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Quality Assurance of Bim for Multi-Faceted Projects

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Abstract

This thesis presents a comprehensive investigation into the automation of compliance management in the Architecture, Engineering, Construction, Owner, and Operator (AECOO) industries. The research addresses the need for efficient information management and compliance checking in projects to enhance project delivery. The study focuses on the implementation of the ISO 19650 standard and explores the use of process automation and document generation to streamline compliance processes.

The research methodology comprises a combination of literature review, system development, and validation. The initial phase involves analysing the motivation behind the research and identifying the most suitable research methods. The thesis incorporates a questionnaire-based survey to gather insights from industry professionals regarding implementing the ISO 19650 standard and the challenges faced. The thesis discusses the development of a process automation platform that enables users to interrogate project status and evaluate compliance smartly. The platform includes features such as automated document generation, compliance checking, and integration with external information management roles. The validation of the platform involves testing various scenarios and assessing its performance against expected results.

Results from the survey indicate a high adoption rate of Building Information Modelling (BIM) among respondents, while the implementation of the ISO 19650 standard varied across client organisations and contractors. The evaluation of the platform demonstrates its effectiveness in facilitating compliant document generation, improving information management processes, and providing accurate compliance checks. However, the study acknowledges certain limitations, including the scope limitation to a specific section of the ISO 19650 standard, the lack of industry and regulatory body verification of the process maps, and the separate development of automation and document generation platforms. Future research is suggested to validate the compliance governance framework and generate content for other documents.

This thesis contributes to the field of compliance management in the AECOO industries by offering a smart approach to automate processes, compliance checking and document generation. The findings highlight the potential of process automation to enhance project delivery, improve information management practices, and streamline compliance processes. The research outcomes provide valuable insights for industry professionals and pave the way for further advancements in compliance management within the AECOO industries.

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Lastly, I would like to express my sincere appreciation to all the individuals, colleagues, and friends who have helped, encouraged, and supported me in various ways. Their contributions,

whether big or small, have played a significant role in the successful completion of this research.

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List of Abbreviations

AECOO	-	Architectural, Engineering, Contractor, Owner, and Operator Industries
AIM	-	Asset Information model
AIR	-	Asset Information Requirements
API	-	Application programming interface
ATS	-	Automated text summarising
BEP	-	BEP - BIM Execution Plan
BERT	-	BERT - Bidirectional Encoder Representations from Transformers
BIM	-	Building Information Model
BPEL	-	Business Process Execution Language
BPM	-	Business Process Management
BPMN	-	Business Process Modelling Notation
BSI	-	British Standards institute
CAD	-	Computer-aided design
CAPEX	-	Capital expenditure
CDE	-	Common Data Environment
CF	-	Construction Framework
CIRIA	-	Construction Industry Research and Information Association
CNN	-	Convolutional Neural Network
CSV	-	Comma-Separated Values
DMN	-	Decision Model and Notation
DSR	-	Design science research
DTA	-	Deep Text Analysis
EIR	-	Exchange Information Requirements
EPC	-	Event-Driven Process Chains
IAI	-	Industry Alliance of Interoperability
IDEF	-	Integrated Definition for Process Description
IDM	-	Information Delivery Manuals
IDP	-	Information Delivery Plan
IFC	-	Industry foundation class
IFD	-	International Framework for Dictionaries

ISO	-	International Standards Organisation
LISP	-	LISP Processing
MIDP	-	The Master Information Delivery Plan
ML	-	Machine learning
MT	-	Machine Translation
MVD	-	Model View Definitions
NBS	-	National building specification
NLG	-	Natural Language Generation
NLP	-	Natural Language Processing
NLU	-	Natural Language Understanding
OIR	-	Organisational Information Requirements
OMG	-	Object modelling group
OPEX	-	Operational expenditure
ORM	-	Object-Relational Mapping
PIR	-	Project Information Requirements
POM	-	Project Object Model
POW	-	Plan of Work
QAS	-	Question & Answering Systems
RIBA	-	The Royal Institute of British Architects
RPA	-	Robotic Process Automation
SGC	-	Spelling Correction / Grammar Checking
SNLI	-	Stanford Natural Language Inference
SQL	-	Structured Query Language
SVR	-	Speech or Voice Recognition
TIDP	-	The Task Information Delivery Plan
UK	-	United Kingdom
UKAS	-	United Kingdom Accreditation Service
UML	-	Unified modelling language
URL	-	Uniform resource locator

Contents

Chapter 1 Research outline

Problem Statement

Within the construction industry, there exists many complex and challenging processes which require the collaboration of multiple actors. An actor can be defined as either an organisation, individual or group of individuals. The collaboration of the various actors is further complicated by the lack of suitable frameworks which allow for projects information to be coordinated across different domains (Alreshidi et al., 2018). The complexity of projects also has the additional burden of delivering and meeting various stakeholders' quality expectations, the subject of which has been the cause of many project cost and time overruns (Egan, 1998).

To tackle the issues surrounding the lack of collaboration, building information modelling (BIM) has been adopted by the Architectural, Engineering, Contractor, Owner, and operator industries (AECOO) as a digital concept akin to Industry 4.0 (Ustundag & Cevikcan, 2018). There have also been many definitions of what is meant by BIM and its implications (Doan et al., 2019). This research uses the term information management to describe a process and BIM to describe an information container. With the advent of this process of collaboration, the industry has produced in combination with the International Standards Organisation (ISO) a standard which aims to formalise the information management domain – ISO 19650 (British-Standards-Institute, 2018). ISO is an international standard development organisation that brings together representatives from national standards organisations of member countries. ISO develops and publishes international standards that provide guidelines, specifications, and best practices in various fields and industries.

There are however issues in how ISO19650 is adopted on both a national and international basis as it is primarily still an analogue method which is in direct contrast to BIM being seen as an industry 4.0 specification.

In order to meet the industry 4.0 challenges within the AECOO domains, information management within the industry must have the ability to not only adopt the new standards but also have the ability to check their current process in a standardised collaborative way.

These processes should be aligned to the specification, request and delivery of information throughout an assets lifecycle which involves many stakeholders across the many domains which contribute to a project's success or failure.

The U.K. is also currently fragmented in the way that BIM is implemented in each of the devolved nations. There is currently no mandate in Wales for BIM to be used in government-procured contracts except for some Welsh government-funded schools (Welsh Goverment, 2022). whilst in Scotland and Northern Ireland, BIM policies have been formalised. This creates a situation where the AECOO industry in Wales is driven to implement BIM through their own initiatives and in turn there is no collective mechanism to enable BIM.

Whilst there are a few tools available for the industry to measure their success in the implementation of BIM in a general format, there are an even limited number of tools which enable BIM processes to be enacted, benchmarked or exchanged with a formalised schema throughout the lifecycle of information management.

The maturity of BIM has been broken down into 3 stages within the ISO19650-1:2018 standard. Within the 3 stages, there are 4 layers: Business, Information, Technology and standards as shown in Figure 1-1.

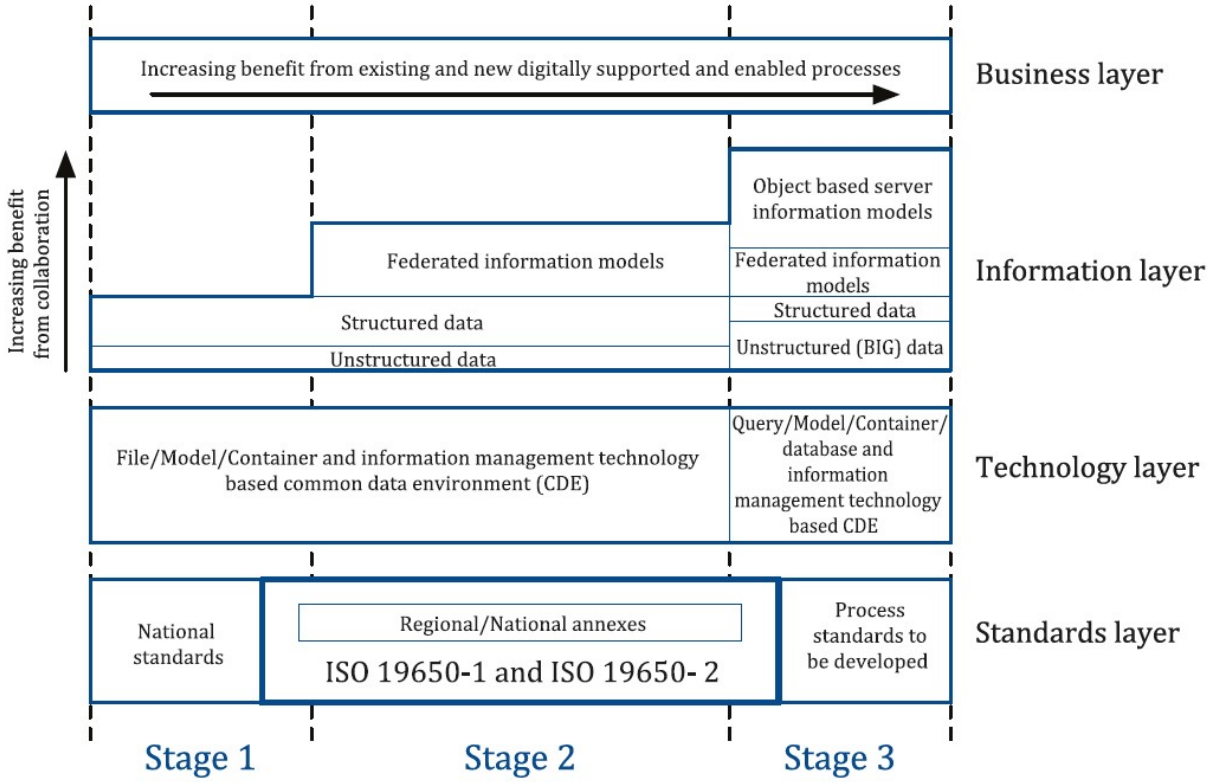


Figure 1-1: Maturity of analogue and digital information management

Each of these layers and their retrospective data formats have currently limited formalisation which leaves actors unable to digitally exchange their requests or status which in turn leaves them without the digital knowledge required to enable them to improve their processes and in turn improve their quality.

In summary, the construction industry faces challenges in collaboration and information management, leading to cost and time overruns. Building Information Modelling (BIM) has been adopted as a digital concept to address these issues. ISO 19650 provides guidelines for formalising information management, but its adoption is hindered by its analogue nature. To meet industry 4.0 challenges, information management needs to adopt new standards and improve processes. The fragmented implementation of BIM in the U.K. complicates the situation. Formalising the maturity of BIM and improving data formats will enable digital exchange and process improvement.

Research Motivation

This section details the main motivation for this thesis and the various stages of the work presented in order to address the issues identified in the problem statement.

The implementation of BIM has increased steadily over a number of years since its first inception when BIM was first published as a concept through to projects where BIM was used primarily in the early stages of a project (Eadie et al., 2013), through to projects where they predominantly use BIM throughout the lifecycle of a project. The use of BIM and how to enable individuals to measure their performance has also been featured in the literature (Succar et al., 2013). The key theme for these areas is that BIM can be classified into the separate but mutually exclusive domains of Organisations, Individuals and Projects. That is to say that a project depends upon at least 1 organisation which is made up of 1 or more individuals. Each of these separate domains has a requirement to undertake some activities in which an input is processed and produces an output. The way in which the inputs are processed to produce an output can also vary not only between organisations but also between individuals. In a recent case study of a BIM project, it has also been identified that this disparity in process management causes issues between what is planned and what is delivered in a project (Boton & Forgues, 2018). While the addition of information management can help in formalising the request and receiving of information, there still exists a disparity in relation to the data exchange requirements and classification of the requested information at stages in an assets lifecycle (Godager, 2018).

Understand industry implementation of information management compliance checking and how it could be improved.

While information management has been around for several years now, there is still not 100% adoption of it on all projects and indeed by all organisations. Consideration needs to be given to obtaining a deep understanding of the issues that organisations face in not only implementing information management but also ensuring adherence to international standards. There have been several frameworks developed which consider the best implementation methods for organisations wishing to undertake information management, however, they are mainly focused upon organisations and do not look at ensuring either

quality assurance of the implementation within the organisation or arguably a project although it has been shown that enhancing information management can improve implementation of a project (Chen & Lu, 2019).

Within the context of the United Kingdom, there are also additional political issues related to implementation within each of the devolved nations. Wales does not currently have a BIM implementation strategy at a national level and as a result, it is important to understand the drivers for the industry in undertaking BIM implementation of their own accord and the issues, they face in doing so without Welsh government support. Although there has been some research undertaken in this area, there is currently a lack of understanding of how information management has been or will be implemented in Wales (Eadie et al., 2015).

Enhance an organisation's view of the current information management status within multiple projects and automate the process where possible.

Currently, organisations can adopt national standards to help them on their journey to implement information management, but it requires a deep understanding and interpretation of the "wordy" standards that exist either at the international level or at the national level. Examples include NBIMS in the United States or China where 12 different standards exist depending upon the state where it is undertaken due to the rapid advancement in technology where policies do not keep up to date (Bingsheng et al., 2017). For the process to become harmonised, the international standard for information was developed to help align information management across organisations but there is a lack of research in this area on how to implement the standards and how to monitor the process involved (Godager et al., 2022). The UKBIM alliance has issued some guidance documents, but they still don't go far enough to help the industry. Therefore, there is a gap in knowledge and guidance regarding the implementation and monitoring of information management processes.

Provide a method of producing required templates and ensure compliance.

Implementation of information management frameworks for construction requires the generation of multiple documents and processes for handling these documents which then require a manual method to update and check that they comply with the information requirements. There have been several attempts to generate the document templates, however, there are issues with regards to how the document contents can be checked and scored. The creation of an information container alone within the standards has many considerations which includes ensuring that the information contained within it meets the information requirement (British-Standards-Institute, 2018). Checking that the container has the correct name and metadata has been looked at in previous research but this does look at checking that the contents are correct (Ajayi et al., 2023). The method of checking the document contents currently relies upon the use of multiple resources both in the context of time and costs. There is currently a gap in the literature which looks to reduce these costs in both the production of the documentation and the subsequent checking of them.

