitates the management team in swiftly identifying the extent of completed and ongoing construction by simply filtering assets on the map. This was praised by P7 when a comparison of documentation progress percentages is a must to know and how CATS may help in this when he said

"I liked what you showed there on the application that shows the colour code, and that's what I was trying to get the guys in BIM to do for me, so that we could say because documentation was so important to give you the go or the no go. If we could demonstrate through the BIM as it comes through our database and it updates, the BIM automatically shows completion. Then we colour code different layers in the BIM. You have a pictorial image of all the pipelines and gas lines and all the other processes and you can see exactly where you were in terms of documentation"

P3 also expressed his view on how CATS understands asset's relationships and uses maps and Geographical Information System (GIS) to report the construction progress

"I like the fact that there is an understanding of the asset relationships … visually I think that looks quite good as well. You know, I think especially the GIS. Maybe SHE [Safety, Health and Environment] got captured there. I think that's all very useful. So yeah, quite. I think conceptually, yeah, I think that's a good idea"

P2 specified how CATS confirms real-time data collection and reporting

"CATS is resilient in terms of data integrity, and it's also operating in close to real time … so that's the other benefit of cats as it captures information absolutely at point of delivery. So there is no loss of data then".

Additionally, one of the supportive feedback items from the participants regarding CATS was from P11 when he stated

"It's a no brainer. It is the way we should be doing it. It's just the fact that you can drive the activities, and you get real time data. Everything we were talking about earlier is, you know, what needs to happen, how we can improve this system, or systems like this are the way forward".

His opinion came from a real experience of CATS outputting data in a format that is user friendly to enable a quicker and easier handover process. P5 also agreed with the previous claim when he said

"CATS is a great tool for structures"

and P2 summarised it by expressing his opinion saying

"the transition from our current way of working to a productionised environment. Uh, it is a step change, It's a fundamental change in how we work …".

Moreover, P12 expressed that CATS helps in identifying critical resources

"And what that will help with is identifying critical resources … If you're only going to get the traffic management guy involved when you've got half mile stuff ready, then once you understand that, you understand how to do your scheduling around critical resources, and that would be a great advantage".

9.2.2 Cost and Time Savings

P1 expressed the importance of using CATS in construction projects by touching the aspect of keeping spending more cost and time as long as construction projects are away from digitising their built process

"I think it is the way we should be heading. If we don't implement something like these systems, we will get left behind and won't become 'digital by default'. Schemes will cost more and overrun etc."

9.2.3 Design Specifications

CATS supports data integrity, scalability, good performance, availability and security. It also supports apps that work offline by storing the data locally until the device has an internet connection to sync the data to the data store.

CATS was designed to work on different platforms using internet and web based applications such as Google Chrome or Microsoft Edge. It was also created with a couple of supported applications working on Android systems to capture reports and updated progress.

The asset model of CATS was designed to host any type of existing assets and any new assets may be added in the future, as it categorises assets within 4 levels and builds a relationship between them as parent and child.

9.3 Interviewees Assessment of CATS and how it could be improved

P1 mentioned the need to make CATS more user specific and friendly, appreciate feedback from the end users, and avoid project specific customisation as mentioned here

> *"Make it more end user specific and friendly. Nothing too complex or onerous. Don't use customisation per project. Get feedback from the bottom up and the top down, don't just focus on one side of the story"*

However, P9 and P2 stress the need to develop CATS further and take it out from being a proof of concept to being adopted and developed further to include all construction phases from planning and design through to maintenance and operation as P2 stated here

> *"We obviously need to develop CATS from the prototype that it currently is to a functional suite software. So those can go hand in hand, but what we need to do is design, the production approach and CATS. At the same time, hand in hand so that they support each other … You try to bring in something that's radically different. People immediately switch off. They don't want to know, they want to go back to working with post it notes and drawings marked up with ballpoint pen, so you know, breaking that behaviour. Um? Obstruction is fundamental"*

in order to describe the importance of tackling human resistance factors.

The importance of capturing data in real-time on the spot once it happens is a point that is discussed by P3

"I think a lot of that is down to capturing information on the ground … I think getting an understanding of where you are now helps at least shape [what] your next steps are going to be into the future".

Moreover, P13, P12, P8, P7, P6 and P4 argue the need to have a platform that integrates with other systems and apps in use, and to make sure to continuously adapt to changes and client needs, P4 said

"I think that's the way you're doing it in terms of an integrated system that will give you all the tools you need to deliver a project, along with continuously adapting to changes and client's needs".

P5 mentions that CATS needs to be extensible to host more asset types such as civil assets (drainage, champers, etc…) as he stated here

"CATS is a great tool for structures but needs work on Civils and how it incorporates the HE SRN (Chainages, nodes and XPS) […] Output for CATS must be as per ADMM requirements, attributes in the correct order for either IAM-IS (see section 6.2.5) or CONFIRM databases[6],"

Also the extraction of CATS should conform to the National Highways (NH) manual and database structure.

P12 stresses that Information Systems and CATS might need to adopt the ability to update work strings as he mentioned here

"the ability to modify your work string. Yeah again it at work stream might have seemed exactly right when you started, and so with some sort of within some sort of breakdown structure"

9.4 Industry Recognition of CATS - TechFest Shortlisted

CATS was shortlisted to win TechFest Award in 2018 as shown on the screenshot below in "Best Use of Technology: Enabling Smart Infrastructure" section. The Costain Team, including myself, had to present and answer questions in a live judgemental

[6] Confirm Database: the database that handover process report to, which contains references to all other databases

panel in front of other attendees from the industry. See figure 52 for details published in 2018.