Research Hypothesis

The issues discussed above have made it clear that there are several challenges which are faced in not only true collaboration but also that of industry 4.0 needs within the AECOO industries. To address these highlighted issues, the following statement is given as the working hypothesis for the research:

"There is a need to automate the process of information management to enable a project's current status to be interrogated and understand its current compliance smartly to improve project delivery within the AECOO industries, hence a smart way to automate compliance checking".

This will enable all actors within a project to have the right information and a clear and logical universal process to enable successful information management.

Research Questions

To consider the research objective in this thesis, 7 research questions have been formulated to evaluate the hypothesis and contribute to knowledge in the process:

1) What does existing literature reveal about the challenges and potential solutions for understanding maturity and enhancing collaboration and information management in the industry, particularly in the context of complex processes involving multiple actors? – **Chapter 2**
2) What are the challenges facing the industry in implementing and complying with the information management standard ISO 19650? **Chapter 4**
3) How can a comprehensive framework and standardised processes be developed to facilitate effective information management and enable seamless collaboration across organisations in the construction industry? **Chapter 5**
4) What are the potential approaches and technologies for automating information management processes in the construction industry? - **Chapter 5**
5) How are documents currently produced and can the contents be created in a structured format? - **Chapter 6**
6) Can documents be checked for compliance with the international standards? – **Chapter 6**
7) Can the proposed platforms provide status information in relation to process and check document compliance? **Chapter 7**

Research Innovations

Contribution to existing knowledge in information management: This research undertakes an ethnographic study to understand how organisations currently undertake information management both at the organisational level and how this is then undertaken at a project level where collaboration is carried out amongst the various actors. This contribution also highlights the current issues that organisations have in implementing information standards

and implements a quality assurance framework that can assist them in understanding shortcomings and allows future scholars to carry out further research accordingly.

Contribution to existing knowledge in process management: This research looks in depth at the relevant ISO19650 standard and identifies the key process which can then be used by a process engine to carry out automation and allow the relevant actor to have information delivered to them at the correct time. The use of business process management notation (BPMN) and its application to an existing standard allows for further research into this area by scholars to replicate the information management standard to other standards.

Contribution to information requirements and documentation generation in BIM: This research identifies the attributes of a document required in information management standards linked to a relevant process and produces a schema that can be replicated across organisations and projects.

Contribution to information requirements and documentation compliance checking in BIM:

A developed document schema allows for applications of natural language processing to score the produced document against an exemplar. This schema could be further developed to transpose it into web ontology language by scholars allowing it to be understood across domains and allow greater interoperability.

Dissertation Structure

This thesis is divided into several chapters, each of which pertains to answers the questions raised in the research hypothesis.

Chapter 1 – Introduction: Introduces the current issues in the industry with regards to information management and the need to understand the issues faced when organisations implement information management standards. This chapter serves as a comprehensive introduction to the research, covering various aspects such as the objectives, research rationale, hypotheses, knowledge contribution, and thesis structure. By providing a clear

outline of these key components, the chapter helps to set the stage for the rest of the research, providing readers with a solid understanding of the research goals and methodology.

Chapter 2 – Literature review: A comprehensive analysis is presented of relevant literature which provides valuable insights into the current understanding of information management and quality assurance. The review delves into several areas relating to BIM maturity frameworks, Process Automation, Natural language processing along with document generation and Compliance Checking.

Chapter 3 Research Methodology: This chapter provides a comprehensive overview of the various research methods used in the study highlighting the strengths and limitations of each approach.

Chapter 4 focuses on the requirements analysis and system design for a quality assurance framework in information management. This chapter aims to provide a comprehensive overview of the key requirements derived from industry practices and international standards. Additionally, it aims to develop a robust system design that serves as the foundation for new process frameworks, ultimately aiming to enhance the quality of BIM-related information management in the construction industry.

Chapter 5 centres on the critical topic of process automation for information management within the context of the construction industry. This chapter delves into the development and implementation of an automated system that streamlines information management processes and addresses the challenges identified in the previous chapters.

Chapter 6 Smart Compliance Checking System development: This chapter focuses on the development of a framework for a smart compliance checking system that ensures the accuracy and compliance of documentation with information management requirements within the construction industry. This chapter addresses the challenges associated with

manual document generation and aims to enhance the quality and efficiency of compliance checking processes.

Chapter 7 Discussion: This chapter provides a comprehensive discussion of the research findings and their implications. It critically evaluates the developed frameworks and systems for information management and compliance checking.

Chapter 8 Conclusion: This chapter serves as the conclusion of the research work undertaken in the previous chapters. As well as highlighting the key findings from the research, it also discusses the limitations. Identification of future work that can be carried out and built upon is discussed which concludes with summarising the research contributions.

Chapter 2 Literature review

Review of information management and BIM

The domain on information management within the construction industry has advanced considerably with the publication of international standards, industry standards and guidelines as well as through the use of BIM on capital expenditure (CAPEX) and digital twins on operational expenditure (OPEX) based projects. The implementation of BIM on a project requires collaboration between many actors both at an organisational and individual level. In order to understand the current state of the art in relation to information management, a review of the literature is presented which focuses on the elements required to enable effective information management to ensure quality assurance across multi-faceted projects.

In order to produce a comprehensive review on the subject of information management and its relations with quality assurance, document generation and compliance checking within BIM, the following components are focused upon:

Research publications: This consists of journal articles and conference papers that inform on the research topics under investigation and existing state-of-the-art work. The information was collected through systematic literature research using keywords and content criteria using the Science Direct and Scopus search engines.

Current standards and procedures: This consists of reviewing relevant international and national standards along with guidance published by industry bodies. This information is collected through online resources including the BSI and NIMA (Formerly the UK BIM Alliance) which is part of the construction industry research and information association (CIRIA).

Review of information management and BIM Maturity

Although BIM is an acronym for building information modelling, the concept of BIM has evolved over the years from its first mention in literature (Aish, 1986) where the use of an integrated approach was discussed as an improvement to isolated CAD drawings to a topic which now covers many different aspects of an assets lifecycle which can have many

applications (Gerrish et al., 2017; Gimenez et al., 2015; Heaton et al., 2019; Ilhan & Yaman, 2016; Oh et al., 2015; Tashakkori et al., 2015). These use cases for BIM have also seen the use of BIM increase which has been driven in the United Kingdom (UK) by the publication of the Rethinking Construction report (Egan, 1998). This report highlighted the benefits in the use of bim through cost and resource savings at a high level. This report further highlighted the need for the construction industry to work closely together to ensure that projects were delivered on time and to budget constraints without identifying how this could be achieved at a granular level. It wasn't until a government strategy was produced that mandated BIM should be used on all UK central government-funded projects that industry was forced to adopt it (Office, 2011). The National Building Specification (NBS) has carried out surveys on the rate of BIM adoption in the UK which has shown that since the initial mandate in 2011 when 43% of respondents had not heard of BIM, in 2020 that number is almost 100% with 73% of respondents stating that they use it. The survey does not however go into detail about the use case adoption or the maturity of the participant's BIM with external audits on their processes.

Bim Adoption

There have been several researchers looking into the methods that BIM can be adopted at an organisational level and subsequently how they can come together at a project level. Indeed when looking at implementation at a global level, the implementation of BIM has been shown to be inconsistent and dependent upon the countries income level where aspects relating to implementation guidance, availability of training and alignment of BIM Perception are some of the critical success factors (Al-Mohammad et al., 2023). Consideration of these aspects in relation to the NBS survey undertaken in 2018 shows that even within a developed nation such as the UK, there is an alignment with the lack of training and in-house expertise although within the UK there is guidance publications available from NIMA. When considering BIM adoption at an organisational level, it involves looking at the skillset of an individual or group of individuals together to decide upon the skills and knowledge needed at each stage of the implementation process. The processes to implement information management has least been outlined at a high level internationally with the recently published ISO 19650 series of standards. They do however fail to address in a standardised format how these processes can

be formalised at a more granular level. This area is discussed further below in Information management processes. The costs to adoption are still an active research area but the focus is on the technology aspects as opposed to the costs to implement processes where the role of information management plays a crucial role in collaboration (Newman et al., 2020; Whitlock & Abanda, 2020). Once BIM has been implemented within an organisation, it may become necessary to undertake an evaluation on the success and failure against its original intentions. From the details described above, certainly within the UK framework, many organisations implemented BIM as a precursor to being able to undertake projects with the UK government.

Bim Maturity

The maturity of BIM within an organisation has been an active research area with several models propose over the years. BIM has been described as related to a stage of growth model which is dependent upon four stages; Infeasibility, Discreteness, Integration and Maturity (Sun et al., 2021). A review of the literature undertaken using Scopus with the search terms “BIM” OR “Building Information Modelling” AND “Maturity was carried out using the PRISMA approach (Moher et al., 2015) to understand the state of the art in relation to this research area as well as international standards know to the author in relation to this topic. The OR was added to the search term to include results that may have abbreviated BIM. Scopus was used due to its accuracy and coverage when compared to other search engines available such as Web OF Science or Google Scholar (Falagas et al., 2008). Limiting the results to only articles within Journals produced an initial 135 sources. A manual trawl was then carried out to remove articles which may have featured the search terms but were unrelated to the literature being researched. Examples include where the term BIM is used as an abbreviation for BCL-2-interacting mediator in immunology. This narrowed the results down to 64 results. The final edited search term used was TITLE-ABS-KEY ("BIM" OR "Building information modelling" OR “Building information model” AND "Maturity") AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (EXACTSRCTITLE , "Journal Of Construction Engineering And Management") OR LIMIT-TO (EXACTSRCTITLE , "Automation In Construction") OR LIMIT-TO (EXACTSRCTITLE , "Buildings") OR LIMIT-TO (EXACTSRCTITLE , "Architectural Engineering And Design Management") OR LIMIT-TO

(EXACTSRCTITLE , "Construction Innovation") OR LIMIT-TO (EXACTSRCTITLE , "Engineering Construction And Architectural Management") OR LIMIT-TO (EXACTSRCTITLE , "Journal Of Information Technology In Construction") OR LIMIT-TO (EXACTSRCTITLE , "Sustainability Switzerland") OR LIMIT-TO (EXACTSRCTITLE , "Advances In Civil Engineering") OR LIMIT-TO (EXACTSRCTITLE , "Frontiers In Built Environment")). These results were then analysed to determine the impact that this research has had over time, the researchers who are active in this field as well as understanding the source country of the authors. In addition to the results returned by Scopus, an additional element relating to tools available to check BIM maturity and performance were identified using both a desk-based study and tool known to the author which are listed in Table 1.

Tool	*Author*	*Year*
Bim Maturity Assessment	Arup	2015
Bim Maturity Assessment Tool	Cambridge University	2018
Organisational BIM Maturity	Penn State University	2013
NBIMS Capability Maturity Model	National institute of Building Sciences	2015

Table 1: Tools identified for BIM maturity assessment.

A comparative study against the frameworks & tools and the international standard ISO 19650 is then carried out in order to understand the gaps in relation to maturity framework for the standard. The number of articles over time is presented in Figure 2 below.

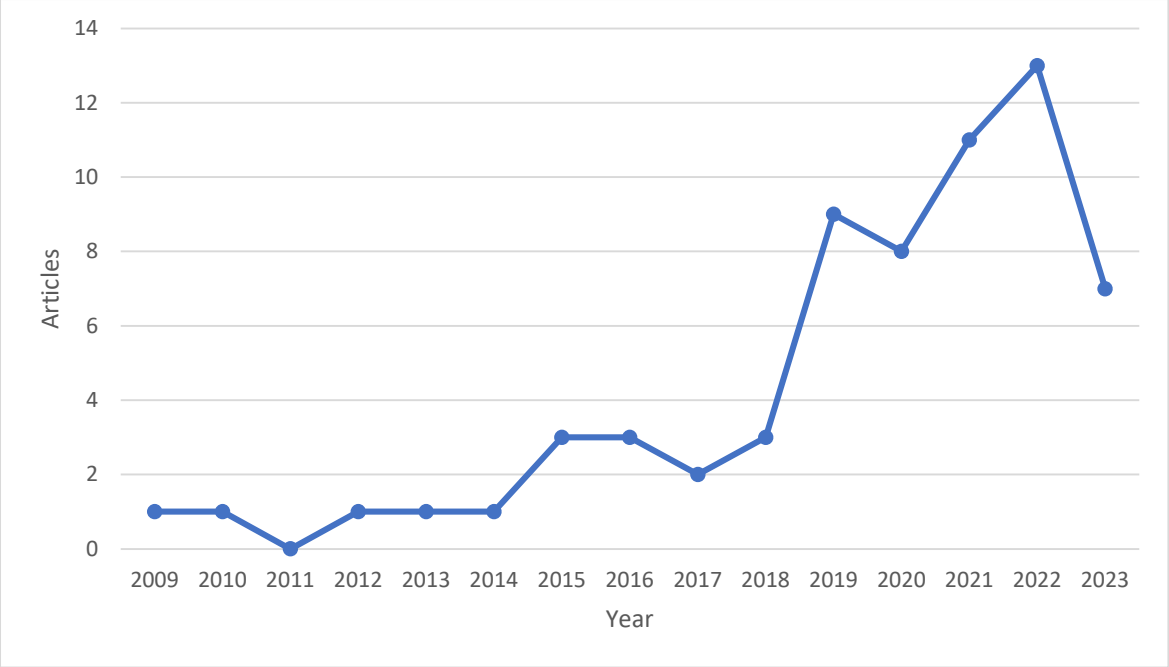


Figure 2: Articles related to BIM maturity over time.