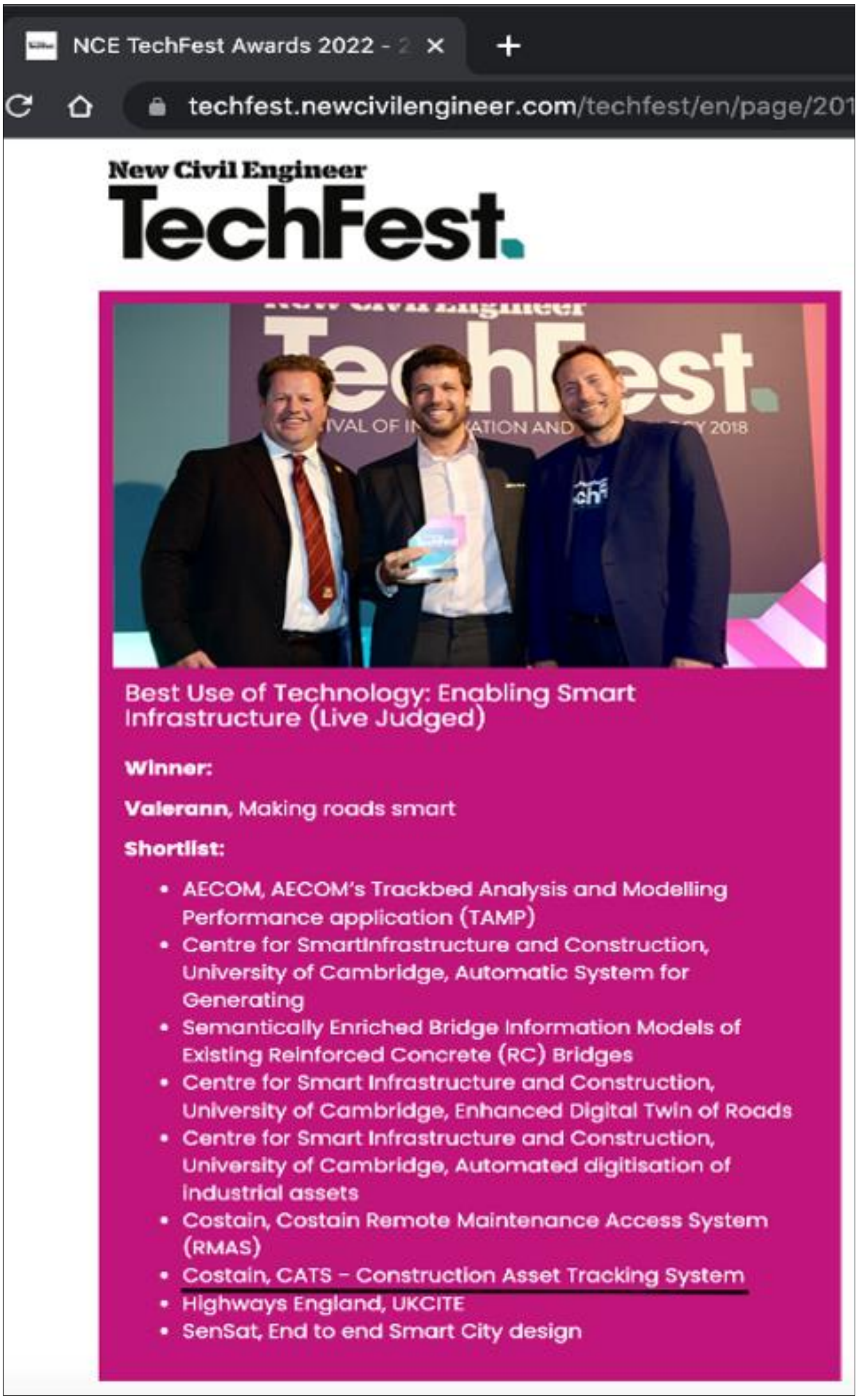


Figure 52: TechFest publishing CATS

9.5 Summary

Interviewees evaluate CATS and its effectiveness in addressing construction management problems. They express a clear need for CATS or similar tools, emphasising its importance for contractors to avoid falling behind in the digital transformation of the industry. Participants highlight CATS's role in standardising processes, improving workflow efficiency, and enabling better decision-making through real-time data collection and reporting. They praise features like the map interface, which facilitates asset tracking and documentation progress. Additionally, interviewees recognize CATS's potential for cost and time savings and its ability to support various platforms and offline functionality. In Section 9.3, suggestions for CATS improvement include making it more user-friendly, expanding its functionality to cover all construction phases, and ensuring integration with other systems and apps. There's also a call for CATS to be adaptable to changing client needs and to support a wider range of asset types. Overall, interviewees acknowledge CATS as a valuable tool for modernising construction management practices but suggest further enhancements to maximise its effectiveness.

Interviewees express their views on the components any digital model should have, as summarised in Table 5 in Section 7.2, and compare these features with existing solutions, including CATS, in Sections 6.1 and 8.3. Table 6 in Section 8.3 confirms that CATS meets the wish list requested by the interviewees.

10.0 Discussion

This chapter delves into a discussion of CATS and how it benefited the industry and academia. The history of CATS is stressed in section 10.1 followed by an assessment of CATS in section 10.2. section 10.3 talks about the way ahead of CATS before highlighting the overall assessment of the project.

10.1 Chronology

The project was conceived in 2014 and started in January 2015. The two main motivations for the project were the government's vision of BIM / DBB forming the basis of government construction projects from 2025 onwards (Chapter 2), and Costain's desire to improve the efficiency of construction management (Chapter 3). I specified and developed CATS between 2015 and 2018. The specification was based on my knowledge of highways construction gained from working at Costain supplemented with conversations with colleagues at Costain, particularly Dave McHugh, the Technology Integration Manager in Costain. The data collection interviews detailed in Chapter 4 took place between September and December of 2020. Their purpose was a combination of evaluating CATS, introducing CATS to a wider audience, and determining a list of requirements that an asset tracking system should meet (Chapter 7).

The main advantage of this chronology was that the prototype, i.e., CATS, provided the interviewees with a deeper understanding of the issues that the final asset tracking system needs to deliver. This in turn stimulates more penetrative insights (Huber et al., 2020).

A secondary advantage of the chronology was that the interviewees are providing an independent assessment of the strengths and weaknesses of CATS, without reference to a prior list of requirements they may have put forward before CATS was developed. Consequently, the checking against the requirements in Table 4 (section 7.1.3) was a separate (independent) validation stage as the requirements emanated from the literature and the team I was a member of.

10.2 Overall Assessment of CATS

10.2.1 Meeting the goals of conforming to the DBB

Following on the document review of National Highways policies and their Asset Data Management Manual (ADMM), along with the interviewees feedback and thoughts, CATS model has made significant progress towards digitising the construction build process.

CATS revolutionises project delivery by adopting a methodology similar to the streamlined processes of factory production lines, effectively digitising and optimising the construction process. This system not only facilitates integration with other Control Management Document System (CMDS) tools like Business Collaborator (BC) and ProjectWise, as detailed in section 6.2.3, but also interfaces with the design phase. By accepting asset data in the form of .csv or Excel files, CATS ensures a cohesive connection between design and construction. Furthermore, CATS empowers users to extract assets and activities data from the system at any time, enabling updates, modifications, and inclusion in handover data or integration with BIM for a comprehensive link between the design model and real-time construction data.

CATS as a digital system contributes to Total Quality Management (TQM) by enhancing various aspects of quality control and assurance of construction projects. For instance, CATS automate processes, and provide real-time data access and reporting, allowing for quicker identification and resolution of quality issues. By integrating CATS with TQM principles, construction projects can improve efficiency (section 3.9), reduce errors (section 3.6.1), and enhance overall product and service quality. Digital tools such as CATS, automated inspection systems, and real-time monitoring systems facilitate data collection, analysis, and decision-making, enabling construction projects to implement TQM practices more effectively.

Regarding cost and time saving, CATS implemented the ideas from the interviews within its process, while it stores data in the time of activity and uses one single source of truth as its data store, it enables real-time reporting and saves the time of an administrator having to collate the information required for reporting to managers or whenever it is needed for a handover stage. CATS also has the ability to export the data in Microsoft Excel format in the structure of the National Highways (NH) databases such as TPMS to enable quicker and easier reporting process and to save the handover team time in collating this information when compared to traditional ways of handling the hand over process.

The CATS functionality in road building construction, which includes real-time reporting of work progress, documentation and image upload, and defect or snagging reports, enhances the system's goal of saving costs and time in reworking by enabling a proactive approach to work through real-time reporting and dashboards linked to CATS. These dashboards provide insights into the number and location of defect reports, the percentage completion of tasks, and links to the construction process and specific assets. All of these features empower CATS users to take action when necessary, preventing issues from escalating and avoiding costly delays, especially during critical project phases such as when projects are open to traffic.

In terms of its influence on societal aspects, communication, and collaboration, CATS introduces a link between the construction site and the production line reporting screen in project offices. This connection is established on real-time data, directly sourced from the site whenever a defect or non-conformance report is created. In urgent situations, such as a member of the public accidentally driving into a construction site requiring immediate traffic management intervention, CATS will notify the appropriate team in the office for prompt action. For instance, CATS would trigger a notification to the traffic management team and assign them the task of leading the individual out of the site safely.

When it comes to addressing behaviour issues from the CATS’s perspective, the focus was on creating a simpler process engine and a user-friendly interface. Users can access most functionalities with just 2 or 3 clicks, making it more intuitive and easy to use. The team was always available to answer any questions related to CATS, and training sessions were organised for system testers to ensure smooth adoption and understanding.

CATS shares knowledge with the team through a dashboard that can be extracted and modified to be published to the rest of teams in a sign of a lessons learnt process.

10.2.2 Future improvements of CATS

Adhering to the feedback provided by the interviewees regarding the improvements that CATS need to have, it is recommended to take CATS further by applying its ability to read files in different formats. This could also mean that it would be good if CATS can automatically connect to the project management software to read in the planned process of the project and automatically create short and long term plans of the project work. Furthermore, the output of CATS is currently in Excel format. This also would be better to be enhanced so that CATS could create an automatic update to the project's management platforms such as Primavera 6. This was mentioned by P7 and recorded in section 9.2.1 and 9.3 by P13, P12, P8, P7, P6 and P4.