The results presented above show that the number of articles of time increased steadily up until 2015 and 2018 when there is a relative increase in the number published since. The significance of the jump in 2015 could be accounted for due to the UK government mandating the use of BIM in 2018 to the ISO 19650 standard being published. The number of articles by country shows that there is an even spread geographically among the developed nations with the United Kingdom producing the highest number of articles in this area as shown in Figure 3 below. The results show that the United Kingdom has the most publications, and that the top 5 countries overall produced over 80% of the total. When compared to the Publications over time by countries, the United Kingdom's policies on BIM implications may be a considerable factor.

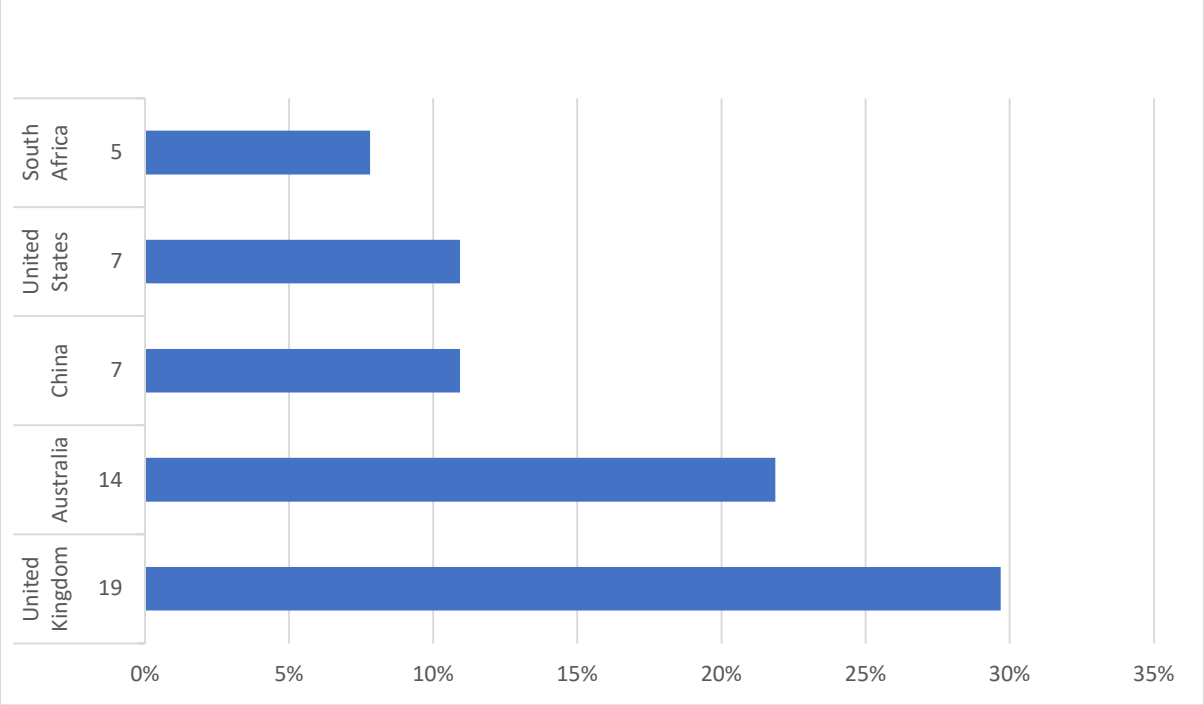


Figure 3: Top 5 Countries by publication

Only the 3 most cited papers are reviewed in detail below with consideration to others presented in Table 1.

Tool	Author	Year
Bim Maturity Assessment	Arup	2015
Bim Maturity Assessment Tool	Cambridge University	2018
Organisational BIM Maturity	Penn State University	2013
NBIMS Capability Maturity Model	National Institute of Building Sciences	2015

Table 2: Tools identified for BIM maturity assessment.

The earliest and most cited (920 citations) paper published looked at grouping international guidance on BIM into several components and discovering their relationships with each other to produce varying levels of BIM maturity (Succar, 2009). The framework is multidimensional and covers lenses, stages and fields as a tri-axial model but is not granular in detail and as such could be considered a high-level roadmap which needs further development for it to become useful. The field dimension considers BIM through interlocking fields of policies, technology and processes. The stages have been listed as falling into one of 4 categories identifying maturity; Pre-BIM is described as systems which are unable to transfer data

between them and no collaboration can take place, Stage 1 is focused around individual objects that are not exchanged between different disciplines, Stage 2 moves towards collaboration between disciplines and improvements in the granularity of information, Stage3 moves towards interoperability and full collaboration of models which are aligned throughout both the design and operations of an asset's lifecycle. In consideration of the article, it is however important to note that the steps required to move from one level of maturity to another will involve maturity in other areas including process and technology maturity as shown in Figure 4: Steps required in BIM Maturity (Succar,2009). That is to say that this model requires *interdependent relationships of maturity* between all the components identified and which have not yet been fully explored by researchers. Another aspect concerning this work is in describing throughout the works that BIM is related to an information container in which information is modelled either as objects or built up as components or that a model could be considered as a non-graphical item. The final aspect of this research considers the use of "Lenses" to look at the requirements for a particular element. The use of a BIM ontology is described to enable all the multiple parts of the framework to be explored further and to create a wealth of Knowledge concerning this area. The use of ontologies as domain knowledge is noted concerning this framework but is not discussed further in this research.

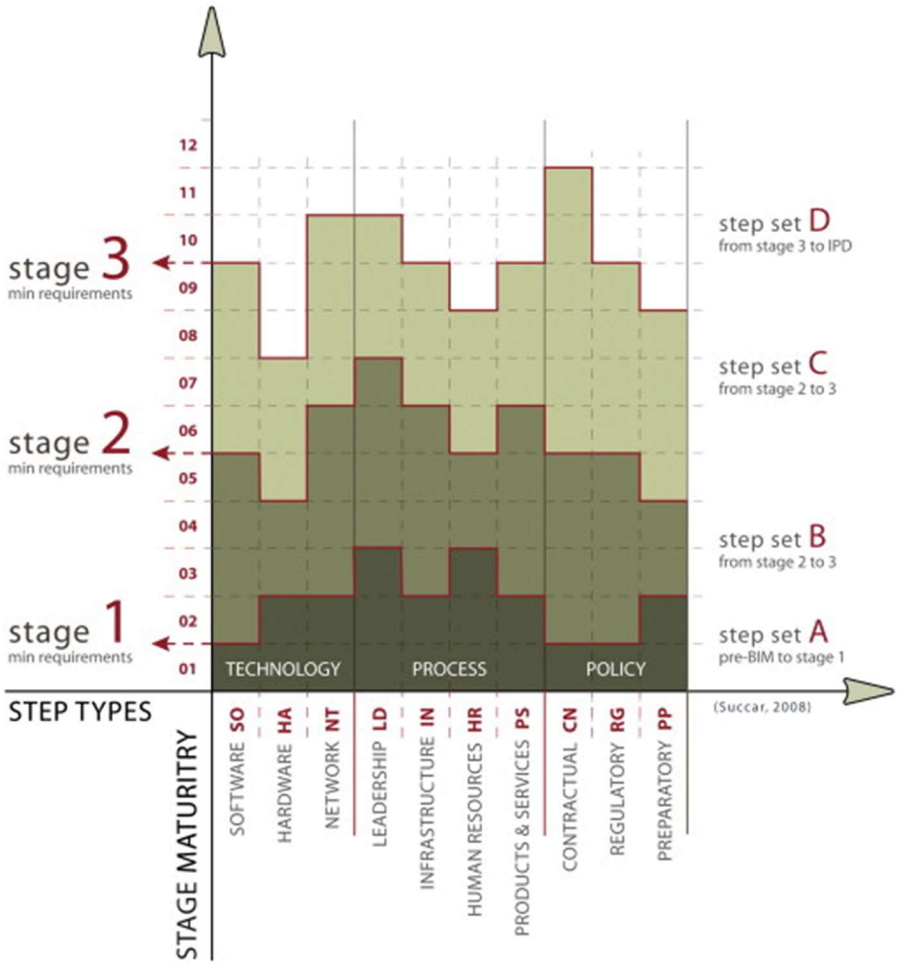


Figure 4: Steps required in BIM Maturity (Succar,2009)

Several articles also refer to the domain knowledge which is a consideration of Lenses as defined by Succar,2009. The next most cited article (313 citations) is one such article and considers the importance of collaboration in the implementation of BIM within public construction frameworks with the outcomes being that there are 5 requirements (Porwal & Hewage, 2013). That there are only 5 low-level considerations discovered for a successful collaboration project is in direct conflict with other research carried out in this area where critical success factors are used (Amuda-Yusuf, 2018; Antwi-Afari et al., 2018b; Ozorhon & Karahan, 2017). Critical success factors are one measurement that many researchers have used to identify elements that contribute to successful BIM-based projects. Critical success factors were first discussed in 1961 and later published in the Harvard Business Review in 1979 as a way to identify their information needs using four basic approaches which were later revised and developed at the Sloan School of Management (Pellow & Wilson, 1993).

Work carried out recently identified 5 critical success factors in consideration of BIM implementation that could be used as a maturity framework for measuring BIM implementation; Collaboration, Early & Accurate Models, Coordination, Information Exchange and finally Planning & Layout of Sites(Antwi-Afari et al., 2018a). It could be argued that while these are factors against a defined implementation of BIM, they all fall within the technology realms described in Figure 4 and do not allow consideration of other important aspects that affect the implementation. Again, like the previous work, this is limited in scope and while it provides a basis for further work, BIM needs to consider maturity not only at the project level but also at the organisational and individual levels to get a measurement of the true maturity. The performance of BIM is also detailed in the search results as a method to assess the many possibilities that the use of BIM can offer. BIM can be used across an array of sectors, organisations, individuals, and projects at varying levels and each of these areas has capability and capacity issues along with different requirements for information. Thus, it is sufficient to say that due to the number of possible implementations, it needs to check not only the maturity but also the performance required. Work undertaken in this area looks to breakdown these issues into 5 distinct areas; 1) Capability, 2) Maturity, 3) Competencies, 4) Organisational Scale, and 5) Granularity (Succar et al., 2012). The issue with this work is that it isn't mature enough to work either at an organisational level and requires further work to advance it to a more granular level and as such could be considered another high-level framework. In direct comparison to this high-level framework is work undertaken to produce a maturity model that works at an organisational level (Penn State University, 2012) and has been adapted to work at the project level (Arup, 2014) through the use of Excel spreadsheets. The original work presented by Penn State University at the organisational level is based upon 6 Levels of maturity ranging from non-existent (0) through to optimisation (6) across 6 Domains; Strategy, BIM Uses, Processes, Information, Infrastructure & Personnel. While the developed tool will indicate the maturity of BIM within the organisation overall, there are several disadvantages which could render the results unsuitable. The first consideration is even if the overall score is high, failure to implement some areas (Infrastructure for example) will not invalidate the result. While the authors recognised this as a shortcoming, the algorithm used to calculate the score has not considered this element. Another consideration with this tool is that it is static in nature and while the elements assessed were applicable

when it was first published, some of the factors affecting implementation since that time may now be irrelevant or not considered. The adapted Arup maturity model shown in Figure 5 below has similar nuances.

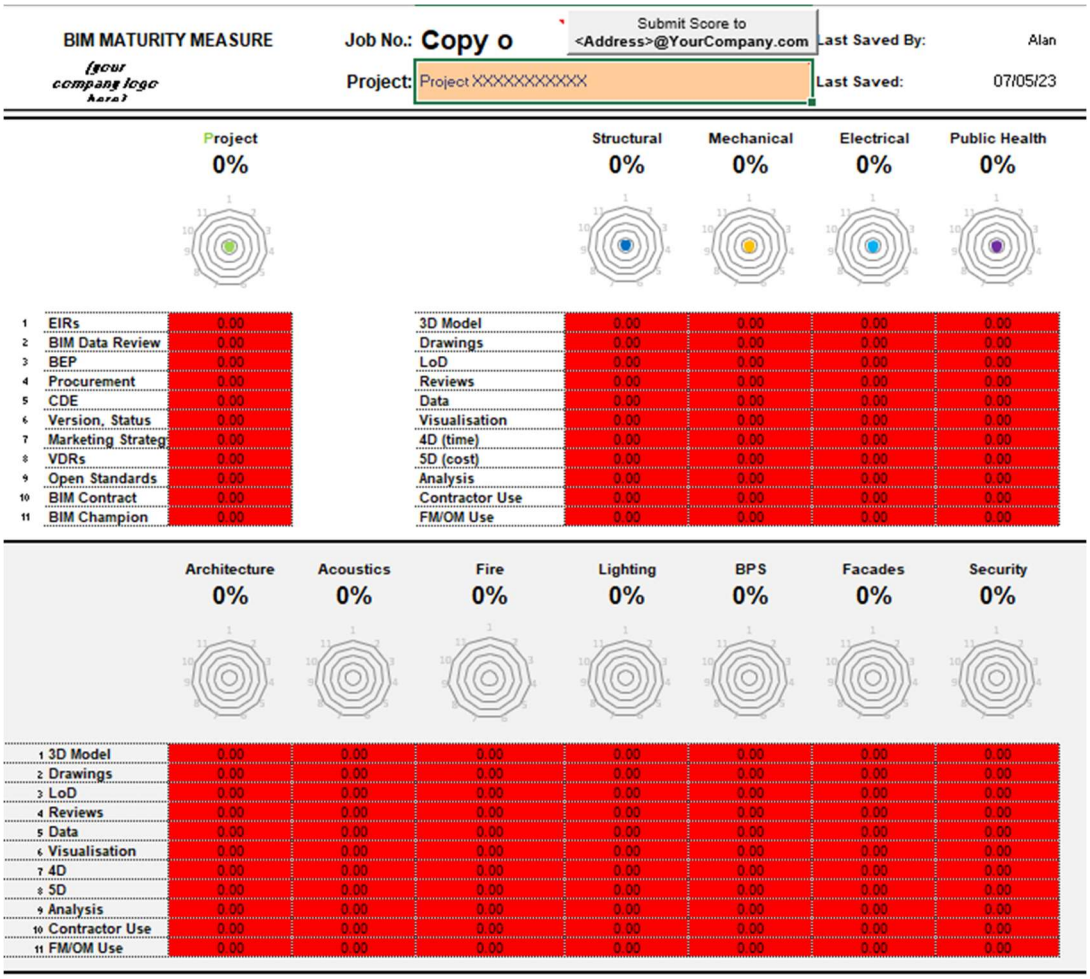


Figure 5: Arup maturity framework. Arup (2014)

Organisations have been classified according to disciplines with the level of granularity relating only to modelling aspects of information with no consideration given to the important elements of communication, collaboration, process or standards of the project objectives. The project elements again have other nuances in that they only consider limited information requirements that mainly focus on the BIM execution plan (BEP) and employer information requirements. The term employer information requirements are described in the PAS1192 standard as a document which explains the information to be exchanged along with the process and standard used by the project team as part of the information delivery process

(Adamu et al., 2015). It has since been updated with the publication of the ISO19650 standard which describes the document as the exchange information requirements although the principles of the document remain the same (ISO, 2018). The level of granularity for the maturity doesn't consider the elements at a low level and for that reason, it could be as open to interpretation by the user. This interpretation would render the evaluation to be interpretive rather than conclusive based on user perception and further validation of the results across multiple users, organisations and projects is required to validate the framework. A tool which aims to undertake assessment and subsequent benchmarking has also been developed which categorises BIM maturity into 1 of 10 Domains and can be used at either the organisational level or project level (Sebastian & Van Berlo, 2010). These domains are categorised as Strategy, Organisation, Resources, Partners, Mentality, Culture, Education, Information Flow, Open Standards and tools as shown in Figure 6 below.