Currently, CATS could be integrated with the BIM model using a location of assets, it would be very beneficial to integrate to BIM through BIM's unique identifier so automation with BIM is simple and straight forward. This was also mentioned by P7 and recorded in section 9.2.1.

Standardisation of the build process is also needed between construction projects as much as possible. Currently CATS deals with many forms of project management of the build process such as Inspection and Test plans (ITP) (section 8.2.6). However, more of enforcing a standard way of building assets may be recommended especially if it comes from the client (National Highways) to make sure the majority, if not all, construction projects are following the same standard in their project management process.

Moreover, it is highly recommended to implement comprehensive reporting and dashboards to support the project's senior management team in the decision-making process. Currently, CATS's dashboard focuses on reporting the progress of asset construction in terms of activities performed per asset. However, expanding reporting to include procurement, cost, and subcontractors' progress could add more value to the system. Reporting and the dashboard were discussed in section 5.6.4.1.

User experience is another area that could be improved in CATS. This could come in the shape of creating an activity reporting app on all platforms to enhance the experience of reporting the progress through their mobile devices. Currently, CATS has an android Work app with a simple user interface that may need an improvement. The Apple platform does not yet have an app. This is because the CATS model was developed as a prototype, rather than as a complete platform. This point was also mentioned in section 9.3 by P2 and P9.

The importance for CATS to manage more than building technology assets but also to include all civil assets such as pavements and walls was also recommended by the interviewees in section 9.3. Currently, as CATS includes the data of technology assets and drainage, it might be beneficial to include all civil assets of construction projects too.

10.3 The Way Ahead

The discussion in section 10.2.2 shed a light on the field where CATS may need improvements. Therefore, because CATS is just simply a prototype of a proof of concept, it is recommended by the construction industry in general and Costain as contractor, to adapt the model further to build a better version of it. This would include better integration and a more user friendly system with enhanced reporting and dashboards, besides standardising their build process to get the best outcome of the CATS model.

Moreover, it is highly recommended to test the CATS model in another field of construction such as the Water or Rail sectors. Being able to accommodate different asset types in CATS makes it uniquely able to accept new assets such as Water Pumps that are in use in the Water sector but not Highways. Also, train tracks are another example of linear assets that are used in the Rail sector but not in Highways and CATS could accommodate these too.

The data gathered in this project could also be considered as valuable insight to any future researcher interested in managing the construction industry. It provides an insight into how the current practices of construction projects are managed as well as the existing drawbacks and the recommendations on how to tackle them.

10.4 Overall Assessment of the Project

This project has evolved from its original goal of creating an asset tracking model for the construction phase to providing assistance and support to the handover team during the handover stage. This development journey involved integrating with the BIM model and collecting reports on snags, safety, and inspection and test plans, demonstrating how CATS has evolved over time.

However, the project's potential impact could be maximised if it were part of a research group, allowing for workload division. This would enable the development of a completed platform rather than just a prototype, which could be directly implemented in the construction industry to enhance their work processes.

10.5 Summary

This chapter started with a project history with a motivation of where the idea was initially developed. After that, an assessment of CATS and how it met the motivation and goals was discussed before delving into the future improvements that were recommended to be added to CATS. It then summarises the way ahead for CATS followed by the overall project assessment by the researcher.

11.0 Conclusion

11.1 Introduction

This chapter summarises the major results provided throughout the thesis. I evaluate the study's accomplishment of its objectives and its contributions to the body of knowledge in this area in section 11.2. I also assess this study's originality and its usefulness in terms of the construction build process's digitalisation in section 11.3. I also discuss the study's strengths and weaknesses in section 11.4 before making suggestions for future research opportunities in section 11.5.

The current study investigated the possibility of digitising the construction industry, with special reference to the build phase of the asset lifecycle. Its main goal was to investigate what constructors and the supply chain need to do to be compliant with Construction Strategy 2025, and therefore to explore the existing solutions and to provide one coherent model that supports digitisation of the build process. This would allow better management of highways construction projects and enable projects' to be BIM compliant.

Interviews with experienced staff members in Costain provided the core knowledge of the functionality required from the CATS model. This was supplemented by National Highways' data manuals documents (ADMM, COBie and TPMS structure) and handover processes as well as existing models discussed in section 6.1. This was then evaluated and assessed by participants with experience in the construction process, including a director, project managers, BIM, technology and handover managers in Costain.

The data collection phase involved the procurement of primary data through online interviews using Microsoft Teams, primarily with Costain employees. Subsequently, the collected data underwent thematic analysis to dive into the interview responses and their implications. This process aimed to examine, identify, and gain a more profound understanding of the main challenges, required solutions, and the alignment of CATS functionality with the government's Construction Strategy 2025 and DBB plan.

11.2 Meeting the study aims and objectives

This study started in January 2015 at a time when there was not much literature covering effective solutions for digitising highways construction industry. This was particularly true of the domain of the build phase of the asset life cycle within the practices of contractors such as Costain. Therefore, the main aim of this study was to explore the existing solutions and to examine how they fitted with the government's 'Digital Built Britain' strategy and the alignment with 'Construction Strategy 2025' that was published in 2013 by the government. After that, develop a cohesive platform to fill the gaps in the current models.

This study achieved a deep understanding of the current settings of the construction processes within Costain projects. The data gathered insight from employees in Costain with roles of quality and technology directors, project managers, team managers of technology and handover and BIM designers. To achieve the study aim, the following research questions were addressed and current practices was examined as follows:

- Q1: What is needed to be done by highways contractors and supply chain members to integrate with Digital Built Britain?