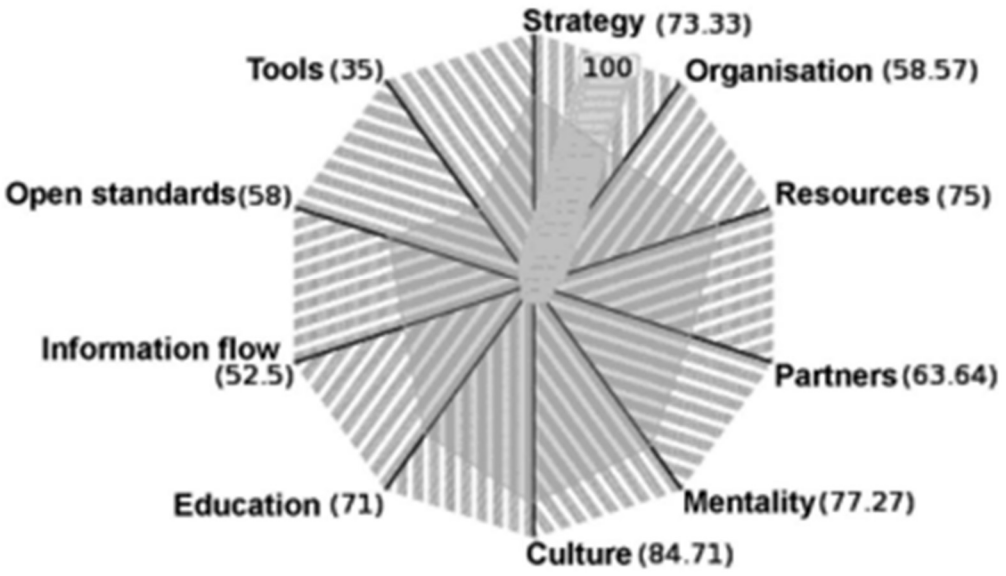


Figure 6: Quickscan results (Sebastian & Van Berlo, 2010)

Each of these domains describes an increase in granularity which fits inside the high-level framework identified by work undertaken by Succar 2009. The most recent tool identified involves participants undertaking a questionnaire in two parts. The first part relates to the requirements delivery between the various actors on a project while the second part looks through the lenses of the process involved between the disciplines and project (Cambridge University, 2018). The tool is loosely based on the specifications outlined in BIM stage 2

discussed above. This means that a project's performance and therefore maturity cannot be measured against further levels of maturity due to the lack of required granularity. The final tool reviewed was developed by the American Institute of Architects technology and is known as the Capability Maturity Model (NBIMS-CCM, 2013). This model is used to track practice and processes in BIM projects and guide them to make improvements. It allows a project to be evaluated against 11 domains and 10 maturity levels but has been criticised for its rigidity and not allowing for the diverse nature of BIM (McCuen et al., 2012; Succar et al., 2013). When comparing the tools and frameworks discussed above with the ISO19650 at a granular level, the results show that there are none which cover the full scope is the standard and only partially fulfil the requirements.

ISO 19650 Reference		**Identified Frameworks & Tools**							
Section	Sub Section	(Succar, 2009)	(Sebastian & Van Berlo, 2010)	(Penn State University, 2012)		(Succar et al., 2012)	(Porwal & Hewage, 2013)	(Arup, 2014)	(Cambridge University, 2018)
Assessment & Need	5.1.1	X	X			X			
	5.1.2		X			X	X		
	5.1.3						X		
	5.1.4						X		
	5.1.5			X					
	5.1.6			X					
	5.1.7			X				X	
	5.1.8								
Invitation to tender	5.2.1								
	5.2.2						X		X
	5.2.3							X	
	5.2.4								
Tender Response	5.3.1								X
	5.3.2								X
	5.3.3								
	5.3.4								
	5.3.5								
	5.3.6			X					
	5.3.7	X		X				X	X
Appointment	5.4.1								X
	5.4.2								
	5.4.3								
	5.4.4								
	5.4.5								
	5.4.6								
	5.4.7								X
Mobilisation	5.5.1							X	X
	5.5.2							X	X
	5.5.3							X	X
Information production	5.6.1								
	5.6.2							X	
	5.6.3							X	
	5.6.4			X				X	X
	5.6.5			X				X	X
	5.7.1								

Information delivery	5.7.2								
	5.7.3								X
	5.7.4								X
Project Close out	5.8.1								
	5.8.2	X				X			X

Table 3: Application of existing frameworks to ISO19650

In summary, although there are several methods and tools available for the assessment of BIM maturity, they lack granular detail and the quality of the assessment themselves lacks adequate quality assurance to enable an assessment to be carried out relative to international standards.

Information Delivery

High-level information delivery is clearly defined in the international standards and is broken down into information requirements which are required at a particular stage in a project's lifecycle and at an organisational level. The definition of information delivery and its standardisation was formalised by the Industry Alliance of Interoperability (IAI) which later became the International Alliance of Interoperability. In 2005 it was again renamed to become Building Smart International (bSI) with the goal of "creating open international standards and solutions for infrastructure and buildings" (bSI, 2023). Within the bSI, there exist three distinct entities; Standards – This area focuses on the standardisation of processes and information exchange that can be used as open data. Compliance – This area looks at certification of software, users and organisations in the use of open standards and finally Support – This area focuses on the provision of support to advance BIM and standards through " technical websites, developer documentation, and support groups…" (bSI, 2023).

The term open data has been again defined by bSI in which they recognise 6 core principles with the UK-BIM-Framework then going one step further and defining interoperability principles based on bSI open data. These have been outlined in Table 4 below. Even though the principle interoperability is outlined by bSi, research carried out highlights that this is still an issue that hasn't been resolved and requires users to be experts in the use of openBIM and that effort is needed to enable general users to be able to adapt to the use of openBIM (Gerbino et al., 2021).

bSI Principle	Definition
Interoperability	The key to digital transformation in the built asset industry
Open	Standard should be developed to facilitate interoperability
Reliable	Data exchange should be reliable and depend on quality benchmarks
Collaboration	Workflows are enhanced by open and agile data formats
Flexibility	Choice of technology should be flexible which creates more value to stakeholders
Sustainability	Interoperable data standards will be safeguarded in the long term by sustainable use

Table 4: openBIM principles reproduced from bSI openBIM definition.

The relationship between the openBIM elements consists of several components which in turn have their own developed international standards or are encompassed within other international standards comprising of ISO 16739 (IFC), Information delivery manuals (IDM), model view definitions (MVD) and international framework for dictionaries (IFD) which in turn is based upon the international structure for classifications (ISO 12006). These are described as the organisational information requirements (OIR), Asset information requirements (AIR), Project information requirements (PIR) and Exchange information requirements (EIR) as shown in Figure 7 below.

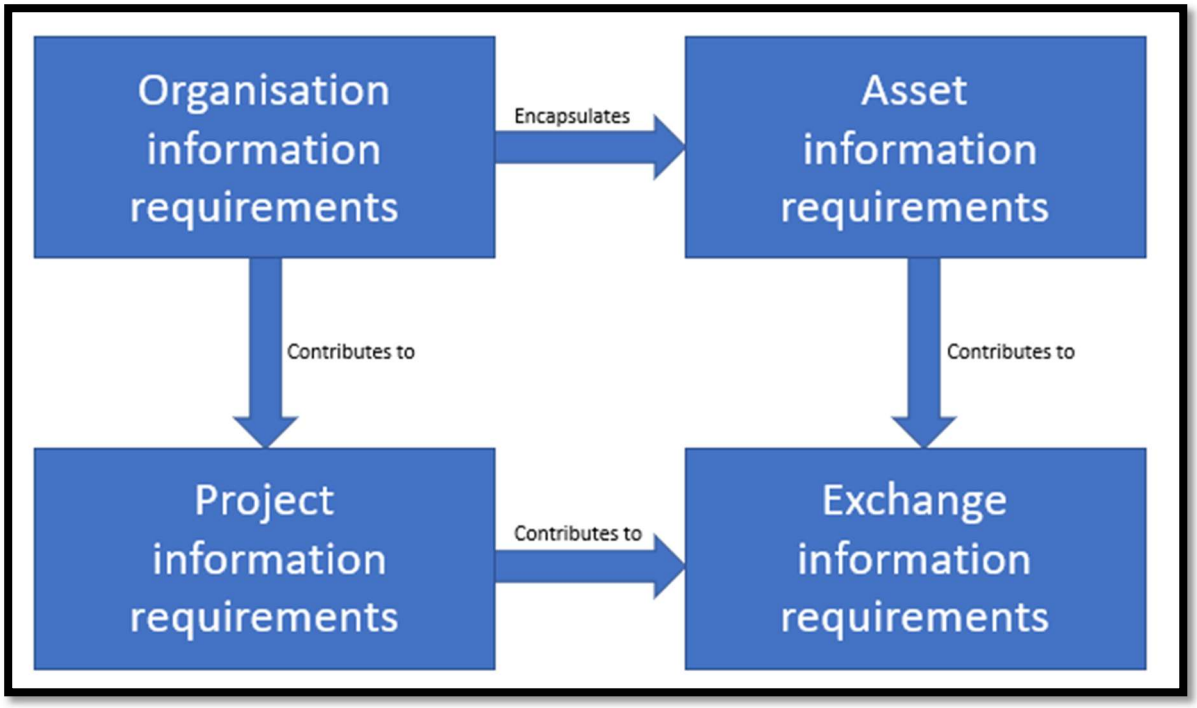


Figure 7: Relationships of information requirements. Adapted from ISO 19650-1:2018 fig 2

These information requirements should be delivered at a particular point during either the project delivery or the operational phase of an asset. The organisation information requirements detail the high-level information needs that an organisation needs in order to fulfil its obligations and policies. Once the organisation has detailed their information requirements, they are then used to contribute to the project's information requirements and determine the asset information requirements. This step is the most critical in gathering the information requirements both in terms of project delivery and the operational life of an asset as they either inform or create a dependency on the remaining information requirements. There have been only a couple of attempts at creating frameworks for the OIR development phase in the literature. While one focused on incorporating a business plan into an OIR (O'Neil, 2018) another detailed that through a comparative study, they were unable to develop a rigid list of requirements that should be included since they are strongly related to business needs and that each business is unique in how it operates (Munir et al., 2020). Given that the OIR are critical in defining the remainder of the information requirements, this is an area that needs to be developed further for organisations to have not only a successful BIM implementation but also a successful information delivery plan. The project information requirements are a key aspect of realising the information required at various stages of the lifecycle of a project and require a clear understanding of the organisation's objectives and relationships with the project. Defining the required outputs from a project clearly at the start can make the difference between either the success or failure of the project’s ambitions. Furthermore, the ability of an organisation to deliver the requirements can be affected by the delivery organisation size, structure, availability of resources along with the maturity of the information processes (Geoghegan et al., 2022). The asset information requirements determine the information that an organisation requires to maintain their assets as either planned, unplanned or preventative maintenance. Within the literature, multiple sources summarise methods of determining the AIR either using a common language platform (Caldera et al., 2022) or through the use of functional asset requirements where they are developed based on use cases (Heaton et al., 2019). The final part of the information requirements is based on the EIR. These information requirements specify the information

that needs to be exchanged at a particular point, who is responsible for the delivery of the information, who is responsible for receiving the information, the format of the information and the data classification. Like all the information requirements detailed above, there is no standardised format for the information requirements at any particular stage and a review of the literature does not reveal any active research in this area. A review of the standards contained in the British Standards Library reveals some high-level frameworks but again there are no standards at present detailing this information at a granular level (British-Standards-Institute, 2023). Once the specifications for the EIR have been detailed the method of execution is defined by the delivery organisation in a format called a BIM execution plan (BEP). Once again, there is no defined format for a BIM execution plan or recognised formats for the exchange of the contents although there have been attempts to develop frameworks which capture the requirements. A recent study concluded that that is a lack of research undertaken in this area due to the complexities of the relationships between the process and requirements(Panagiotidou et al., 2022). Attempts have been made by bSI to develop information delivery manuals (IDMs) as a method for capturing process and information exchange requirements although they have issues regarding exchange formats, limitations on the mapping between requirements and no formalised quality assurance process this is despite their principle that OpenBIM should have reliable data exchange that depend on independent quality benchmarks (bSI, 2010). To try and achieve a level of integration between the elements, a method was proposed to tightly couple them together (Lee et al., 2013). The method however still had issues concerning reusability, quality assurance and possible duplication of relationships. The information requirements once generated, still require the information contained in them to be sent to the correct actor at the correct time with the correct information. The method in which this is detailed is called an information delivery plan (IDP) which is generally broken down into two parts; The Master information delivery plan (MIDP) or the task information delivery plan (TIDP). The TIDP contains a subset of information detailed within the MIDP and sets out the information to be generated by a specific team or individual at a particular point in time along with a detailed breakdown of the information to be delivered. During an asset's lifecycle, from initial conception through to the end-of-life demolition or repurposing, there are multiple sources of information which have to be requested by the many forms of actors. Traditional construction methods before

the advent of digital technologies meant that these information sources were manual drawings, reports, or other forms of documentation which had to be duplicated, amended and distributed amongst the many participants. The timings for these information sources generally followed a plan of work which in the UK was the Royal Institute of British Architects (RIBA) scheme of works for buildings. Many other organisations also have similar schemes of work which are either more detailed in a particular stage or less dependent on the information needed. The advent of digital transformation has meant that although the schemes of work are still relevant, the process, standards and methods in which the information must be delivered have had to change- see processes below.