The challenges associated with traditional construction methods were evaluated based on both literature and interview data. The literature review encompassed existing solutions, the government's Digital Built Britain (DBB) plan, and the enhancement of project quality through Information Systems (IS) as a Total Quality Management (TQM) tool. This analysis highlighted the need for a cohesive digital platform like CATS to address the issues identified in the interview data (discussed in section 9.2), aligning with the government's Construction Strategy 2025 and DBB plan while digitising the construction build process.

- Q2: How well does the Construction Asset Tracking System (CATS) meet the requirements of DBB and BIM compliance?

The answer to this question was enabled by identifying the core elements of CATS. The core elements identified were the asset, activity, document and location (see section 7.1 and table 5 at section 7.2) accompanied with supporter sub-models of groups, tasks and attributes that were used by CATS to store data (see section 8.2.3). The data stored in these models are then used to efficiently support the handover process as well as integrating to the raw assets within Building Information Modelling (BIM) for the project. The link with BIM's assets takes the form of direct retrieval data from the database depending on the assets' location and types that are shared between both models (BIM and CATS), see section 8.2.4. The literature showed that there was a lack of applications to combine all the model parts together to achieve this research's aim. This was remedied by CATS.

11.3 Research contributions

This study's main goal was to investigate what constructors and supply chain members need to do to be compliant with Construction Strategy 2025. This research was accomplished by gathering insights from industry experts including directors, managers, and BIM designers. This research is notable for being the first of its sort in the construction sector.

It became clear over the course of this investigation that there is a gap in the body of knowledge about all-inclusive solutions for the construction build process. There are not many comprehensive systems that can efficiently plan and monitor construction operations, reduce rework, accelerate handover procedures, and conform to the DBB plan.

From a practical standpoint, the significance of digitising the construction build process and the need to produce knowledge for the benefit of the construction industry as a whole, highlight the need to increase the volume of existing knowledge on Information Technology (IT) in the construction sector. This research makes a significant contribution to this body of knowledge and to the future strategies for digitising assets during the construction phase.

A number of important conclusions came from the data analysis phase, including the need to digitise the existing construction processes, address cost and time-saving solutions while reducing rework, address societal issues like human behaviour, political influences, and cultural settings, improve communication and collaboration among all stakeholders, and improve the design specifications for any proposed digital platform.

Furthermore, this study is anticipated to be helpful to academia, particularly those in the construction industry field, by advancing their knowledge and providing ideas for future research in other phases of the asset lifecycle, such as the procurement and operational and maintenance phases, and provide data gathered from experts in the construction industry to tackle issues and problems currently happening in the construction projects.

Finally, the link made between the quality field and digitising the construction industry in Chapter 3 contributes to applying IT in Total Quality Management (TQM) within the construction industry. This inputs advances field knowledge and aids researchers by raising their level of awareness and comprehension.

11.4 Strengths and limitations of the study

There is a shortage of research on the digitisation of the construction build process within the field of asset management. Moreover, no earlier study has investigated these issues of current construction settings and applied suggested solutions using qualitative approaches. As a result, the findings of the present study offer fresh perspectives and enrich the understanding of what is needed to achieve digitisation during the construction build phase in line with the government strategies and DBB plan.

11.4.1 Strengths

The strengths of this study are as follows:

- Contributing to the academic field by conducting a Literature Review in chapter 3 that filters out all papers in the field of construction industry in the Highways field that discuss applications and features of digital systems currently in use plus the gaps and issues that the construction industry currently suffers from.
- Contributing to the existing knowledge in the field of asset management and the construction industry through the thematically analysed data.

- The production of the CATS model that can be adopted by highways contractors and could be adopted by other sectors (i.e. water or rail) contractors with minimal changes
- The CATS data extraction is aligned with BIM structure and enhance the handover processes
- The CATS model is a step that bridges the gap between contractor and government's Construction strategy 2025

11.4.2 Limitations

- While this study is qualitative and based on data collected from one contractor (Costain), it's important to note that this limitation doesn't render the study's findings irrelevant. The insights gained from this study can be valuable for other contractors as well, as they all work under a common client (NH) and aim to align with Construction Strategy 2025 and achieve BIM compliance.
- At the time of finishing this study, contractors have not advanced with the adoption of new IT technology such as the Internet of Things and Digital Twin. These could add more value if the CATS model was updated to be aligned with new IT technologies that may influence the construction industry's future.

11.5 Recommendation for future work

Some of the models discussed in chapter 6 have included future work recommendations, these comes in the shape of implementing more data integration (Sitzabee et al., 2009) or applying the solution to the other phases of asset lifecycle (McClure & Yuan, 2016; Yuan et al., 2017).

At the completion of this project, it became clear that there are several avenues for more investigation regarding the broader field of asset management within construction industry, this is also connected to the:

- Investigating the possibility of using CATS in the Operation and Maintenance (O&M) phase as well as the building phase of asset lifecycle, such as the recommendations of McClure & Yuan (2016), and Yuan et al. (2017).

- A study is needed to investigate a way to provide a solution to the human behaviour of resistance to change in adopting a more digital way of working within the context of the highways construction industry.
- Leveraging the use of the CATS model and its functionality to reach out to other sectors such as Water and Rail.
- Investigating the possibilities of other phases of the asset lifecycle being linked with CATS such as Design, Procurement, and Operation & Maintenance phases. This would mean that BIM would integrate with the whole asset lifecycle, not just the build phase. This is also aligned with Sitzabee et al. (2009).

11.6 concluding remarks

Chapter 11 provides a comprehensive summary of the main findings and contributions of the thesis. In section 11.2, I evaluate how the study has achieved its objectives and its contributions to the existing body of knowledge, focusing on the digitization of the construction build process. Additionally, I assess the study's originality and its practical usefulness in terms of aligning with the Construction Strategy 2025. In section 11.3, I discuss the strengths and limitations of the research and suggest future research opportunities in section 11.5.

The study aimed to explore the feasibility of digitising the construction industry, particularly during the build phase of the asset lifecycle, to meet the objectives of Construction Strategy 2025. Through interviews with industry professionals and a thorough examination of existing solutions, the study identified the need for a comprehensive digital platform like CATS to enhance highways construction projects and achieve BIM compliance.

The data collection phase involved online interviews primarily with Costain employees, supplemented by data manuals and existing solutions. Thematic analysis of the interview responses aimed to uncover the main challenges, required solutions, and the alignment of CATS functionality with the government's strategies.

The study's achievement of its aims and objectives is evaluated by gathering insights from industry experts, including directors, managers, and BIM designers, the study gained a deep understanding of current construction processes and identified areas for improvement. Research questions were formulated and addressed, focusing on the integration of highways contractors with Digital Built Britain and the effectiveness of CATS in meeting DBB and BIM compliance requirements.

Furthermore, the study's contributions to the field has filled a gap in the knowledge of comprehensive solutions for the construction build process, providing insights into planning, monitoring, and improving construction operations. The study emphasises the significance of digitising the construction build process and contributes valuable knowledge to academia and the industry.

The strengths of the study lie in its thorough literature review, thematic analysis of data, and the development of the CATS model. However, limitations include the qualitative nature of the study being focused on one contractor, Costain.

The recommendations for future research are exploring CATS implementation in the Operation and Maintenance phase, addressing resistance to change in adopting digital practices, and extending CATS functionality to other sectors like Water and Rail. Overall, the study's findings offer valuable insights and open avenues for further investigation in the digitization of the construction industry.

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➢ **Appendices**

1.1 Appendix 1: Literature Review Context

Author	Year	Journal
Gharaibeh, N.G., Darter, M.I., Uzarski, D.R.	1999	Journal of Infrastructure Systems
Dolezilek & Ayers	2001	IEEE/PES, Transmission and Distribution Conference and Exposition, 2001
Kostic	2003	IEEE Power Engineering Society General Meeting
Brown & Spare	2004	IEEE PES Power Systems Conference and Exposition
Davidson	2005	IEEE Power Engineering Society Inaugural Conference and Exposition in Africa
Yep, R.	2005	AWWA 124th Annual Conference and Exposition: The World's Water Event, ACE 2005
Hall, J.P., Robinson, R., Paulis, M.A.	2005	Transportation Research Record
Tor & Shahidehpour	2006	IEEE Power Engineering Society General Meeting
Apeldoorn, S.	2006	Australasian Society for Trenchless Technology - 24th No-Dig International Conference and Exhibition, No-Dig Down Under 2006
Hafskjold, L.S., Vanrenterghem-Raven, A.	2007	Proceedings of the Combined International Conference of Computing and Control for the Water Industry, CCWI2007 and Sustainable Urban Water Management, SUWM2007
Hanley & Clayton	2008	IET Institution of Engineering and Technology
Landers	2008	ASCE: American Society of Civil Engineers
Agrawal, A.K., Ramalingam, K., Kawaguchi, A., Rozelman, K.S., Kulcsar, F., Farooqi, N.	2008	Proceedings of Pipelines Congress 2008 - Pipeline Asset Management: Maximizing Performance of Our Pipeline Infrastructure
Sitzabee, W.E., Rasdorf, W., Hummer, J.E., Devine, H.A.	2009	Journal of Computing in Civil Engineering
Ananraya, K., Ammarapala, V.	2010	ICSSSM: 7th International Conference on Service Systems and Service Management, Proceedings of ICSSSM' 10
Robery, P.C.	2010	Bridge Maintenance, Safety, Management and Life-Cycle Optimization - Proceedings of the 5th International Conference on Bridge Maintenance, Safety and Management
Munslow	2011	IET and IAM Asset Management
Ehsan et al	2011	Remote Sensing, Environment and Transportation Engineering (RSETE)
Miller et al	2012	IET & IAM, Asset Management Conference 2012
Mohammad, S.	2012	Highways
[No author name available]	2013	Pipeline and Gas Journal