UK BIM Framework

The UK BIM Framework which has been developed by both academic and industry experts, serves as a comprehensive guide for implementing Building Information Modelling in the United Kingdom. Aligning with the ISO 19650 series, the framework offers a structured approach, aiming to standardise BIM processes and enhance project outcomes. The framework encompasses several guidance documents, with Guidance Part 2, Guidance Part A, and Guidance Part D being particularly relevant to information management within the BIM process and the work undertaken in this research. Guidance Part 2 presents a series of process maps that illustrate the information management workflows throughout a project's lifecycle. These maps provide a visual representation of the various tasks, decision points, and information exchanges involved in BIM implementation. For instance, the "Collaboration and Information Exchange Process Map" outlines the steps from project initiation to completion, highlighting key activities such as defining information requirements, developing BIM execution plans, and managing information delivery. These process maps not only provide a roadmap for BIM implementation but also emphasise the collaborative nature of BIM. They underscore the importance of clear communication, well-defined roles and responsibilities, and the use of common data environments (CDEs) for effective information exchange. However, as with a lot of guidance documents, they lack the granularity specifically required to guide the end users and address the complex and nuanced scenarios that often arise in complex projects. An example of this can be considered when comparing the process maps

generated by the ISO19650 parts 1 and 2 with the ones presented in the guidance which itself it noted in the guidance.

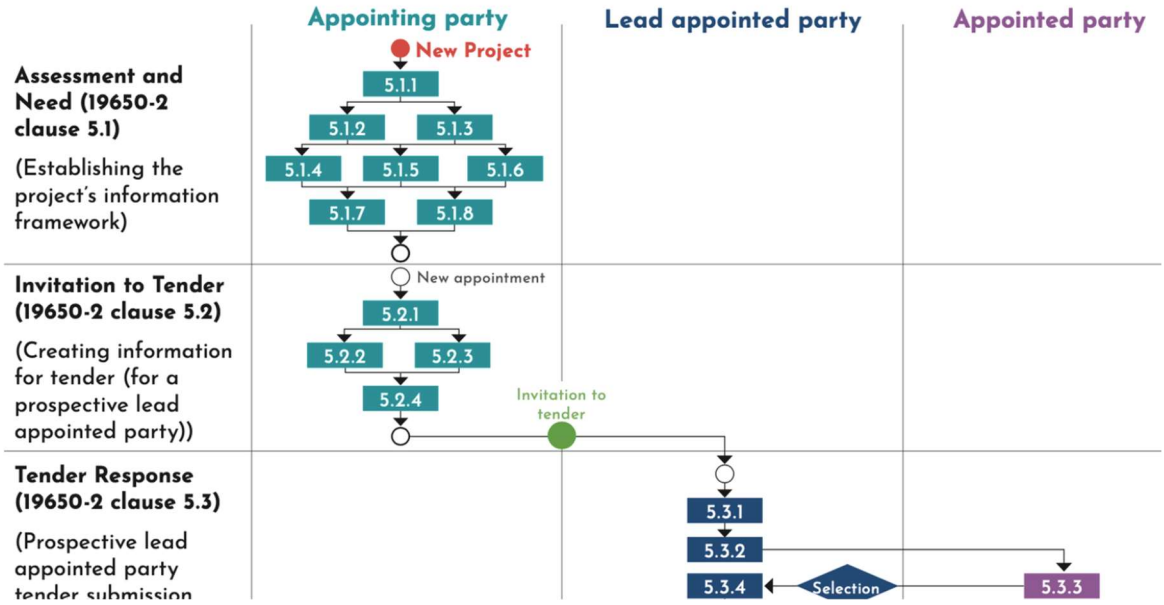


Figure 8: Extract of UK BIM Framework-Guidance 2

Guidance Part A serves as a comprehensive resource hub for BIM implementation. It offers a curated list of standards, guides, templates, and case studies, providing practitioners with a wealth of information to support their BIM journey. The resources cover a wide range of topics, from information management and model federation to legal and contractual considerations. It could be argued that the sheer volume of information and lack of categorising of resources makes it difficult for users to identify the most relevant and essential information for their needs. Guidance Part D focuses on Information Requirements (IR), which are crucial for ensuring that the right information is captured, managed, and exchanged throughout the project lifecycle. It provides detailed guidance on how to define IRs, including examples and templates for different project stages and stakeholder groups but fails to cover the full spectrum of information needs across various disciplines and project stages.

The guidance emphasises that IRs should be specific, measurable, achievable, relevant, and time-bound (SMART). It also outlines the importance of aligning IRs with project objectives, ensuring that the information collected and shared is relevant and useful to the project team.

In summary, both the implementation of BIM and the measurement of BIM maturity can use a multitude of frameworks or implementation tools although the review has shown most of them are either high-level frameworks, too rigid or fail to address the importance of information management at a suitable level of granularity that fail to consider the complexities of the relationships between each entity.

Review of Document generation and classification

As highlighted above, the implementation of BIM involves many different actors involved with many activities which are further exacerbated on large-scale projects where the number of activities and actors increases. At particular points within the IDP, information needs to be delivered to the correct actor at the correct time. ISO 19650-2:2018 identifies these processes at a high level using a format known as BPMN for project delivery but fails to address the individual relationships at a granular level as shown in Figure 9 below.

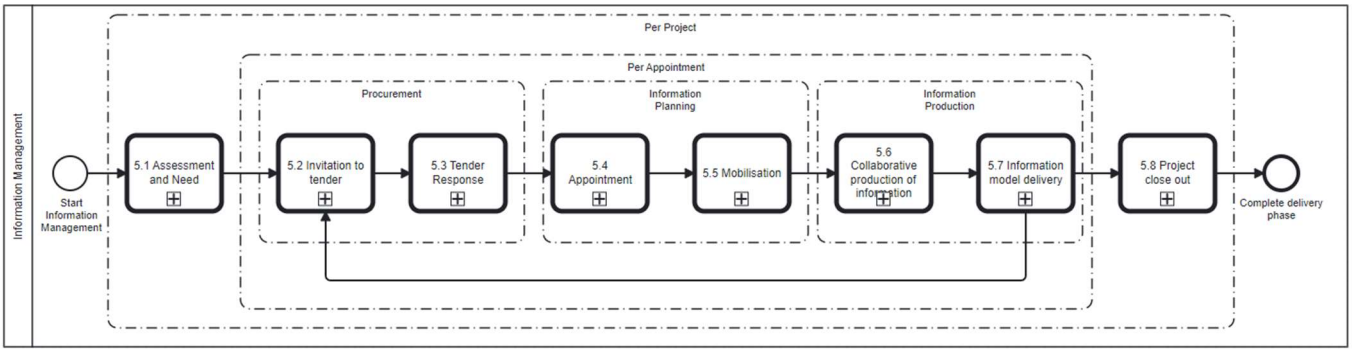


Figure 9: Information Management as a process (Adapted from ISO 19650-2:2018)

The ability to communicate simple or complex processes in a visual method while still maintaining the required semantics for all actors is defined in the BPMN standard (Object Management Group, 2011). (Recker et al.) describes BPMN as a "…structured, coherent, and consistent way of understanding, documenting, modelling, analysing simulating, executing,

and continuously changing end-to-end business processes and all involved resources in light of their contribution to business performance". Another alternative structure is available to users through the use of the integrated definition for process description (IDEF) standard. The selection of the correct modelling method has been described by (Shen et al., 2004) in respect of the IDEF standard. Although not in the context of the BPMN syntax the principles of selection remain valid in that it is essential to transmit the complex systems in a way that is acceptable to be used by a range of actors. Other considerations lie concerning the distinct difference between the two standards; While BPMN can map processes into pools or lanes for different actors, IDEF standard doesn't rely on either chronological continuity, sequence or roles as demonstrated by (Bartley et al., 2016) although both at the simple level require inputs and outputs and it the process itself that undertakes the work. In UML their work in mapping process flows to align the BIM process showed that IDEF can describe the current systems without having to map to specific data structures or organisational structures. The use of BPMN is also noted as the recommended approach when undertaking the development of the process required in an IDM detailed above (ISO, 2017). Work undertaken by (Alreshidi et al., 2016) describes the use of BPMN and unified modelling language (UML) to implement a BIM governance framework. This framework maps out the processes required for actors to retrieve access to data based on their role in a project. BPMN is utilised for mapping the business process required while UML is used to allow amongst other items, for rules to be created. Other work undertaken in this area relates to the use of not only BPMN but also Decision Model and Notation (DMN) to design a system for checking rail standards in Germany (Häußler et al., 2021). The use of DMN is another standard developed by the OMG as a method of enabling complex routing to take place where simple routing using BPMN isn't sufficient. While both of these frameworks outline use cases for either BIM or standards, there is currently no work undertaken with regards to granular level process maps for ISO19650 standard which can map actors and activities together.

Within the industry, there has also been a drive to automate as many functions as possible using what is termed robotic process automation (RPA). This approach does require some fundamental prerequisites before it can be used which include standardised, rules-based structures along with being repetitive or complex (Hofmann et al., 2020). A recent study

highlighted that there is little research undertaken in this area although the implementation of the technology within various industries is quite high (Siderska, 2020).

While the use of BPMN is noted across the literature and standards concerning BIM, it is important to note that there are other modelling standards available. There has been a multitude of literature reviews on this topic over the years which highlights not only that is it an important area of active research but also that the standards and techniques used to define processes and models keep evolving. In work undertaken by (Aguilar-Savén, 2004) he highlighted the many different systems and techniques available including presenting the use of 5 stages of process maturity first presented by (Macintosh, 1993) shown in Table 5 below.

Maturity Level	*Description*
Initial	Setting up of processes
Repeatable	Repeatable processes
Defined	documented processes standardised throughout an organisation
Managed	Measured and controlled processes
Optimised	Continuous process improvement

Table 5: 5 Levels of process maturity (Macintosh, 1993)

In the context of BIM, these stages of maturity apply equally across not only project delivery but also during the operational phase of an asset. The initial stage involves identifying the existing process within a context. Concerning BIM, this could apply to one of many processes involved in not only information management such as sending information to or from an actor, but also to the creation of either structured or non-structured data such as models or room schedules as lists. The next stage in the maturity scale means the identification of the process that could be repeatable. This could be applied to instances such as the IDP being mapped to a particular stage of the RIBA plan of work or that once the graphical models have been created, they are checked for clash detections. The third stage identifies that all the processes are standardised throughout an organisation. Not only is this applicable to various organisations concerning quality management plans which are defined through the use of quality management systems such as ISO 9001 but also for ISO19650 which encapsulates quality assurance throughout all the activities carried out.

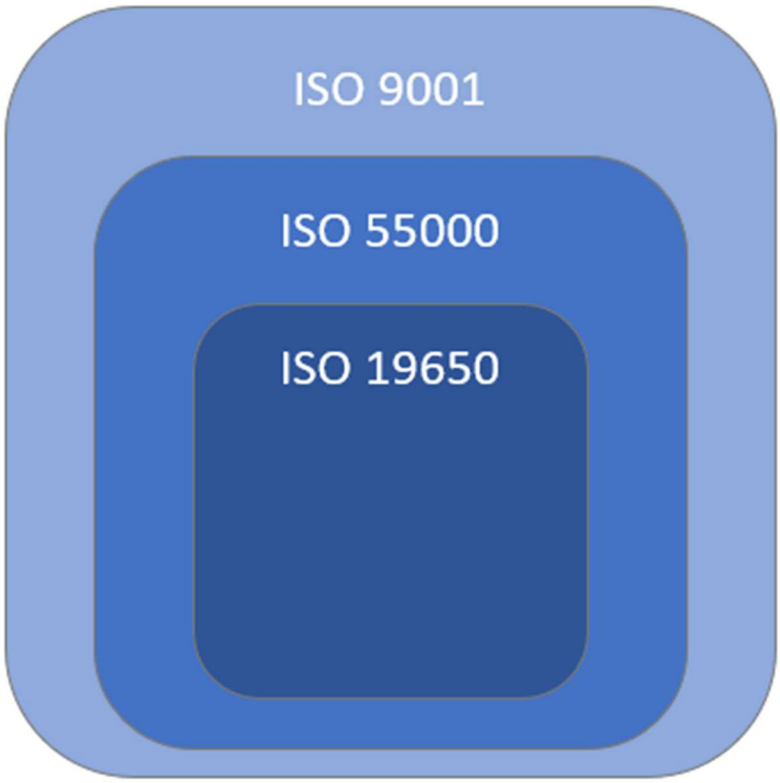


Figure 10: Encapsulation of different standards in relation to ISO19650-1

Research related to this particular aspect is demonstrated by (Donato et al., 2017) where they demonstrate the use of model checking using a database and structured lists as a source of information. This work could also be applied to the fourth and fifth element in the list where the performance of the process is monitored and improvements to the process made. Another business process literature review undertaken 4 years later still found the same complexities as (Aguilar-Savén, 2004) and attempted to classify them into one of 4 categories; Execution, Interchange, graphical and diagnosis (Ko et al., 2009). It is the use of the graphical nature of BPMN which has allowed for the creation of many other frameworks to be developed including modelling a maintenance management system (da Silva & de Souza, 2022) which applies the fundamentals of ISO55000 which like the ISO 9001 series encapsulates the 55000 series as depicted in Figure 10above. This work highlights that formal standards can be mapped at a granular level for use at an end-user level although there is currently no work being carried out concerning ISO 19650 BPMN granularity or implementing

IDEF at any level. One important aspect concerning the visual element of process maps is with regard to the security implications. There may be times when a process is identified within an organisation that has to be included but which may not be suitable for sharing with other actors on a project. This is an area of research which was covered by (Sang & Zhou, 2015) and highlighted an important aspect of confidentiality within the healthcare sector but which could equally apply to the AECOO sector where these concerns are also applicable. The research concluded that the Current Version of BPMN has no diagrams related to security and proposed methods which would overcome these issues. Other modelling languages are described in work carried out by (Oliver et al., 2009) where they identify similarities and differences between what is termed graph-based and block-structured modelling languages. They describe not only BPMN but also Business Process Execution Language (BPEL) and Event-driven process chains (EPC) as exemplar modelling systems. The main characteristic difference between the types of modelling is that while BPMN is noted for use in process documentation, BPEL was placed better in providing process automation. It is however worth noting that the complex join features in BPMN allow for visual improvements overall compared to BPEL and that since the paper was published, version 2.0 of the BPMN allows for process execution to take place – A point that the authors also acknowledge.

There are many platforms available which allow processes to be captured in a format such as BPMN which can then be used to automate the workflows. A compiled list of Process Engines known to the author has been presented below in Table 6 below.

Vendor	*Modelling Type*	*Description*
Camunda	BPMN, RPA, CMN, DNM	Free version offers access to full suite of BPMN modelling. Simulation is offered for limited processes. API access is available on standalone version.
Bonita	BPMN, RPA, CMN, DNM	Free version offers limited access to BPMN modelling. No access to simulation or API access
UiPath	BPMN, RPA, CMN, DNM	Web based platform with access to BPMN. Limited web based api access
G1ANT	BPMN, RPA	Predominantly automation of tasks, not suitable for complex process maps.

Table 6: Analysis of different BPMN tools

Document Production

The production of the required documents during the information management defined in ISO19650-2:2018 involves different documents to be specified, requested and received between the various actors. The production of these documents along with the required formats, metadata and other attributes are also aligned with different stages of the processes in conjunction with the project's defined methods, standards & procedures. Frameworks have been researched concerning the required documents for specific projects, but they have been presented in isolation to the family of information requirements described in the standard. As discussed above, the information requirements commence at an organisational level and end with the production of the exchange requirements. Therefore, each exchange information requirement should be unique to each project although the asset, project and organisational requirements can stay the same. In the work carried out by (Sanhudo et al., 2021) they discuss the specification for information requirements concerning energy-related projects by undertaking a literature review and applying the key findings to produce exchange information requirements. While the work also acknowledges the findings presented above, that there are no defined standards for information requirements, they argue that the starting point for the delivery of information requirements starts at the EIR and have failed to implement the full life cycle of requirements. That is to say that by starting at the EIR they have not considered an organisation or the project objectives which as defined in ISO19650-1:2018 should not be considered in isolation. Research carried out by (Karim et al., 2008) highlighted the fact that information requirements are predominantly produced within software such as Microsoft Word which is subsequently exported as a PDF format and the structured components are lost. They further propose that research is needed to address these challenges to ensure that the structure of requirements is not lost. 5 years later, work was carried out to try to formalise the exchange requirements in the form of a template by (Ashworth et al., 2017). They discussed that by meeting with industry experts they were able to capture the exchange requirements for a project based upon a collaborative effort and applied the research successfully yet still failed to define the requirements as a structured or semi-structured list. In considering the need to implement documentation or requirements within a project, there still exists a challenge that an actor will need to know what

documentation to produce and at what time the documentation will need to be ready. There is still a need to at least formalise these documents in a semi-structured format so that the required documents are produced and linked to a correct process with the correct naming convention applied to each one. While undertaking a review of the literature, there is currently no research being undertaken in this domain although partial elements exist such as the building smart data dictionary, there is still no consensus on the structure or formal transmission of these documents. There have however been small successes in implementing one aspect of the standard by the way of formal naming conventions in the literature. The naming convention defined by the standard should be standardised across a project and should include fields separated by a hyphen (ISO, 2018). This allows a document to be classified by not only its project but also other attributes including the organisation producing the information and the location within the asset which overall give the document a unique number. To control the document naming system on a project, it usually falls to anthropogenic intervention but the recent work highlighted that this can be automated across a project (Ajayi et al., 2023). The authors highlight how this system implemented on a project can save time by automation of a repetitive process. However, the work falls short of full automation as it still requires human intervention to select the naming convention and then a plugin which only works with limited software. Industry software has shown that while it is able as a concept to produce documentation in a structured format following the recommendations made by (Karim et al., 2008) it fails to link the requirements from one stage to another as required in ISO19650-1:20180 (ISO, 2018).

Conclusion

There are many systems available that allow for processes to be mapped visually and then placed into a workflow engine for automation. While the literature shows that this has been undertaken for a number of domains already, no work has been carried out so far concerning ISO 19650 at a granular level. Furthermore, research has focused on implementing the information and document generation required for the standard but not in a structured or semi-structured format or allowing an organisation to track it progress concerning the standard.

Review of Compliance Automation

International standards are stated as *"….a formula that describes the best way of doing something that are internationally agreed by experts*" (ISO, 2023). Within the information management domain, as described above, the international standard is defined as ISO 19650. Within this standard, there are a range of criteria that must be met in order to comply with all the requirements. In order to understand and implement these requirements, a domain expert is often required due to ambiguity in determining what the requirements are (Ferrari et al., 2017). Within the ISO 19650-2:2018 as it currently stands, there are 8 main clauses with 233 different considerations that must be interpreted and applied against the correct actor. In order to ensure compliance with the standard, multiple resources may be employed by an organisation which is multiplied when the standard is applied to many projects with many different actors. One method that organisations can use to demonstrate their competency is to undertake an external audit of the implementation by a third party against published standards. Within the UK, there are several organisations which offer this service. Research undertaken in this area highlights that even when an organisation has achieved certification by an external body, they still have issues with the implementation of BIM on projects which are related to processes, software interoperability and contract issues (Jang & Collinge, 2020). The current focus within the AECOO industry is focused on the compliance checking of the models against regulatory requirements or design constraints. There has been significant research undertaken within this domain which includes literature reviews and various software implementations (Dimyadi et al., 2016; Getuli et al., 2017; Häußler et al., 2021; Lee et al., 2016; Lin & Guo, 2020), the overall work in relation to compliance with the ISO19650-1:2018 features only to ensure compliance with naming standards (Ajayi et al., 2023).

Compliance Checking

As described, one of the major challenges in undertaking compliance checking is understanding and interpreting the requirements of the standards which often contain diagrams, footnotes and exception clauses. Within the AECOO sector, the general practice in relation to applying standards has been manual which in itself contributes to error as well as being highly inefficient (Amor & Dimyadi, 2021). In essence, the current process for the

application of standards starts with domain experts agreeing on a set of high-level rules which are then interpreted by domain experts, subsequently applied and finally manual checking as summarised in Figure 11 below.

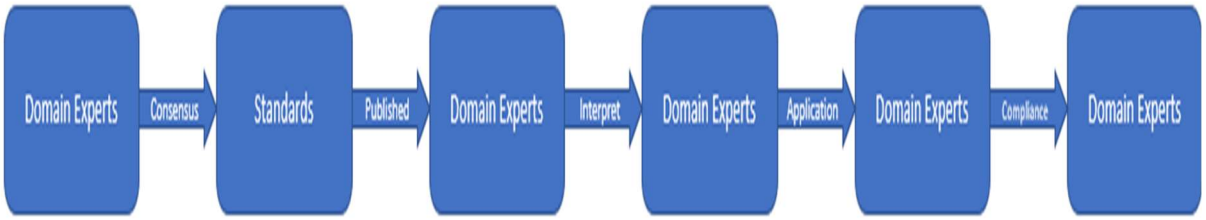


Figure 11: Current standards journey - Inception to Compliance

At a high level, from Figure 11, it is easy to see that there are 5 steps concerned with standards development from initial conception through to application and compliance checking all of which require domain experts. Standards are ordinarily published as a set of procedures that must be followed in order to deliver successfully against the stated objectives. These procedures are again ordinarily stated as a set of words that must be interpreted against the human aspect.

Natural Language Processing

There have been several attempts to use not only natural language processing (NLP) but also ontologies to extract these interpretations against the stated objectives (Shen et al., 2022; Shynkarenko et al., 2022). The domain of natural language processing has progressively increased over the years and now encompasses a range of fields which have been categorized by (Khurana et al., 2023) and presented in Table 7 below.

Term	*Description*	*Abbreviation*
Natural language generation	System to generate meaningful text	NLG
Natural Language understanding	Enablement of machine to understand language	NLU

Speech or Voice Recognition	Enablement of machine to understand the spoken voice	SVR
Machine Translation	Translation from one language to another	MT
Automated text summarising	Provision of short text description from a larger text	ATS
Spelling Correction / Grammar Checking	Ability of a machine to understand spelling and grammatical errors	SGC
Question & Answering Systems	Ability of a machine to provide an answer to a question	QAS
Deep text analysis	Ability of a machine to understand text and provide insights	DTA

Table 7: Current NLP Fields

In the context of the ability of a computer to understand the meaning of a standard and the application of checking the documented method for compliance, only natural language understanding will be analysed further. In order to understand the state of the art in relation to natural language understanding, a search of the literature was carried out using Scopus only with the search terms defined as “Natural Language Processing” OR “NLU”. To limit the scope of the search, only published articles were searched for within the domains of Computer science, Mathematics, Social Sciences, Arts and Humanities, Engineering, Neurology and Decision Sciences. This decision to limit the scope to only these areas of application was due to the inferences from other domains with terms NLP which have the same term but different meanings. The final search term used was “TITLE-ABS-KEY ("natural language understanding" OR "NLU") AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "MATH") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "ARTS")) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "DECI") OR LIMIT-TO (SUBJAREA , "NEUR"))” This initial search returned 849 documents. A further manual trawl of the returned results was then carried out to ensure that only relevant articles were reviewed which resulted in 5 articles being removed. The final article count was 845 which have been analysed below.

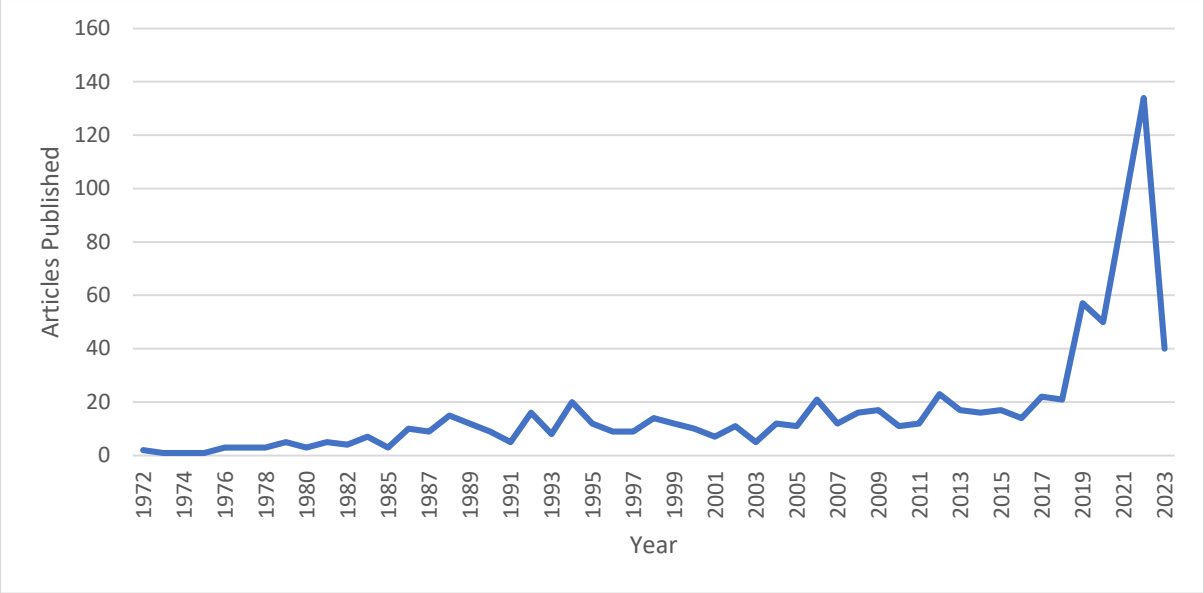


Figure 12: NLU Documents by Year

From Figure 12 above, the results show that the field related to NLU start with the first publication in 1972 on a steady incline with a peak beginning in 2019. In the last few years, however, the number of articles published in this area has increased dramatically. The first significant article published in 1975 discusses the use of a system that can analyse the meaning of a sentence by breaking it down into 3 systems of analyser, inference and encoder (Riesbeck et al., 1975). This work however is limited in that although it still only has the ability to infer meaning within a single sentence it doesn't consider that the semantic meaning of a sentence may vary when applied to a paragraph. However, it is important to point out that this particular piece of work is one of the first published and broke ground in the use using computers to make meaning of language in a particular context. The work builds upon a previously published model called the "Conceptual Dependency Theory" which breaks down sentences into basic concepts which are then expressed as a set of semantic primitives (Schank, 1975). These semantic primitives are then combined to present more complex meanings. The issue with these complex meanings is that they are broken down into 1 of 11 conceptual tenses which may not always be the case within language.