Wang, C., Liu, Y., Wang, H., Li, Z.	2013	Advanced Materials Research
Posavljak, M., Tighe, S.L., Godin, J.W.	2013	Transportation Research Record
Kivits, R.A., Furneaux, C.	2013	The Scientific World Journal
Teall	2014	Proceedings of the ICE - Management, Procurement and Law
Jung, Sinha, & Whittle	2014	Journal of Infrastructure Systems
Abaffy, L.	2014	ENR (Engineering News-Record)
Turkan et al	2015	ITcon - Electronic Journal of Information Technology in Construction
Zeb, J., Froese, T., Vanier, D.	2015	Built Environment Project and Asset Management
Berardinelli, U., Canhoto Neves, L., E Matos, J.C., Guimarães, H.	2015	Life-Cycle of Structural Systems: Design, Assessment, Maintenance and Management - Proceedings of the 4th International Symposium on Life-Cycle Civil Engineering, IALCCE 2014
McClure & Yuan	2016	ITcon - Electronic journal of information technology in construction
Sairam, N., Nagarajan, S., Ornitz, S.	2016	Sensors (Switzerland)
Yuan, C., McClure, T., Dunston, P.S., Cai, H.	2016	ASCE: PROCEEDINGS Construction Research Congress 2016
Le & Jeong	2016	Automation in Construction
He Y.; Song Z.; Liu Z.	2017	Measurement: Journal of the International Measurement Confederation
Yuan C.; McClure T.; Cai H.; Dunston P.S.	2017	Journal of Construction Engineering and Management
Aziz Z.; Riaz Z.; Arslan M.	2017	Facilities
Md Aslam H.; Ahmad Tarmizi H.	2018	MATEC Web of Conferences
Le T.; Le C.; Jeong, H.D.	2018	Journal of Management in Engineering
Fan Y.; Yin Y.	2020	IOP Conference Series: Materials Science and Engineering
Floros G.S.; Ellul C.	2021	ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences
Patel T.; Suthar V.; Bhatt N.	2021	SpringerLink
Abdullah S.; Tahar K.N.; Rashid M.F.A.; Osoman M.A.; Abdullah F.	2021	IOP Conference Series: Earth and Environmental Science

Table 7:Chapter 3 literature review related papers

1.2 Appendix 2: Literature Review Findings

Journal	Papers
Report/Policy	8
IEEE	6
IET	3
ITcon	3
Journal of Management	2
IOP Conference Series: Materials Science and Engineering	2
Administration and Policy in Mental Health and Mental Health Services Research	1
American Society of Civil Engineers	1
Association for Computing Machinery (ACM)	1
Automation in Construction	1
desrist	1
ICE	1
Journal of Infrastructure Systems	1
Program-Electronic Library and Information Systems	1
RSETE	1
Strategic Management Journal	1
Measurement: Journal of the International Measurement Confederation	1
Journal of Construction Engineering and Management	1
Facilities	1
MATEC Web of Conferences	1
ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	1
SpringerLink	1

Table 8: Journal publishing

1.3 Appendix 3: Features of the Core Asset Model

The Features of core Model	Authors (Year)
Asset model	(Landers, 2008); (Le & Jeong, 2016); (McClure & Yuan, 2016) ; (Munslow, 2011)
Activity Model	(Kostic, 2003); (Le & Jeong, 2016) ; (McClure & Yuan, 2016) ; (Munslow, 2011)
Document	(Le & Jeong, 2016); (Turkan et al., 2015) ; (McClure & Yuan, 2016), (Jung et al., 2014)
Data Structure	(Tor & Shahidehpour, 2006); (Le & Jeong, 2016); (U.S.A Department of Transportation Federal Highway Administration, 2010) ; (Munslow, 2011), (Jung et al., 2014)
Data interrelationships – hierarchy	((HIGHWAYS AGENCY), 2014); (Le & Jeong, 2016) ; (McClure & Yuan, 2016)
Groups and subgroups	((HIGHWAYS AGENCY), 2014; Teall, 2014) ; (Munslow, 2011), (Jung et al., 2014)
Location	(Tor & Shahidehpour, 2006); (Dolezilek & Ayers, 2001); (Le & Jeong, 2016); (U.S.A Department of Transportation Federal Highway Administration, 2010) ; (Munslow, 2011) ; (Ehsan et al., 2011), (Jung et al., 2014)

1.4 Appendix 4: The Features of system Objectives

The Features of objectives	**Authors (Year)**
Efficiency in cost & time	(Kostic, 2003);(Hanley & Clayton, 2008); (Landers, 2008); (Dolezilek & Ayers, 2001); (Brown & Spare, 2004); (Le & Jeong, 2016) ; (McClure & Yuan, 2016); (Munslow, 2011); (Ehsan et al., 2011), (Jung et al., 2014)
Interoperability/ Integration	(Hanley & Clayton, 2008); (Tor & Shahidehpour, 2006); (Le & Jeong, 2016) ; (McClure & Yuan, 2016); (Ehsan et al., 2011)
Self-Extensibility	(Tor & Shahidehpour, 2006)
Future proof	(Tor & Shahidehpour, 2006) ; (Munslow, 2011)

1.5 Appendix 5: The Features of System Factors

The Features of factors	**Authors (Year)**
Usage (Accessibility, Different platforms, user behaviour)	(Landers, 2008); (Hanley & Clayton, 2008); (Tor & Shahidehpour, 2006) ; (McClure & Yuan, 2016)
Real-time Data	(Tor & Shahidehpour, 2006); (Dolezilek & Ayers, 2001); (Le & Jeong, 2016) ; (McClure & Yuan, 2016)
Data Sharing	(Hanley & Clayton, 2008);(Le & Jeong, 2016); (Dolezilek & Ayers, 2001); (U.S.A Department of Transportation Federal Highway Administration, 2010) ; (McClure & Yuan, 2016), (Jung et al., 2014)

1.6 Appendix 6: Ethics Application

1.6.1 Ethics Approval Letter

The University Of Sheffield.