Although there was only a small number of publications up until 1988 when the number spiked, one article published in 1982 is cited 104 times and relates to understanding language processing by studying the amount of time a human takes to read a word in context to a sentence and then make meaning of the sentence in full by applying the processing times in relation to NLU (Thibadeau et al., 1982). This important work builds again upon the Conceptual Dependency theory although the difference between this system and the work described by (Riesbeck et al., 1975) is that processing times can be allocated against particular words to get a deeper understanding and meaning of them within sentences. That is to say, when a human reads a sentence quickly, they may get a different meaning than reading and analysing it slowly. One important drawback to this system however is that it was only trained to comprehend one paragraph which required a large knowledgebase of relationships and concepts. In relation to the AECOO industry, this aspect is important as many documents are produced on projects which when combined, may give rise to different meanings and require a large breadth of knowledge. The rapid increase in publications from 2017 onwards accounted for 64% of the total publications with the 2 most cited articles being related to describing Bidirectional Encoder Representations from Transformers (BERT) (Devlin et al., 2019) and Deep learning for management health applications (Fink et al., 2020). The BERT model is an example of a language model that has undergone unsupervised learning on a large text based on Wikipedia as the source. The transformer part of BERT has become one of the dominant architectures in which it has the ability to process and apply data enabling it to make some predictions(Vaswani et al., 2017). The application part of the data allows the model to be fine-tuned. This has the advantage of allowing for general use of the pre-trained model while allowing another trained dataset to be applied to get better consistency for a particular domain. Previous work in this area focused on forward application of understanding, that is reading from left to right or right to left, while the new model allows for a deeper understanding by allowing right to left and left to right in parallel using masking and next sentence prediction (NSP). While the training set described has used open-source data from Wikipedia that is open to users to edit and add bias to, it still achieved a general language understanding evaluation (GLUE) score of 80.5%. GLUE was proposed by (Wang et al., 2019) to test a language models general behaviour and implicit knowledge using a standardised scoring system. The overall score of 80.5% currently sets it as the best model for

inference concerning the issues of understanding the implementation of documents in standards.

In terms of the overall spread of countries contributing to published articles, Figure 13 below shows that the top 10 countries accounted for 84% of all articles.

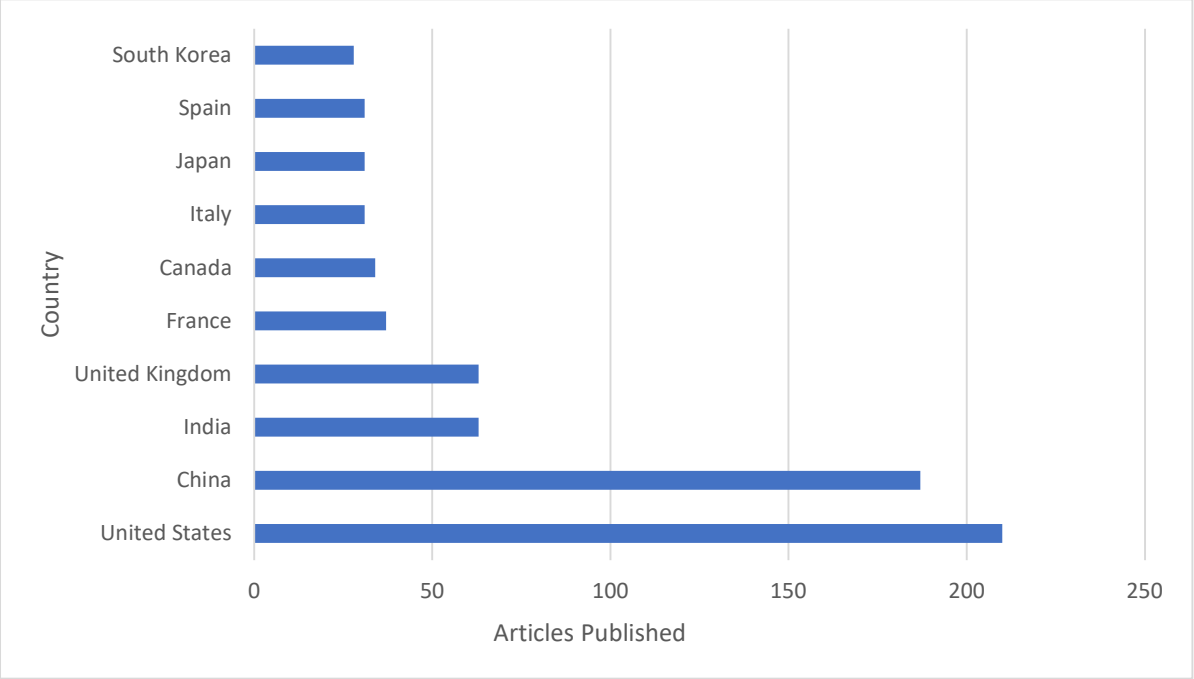


Figure 13: NLU Articles published by TOP 10 Countries.

From this number, the United States Contributed 25%, China 22% and India 7%. The 3 most cited papers in the United States in this domain relate to the complexities of graph neural Networks and highlighting the research directions (Wu et al., 2021), the need for understanding reasoning and decisions in a complex world of uncertainties (Zadeh, 2008) and the paper discussed above in relation to conceptual dependency theory. The 3 most cited articles from China relate to understanding text implication recognition, emotive classification and sentence representation (Zheng et al., 2021), the undertaking of a comparison of modern artificial dialogue systems with the original Eliza program and finds that the newer systems have improved conversation abilities, can learn from human

interactions, and are successfully used as virtual assistants in various domains, demonstrating the capability to participate in conversation and exhibit human-like traits (Shah et al., 2016). The 3rd highest paper from China addresses the limitations in sentence representation reasoning technology, such as incomplete semantic expression, shallow reasoning models, and lack of interpretability. To tackle these challenges, the paper proposes a deep fusion matching network with improved matching layers and a dependency convolution layer that enhances reasoning depth and interpretability. Experimental results demonstrate that the proposed model outperforms shallow reasoning models, achieving an accuracy rate of 89.0% on the SNLI test set, and the dependency convolution layer contributes to improved interpretability in the reasoning process. (Zheng et al., 2022). The first most cited paper from India addresses the challenge of fake news detection in the context of social media platforms. The paper proposes a BERT-based deep learning approach called FakeBERT, which combines parallel blocks of a single-layer deep Convolutional Neural Network (CNN) with BERT to capture semantic and long-distance dependencies in sentences. The proposed model outperforms existing models, achieving an accuracy of 98.90%, and addresses the challenge of ambiguity in natural language understanding (Kaliyar et al., 2021). The second paper from India provides an overview of the field of NLP and its applications in various domains, such as machine translation, email spam detection, information extraction, summarization, medical, and question answering. It discusses the different levels of NLP, the components of Natural Language Generation, and the history, and evolution of NLP. The paper further explores the state of the art, including current trends, challenges, available datasets, models, and evaluation metrics in NLP (Khurana et al., 2023). Finally, the third most cited paper from India focuses on the use of chatbot systems in the healthcare domain to address common small-scale diseases. It highlights the need for chatbots to provide more personalized and natural communication with users, similar to interacting with a human. The paper proposes incorporating NLU, NLP, and ML techniques to achieve this goal and compares different approaches to enhancing the functionality of healthcare chatbots (Bhirud et al., 2019). While the research focus from the United States is centred around the need for understanding complex problems, China's most cited papers centre around comparisons of existing technologies and India is focused on the broader application of natural language understanding in life-based scenarios.

Finally in relation to the current state of the art concerning Natural Language Understanding, an analysis of the current active researchers is undertaken with the results shown in Figure 14 below.

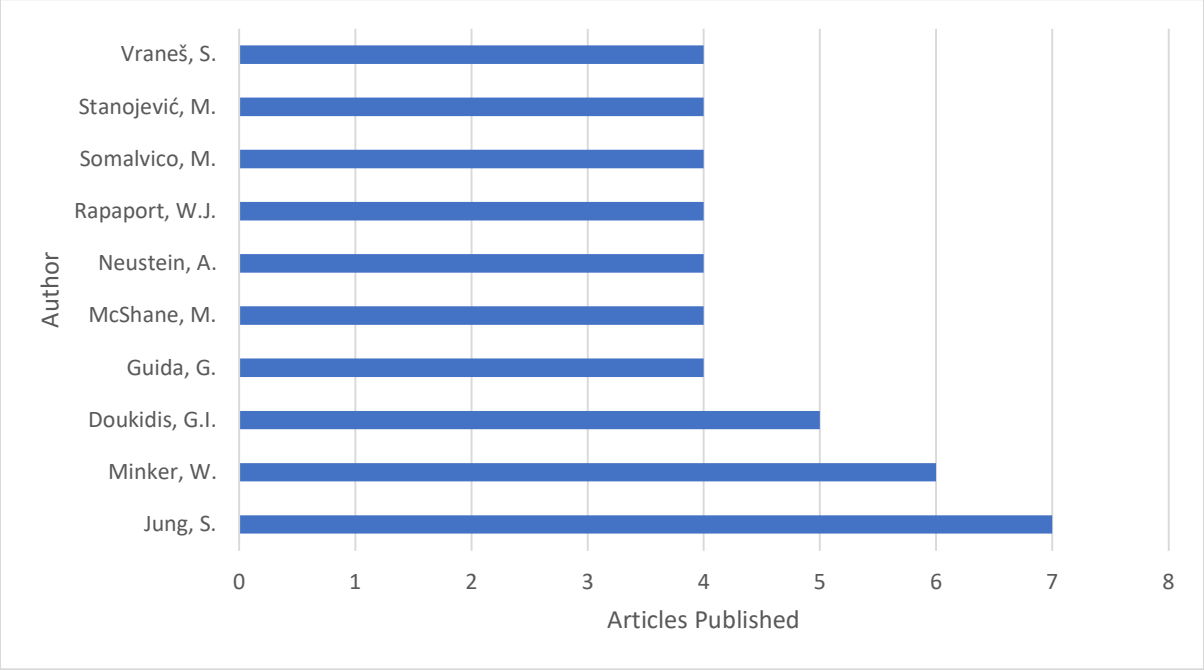


Figure 14: NLU Articles published by Author.

In total there are 159 authors active within the field relating to NLU although, out of these, 113 authors have contributed to 2 articles, 35 contributed to 3 articles, 8 contributed to 4 articles. The top author within this domain is Jung, S who has contributed to 7 papers with research focusing on the development of a framework for embedding semantic correspondence between unstructured text and extracted semantic knowledge in natural language understanding, enabling visualization, semantic search, intent classification, and re-ranking based on vector-based semantic similarities. Out of these 7 papers, however, only 3 are cited 35 times. The second most contributing author is Minker, W with 6 published articles and 41 citations whose research covers natural language understanding in translations. The third most published author's research covers a period from 1985 through to 1987 and focuses on computer assistance in the formulation phase of a discrete-event simulation model. Their work involved developing prototype expert systems using LISP programming

language and an Apple II computer. They explored different approaches, including the "MYCIN" approach and a natural-language understanding system, to aid in the creation of simulation models or the ability to analyse outcomes based on a set of inputs based on language.

Overall, in relation to Natural Language processing, research has been an active area with several approaches being used across the globe and with multiple contributing authors. In relation to the use of Natural Language Understanding and the application of standards and the corresponding required documentation for BIM standards, no one has yet explored this area which although domain-specific, could be expanded to other applications.

Summary

1) This chapter aimed to answer question 1:
   "What does existing literature reveal about the challenges and potential solutions for understanding maturity and enhancing collaboration and information management in the industry, particularly in the context of complex processes involving multiple actors? "

Given that the AECOO industry is an information-intensive industry, it makes sense then to have the ability to not only understand the requirements of a particular standard but also have the ability to understand the contents of a document to check if they align with the requirements automatically. Furthermore, by linking those documents to a particular element of the required standard, it is then possible to have the ability to check the process contained within the same. This method of checking is currently a manual process which requires an external auditor to check through each of the required documents and ensure that the contents are generally aligned which can take considerable time for larger organisations and projects. There is currently no method in place to undertake this either automatically or smartly. There is also no current framework available to monitor the maturity of an organisation's compliance with industry standards.

Chapter 3 Research Methodology

Methodology overview

In this chapter, the primary focus is to outline the methodology employed in conducting this research, providing a clear understanding of the principles and methods utilised. The methodology serves as a roadmap for the entire research process and ensures the validity and reliability of the findings.

Methods employed

The Saunders Research Onion (Saunders et al., 2007) shown in Figure 15 below, is a widely used framework that provides guidance for the methodology section of research projects predominantly used in business research. Although it offers numerous benefits, it also has certain constraints that researchers should bear in mind. One limitation of the Saunders Research Onion is its applicability to different types of research. For instance, it is noted that it may not be suitable for studies that concentrate on a single case or utilise experimental designs. The onion model is better suited to qualitative or mixed-methods research, where data collection from multiple sources is necessary.