Downloaded: 09/12/2016
Approved: 13/05/2015

Ibrahim Al-Ghraify
Registration number: 140255869
Management School
Programme: Standard PhD

Dear Ibrahim

PROJECT TITLE: A model for handling and managing core asset data
APPLICATION: Reference Number 002933

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 13/05/2015 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 002933 (dated 07/05/2015).
- Participant information sheet 005907 version 4 (07/05/2015).
- Participant consent form 005906 version 1 (27/02/2015).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Yours sincerely

Mark Latham
Ethics Administrator
Management School

Figure 53: Ethical Approval Letter

1.6.2 Project information letter to introduce the topic to the interviewees

****

From: Ibrahim Al-Ghraify

Email: ifal-ghraify1@sheffield.ac.uk

Dear xxx,

A model for handling and managing core asset data

I am a PhD student in the Management School at the University of Sheffield. I am a permanent employee at Costain Group and they provide funding for this PhD.

Costain Group (http://en.wikipedia.org/wiki/Costain_Group , www.costain.com) is a construction and civil engineering company. Costain consists of 2 divisions: Natural Resources (water, waste, nuclear process and oil & gas), Infrastructure (highways, rail, and power).

The research will enrich the industry in general NOT just Costain Group, and the publication of the result will be available to anyone through the university and academic science papers/databases. I confirm that there will be no conflict of interest between the participants and Costain. I work in Highways sector and the research should benefit managing highways assets that Costain construct on main roads. The main aims of my research project are:

- To specify an asset management database that
    - (i) will include all the aspects and assets involved in managing and monitoring the road network
    - (ii) will allow the whole life cycle of the asset to be tracked.
- To create an integrated asset management system, that allows data from multiple sources to be linked to a core asset intelligence system.
- To develop a model that is accepted and adopted by the industry, and so has an impact on highways management systems.
- To analyse options for managing core asset data through the full life-cycle of the assets.

➢ Why the interviewee was chosen?

Because we (the research team) believe you (the participant) are an expert in this area.

➢ What will happen if the interviewee takes part?

The interview will last for about one hour. The questions in the interview will be concentrated around the database and the model, e.g. how you modelled your database? What type of databases you using? How you deal with large amount of data? What data type of fields you use? What application/tool you using to interact with the database?

➢ What are the benefits of taking part?

Taking part in the research will help enrich the public domain knowledge.

➢ What are the possible disadvantages and risks of taking part?

I personally see no risk/disadvantage of taking part apart from the time (one hour) that you (the participant) kindly grant us (the research team).

I would be very grateful if we could meet to discuss your industry/organisation/council data model/structure as well as the application/software used to manage this data and how it could improve and update the research field. Although I would greatly appreciate your views, obviously participation is entirely voluntary and you can withdraw at any time.

The information and data you provide will be treated as confidential within the research team (me and my 2 supervisors: Dr Andrew Brint and Dr John Holiday) who are aware of the ethics combining the project. The data and information collected from this project will be stored in secure devices/draws and it will not be shared with any third party outside the team and nothing from this interview will be published without your authorisation. Any comments you make will be treated anonymously and neither you nor your organisation will be identifiable as I will be mentioning the sector that your organisation fits in rather than the organisation by itself.

This research ethics fulfil Sheffield university ethics requirements. If you have any complain please contact Sheffield University Management School's Dean: Professor David Oglethorpe email: d.oglethorpe@sheffield.ac.uk

I hope you will be happy to have a discussion – if you want any further information about the project, then please contact my supervisor (Andrew Brint, email: A.Brint@sheffield.ac.uk) or me.

Yours sincerely,

Ibrahim Al-Ghraify
Doctoral Student
Sheffield University Management School
****

1.7 Appendix 7: Student Development Activities

Table 9: Compulsory modules

Module Code	Title	Date
MGT 6100	Research Ethics and Integrity (Lecture)	**17th Feb 2015**
MGT 6100	Research Ethics and Integrity (Workshop)	**17th March 2015**
FCS 6157	Social Theory for Management Researchers	**Feb - Jun 2016**
FCS 650	Quantitative Methods for Social Science Research	**Oct – Dec 2015**
FCS 660	Foundations of Social Science Research	**Oct – Dec 2015**
FCS 670	Qualitative Methods for Social Science Research	**Oct – Dec 2015**

Table 10: Optional Modules

Module Code	Title	Date
INF6050	Database Design	**Jan - Jun 2015**
	First Steps with NVivo	**7th Mar 2015**
	Tools for literature searching	**5th Nov 2015**
	Kickstart your PhD: 1- How the library can support your research	**28th Oct 2015**

	Kickstart your PhD: 2 - Managing the relationship with your supervisor and other colleagues	**11th Nov 2015**
	Kickstart your PhD: 3 - Managing your time and your project	**25th Nov 2015**
	Study skills tutorial	**19th Jan 2016**
	Critical Thinking workshop	**9th Dec 2015**
	Smart Monitoring of Infrastructure	**6th Dec 2016**
	Internet of Things Conference	**25th Mar 2016**
	Mathematical Methods in Reliability, CONDITION MONITORING – University of Salford	**16th June 2015**

1.8 Appendix 8: Research Publications and Award

Date	Presentation	Place
16th June 2015	Whole life condition databases for managing utility assets	Mathematical Methods in Reliability - CONDITION MONITORING - THINKlab, Maxwell Building, University of Salford