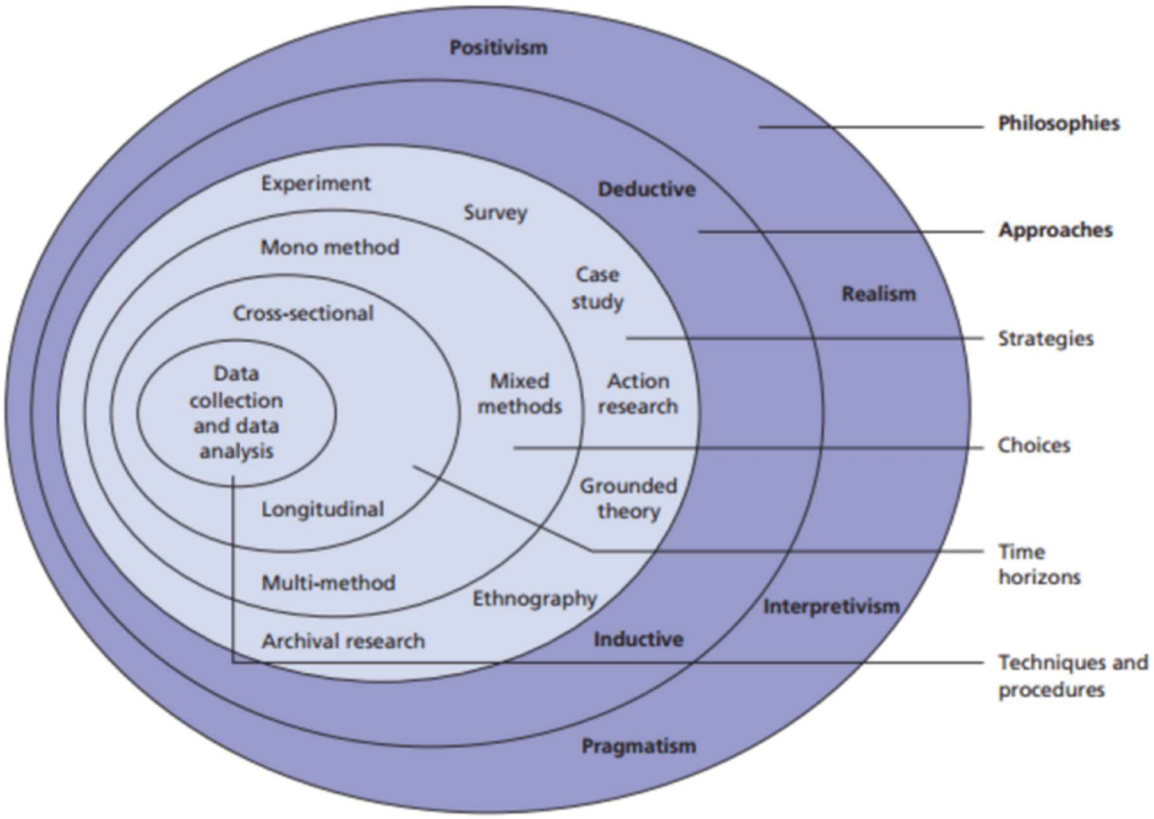


Figure 15: Saunders research onion (Adapted from Saunders 2007)

Another drawback of the onion model is its complexity, which may pose challenges for novice researchers. With multiple layers, each comprising distinct research methods and techniques, the model can be overwhelming for individuals unfamiliar with its terminology and concepts. Critics also argue that the onion model oversimplifies the research process and fails to capture the intricacies of real-world research. They contend that the model presents a linear and hierarchical perspective, which may not accurately depict the messy and iterative nature of research in practice. Certain critical reviews have scrutinised the application of the Saunders Research Onion in specific fields or research contexts. For example, researchers have argued that the onion model may not be suitable for disciplines like engineering or natural sciences, where quantitative methods and experimental designs hold greater importance.

Philosophies

The outer layer of the onion considers the different philosophies that apply to research which fall into one of four categories, positivism, realism, interpretivism and finally pragmatism.

Positivism, for example, emphasises the importance of measurable and quantifiable data that can be scientifically tested. It involves formulating hypotheses that are further broken down into research questions. These hypotheses can be tested and validated through empirical data, and the research can be replicated to generate similar results. On the other hand, realism takes a different perspective by not considering the scientific method as the ultimate or perfect solution. It acknowledges that alternative methods can be explored to address specific issues or challenges. Realism recognises the complexity of the research process and encourages researchers to be open to different approaches and methodologies. Interpretivism, in contrast, focuses on understanding the nature of human participation in social sciences. It places greater emphasis on qualitative studies, seeking to uncover meanings, experiences, and subjective perspectives. Interpretivist researchers aim to explore the subjective realities and contexts of individuals and groups, often employing methods such as interviews, observations, and textual analysis. Pragmatism, as a methodological approach, argues that researchers should not limit themselves to a single methodology or philosophical stance. Instead, they should adopt a pragmatic stance by considering the most suitable methods and techniques to achieve the desired research objectives. Pragmatism recognises that different research questions may require different approaches, and it advocates for the integration of multiple research methods, both quantitative and qualitative, to provide a comprehensive understanding of the research topic. Acknowledging and understanding these different philosophical approaches, researchers can select the most appropriate methodology based on the nature of their research questions and objectives. It is important to consider the strengths, limitations, and underlying assumptions of each approach to effectively design and conduct research. In some cases, a mixed-methods approach combining quantitative and qualitative methods may be the most suitable option to gain a more holistic understanding of the research topic and achieve the desired outcomes.

Approaches

The second layer of the onion is split into two main approaches, deductive and inductive. The deductive approach begins with a set of general theories or hypotheses, and the research aims to test and confirm these theories or hypotheses through empirical evidence. It involves starting with a broad theoretical framework and then narrowing it down to specific research questions and hypotheses. This approach is often associated with quantitative research methods, where data collection and analysis are structured to test specific hypotheses or theories. On the other hand, the inductive approach starts with specific observations or patterns in the collected data and seeks to develop generalised theories or hypotheses based on these observations. It involves a bottom-up approach, where researchers analyse the data, identify patterns or themes, and generate theories or hypotheses that explain these patterns. This approach is commonly associated with qualitative research methods, such as interviews, observations, or content analysis.

This research uses an abductive approach which combines both approaches. Abduction involves reasoning from specific observations or patterns to develop plausible explanations or theories while acknowledging that research often involves a back-and-forth movement between theory and data, where researchers may start with some initial theories or hypotheses but also allow the data to shape and refine their understanding. The abductive approach is particularly useful when studying complex phenomena where there may not be a clear cause-and-effect relationship. It allows researchers to iteratively analyse the data, generate hypotheses, and refine theories based on the findings. This approach enables a more nuanced and contextualised understanding of the research topic. By selecting an abductive approach, this research acknowledges the importance of both deductive and inductive reasoning in the research process while allowing for flexibility and openness to new insights while still maintaining a theoretical framework to guide the research. This approach provides a balanced and comprehensive approach to addressing the research questions and generating knowledge.

Although the Saunders Research Onion serves as a valuable framework for guiding the methodology section of research projects, it is crucial to acknowledge its limitations and consider alternative models and approaches when appropriate.

The third layer of the onion considers the strategies that could be used which include experimental, surveys, case studies, action research, grounded theory and ethnographic studies.

Ethnographic Research

Ethnography is a specific research strategy that involves immersing oneself in a specific social or cultural setting to observe and understand the behaviours, beliefs, and practices of the participants. It emphasises the importance of being embedded in the context under study and actively participating in the daily activities and interactions of the researched group. The ethnographic research strategy often includes extended periods of fieldwork, where the researcher gathers data through direct observations, participant observations, interviews, and document analysis. The goal is to gain a deep understanding of the cultural, social, and contextual factors that shape the participants' experiences and perspectives. In the context of understanding the issues both organisations and projects face in implementing standards, ethnographic research can be a valuable approach. Researchers can spend time within the projects and organisations, observing their operations, interactions, and decision-making and gaining a deep understanding of the challenges, barriers, and facilitators related to implementing standards. Ethnographic research does however have some challenges and considerations which need to be understood when it is used. The first consideration relates to the fact that the immersive nature of the method requires the researcher to spend considerable time embedded with the organisations and projects. This fact needs to be considered when designing the research. The second factor again relates to the first factor although when it is carried out within a full project lifecycle the issues become multiplied as some projects can take years to complete. A review carried out by (Hammersley, 2006) discussed other issues related to ethnography describing the fact that if the time spent by the researcher being embedded in an organisation or project in this context is reduced, the

overall potential for oversight becomes larger and methods need to design to take this into account.

Agile Method as a function of design science research

In the context of this research, the agile methodology has been adopted as a suitable approach due to its inherent characteristics that align with the research objectives and requirements. Agile research provides an iterative and adaptive framework that allows for quick responses to changing research needs and emerging insights (Pries-Heje et al., 2008) and forms part of the Design science research (DSR) theory (Brocke et al., 2020), by embracing uncertainty and acknowledging that research questions may evolve, agile research enables researchers to adjust their approach and incorporate new information during the research process. This approach is particularly valuable in a dynamic field that involves research and technology, where advancements and changes are frequent. The iterative nature of agile research facilitates the exploration and integration of new technologies, ensuring that the research stays up to date-with the latest developments. Additionally, the user-centred focus of agile research is crucial in understanding user needs, preferences, and behaviours in relation to the research and technology being investigated. Involving users early on and continuously gathering feedback, agile research allows for the refinement and improvement of the research outcomes. Moreover, the prototyping and testing aspects of agile research enable researchers to iteratively validate assumptions and ensure that the technology aligns with user expectations. The adoption of agile research provides a flexible and adaptive approach to address the research objectives, incorporating user insights and keeping pace with technological advancements to deliver valuable and relevant findings. The final strategy involves the use of case studies which provide a bridge between both the theoretical and the practical aspects of this research. This allows for the testing and validation of the process automation related to standards along with the validation of the documentation production and compliance testing. In relation to the time horizon of the research onion, there is a choice between horizontal and or cross-sectional. The longitudinal horizon involves repeated measurements of an aspect of a time, whereas the cross-section study involves a measurement at a single point in time. This research focuses on the longitudinal horizon in relation to the sampling of data and processes over a period of time.

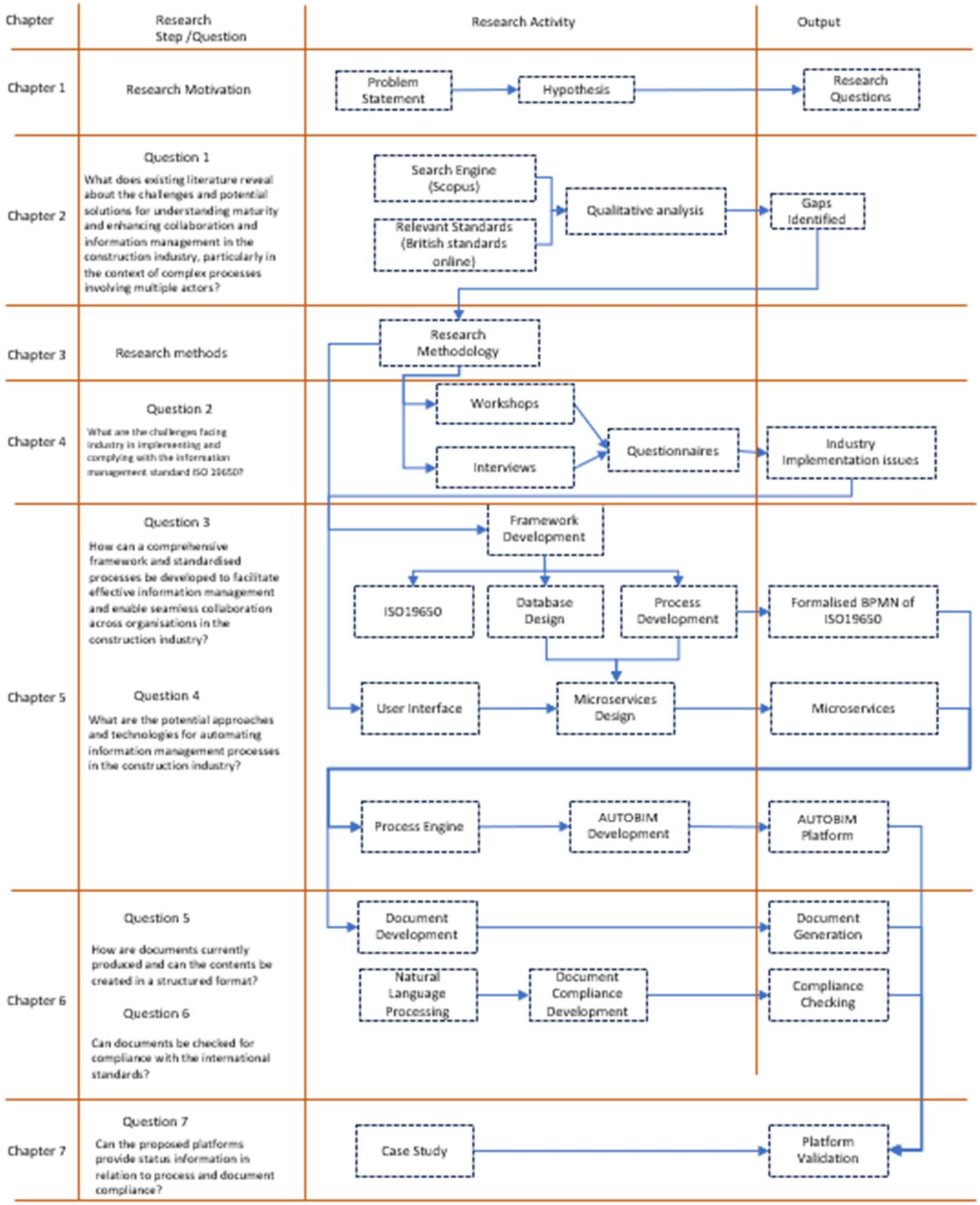


Figure 16: Research methodology flowchart

Step 1 – Research Motivation

The research motivation phase is a crucial step in the research methodology as it lays the groundwork for the study and establishes the reasons behind conducting the research. It involves delving into existing literature, industry trends, and practical challenges to identify the gaps in knowledge or areas that require further investigation. By understanding the motivation behind the research, the study can be contextualised, and its relevance and significance can be justified. In the context of this thesis, the research motivation revolves around the need to address the challenges in information management and compliance checking within the AECOO industries. These industries often face complex project requirements and compliance regulations, which can hinder project delivery and efficiency (Sacks et al., 2010). Therefore, there is a growing demand for automation in information management to enable a smart and streamlined approach to compliance checking.

Step 2 – Understanding the Status Quo

To understand the current domain in relation to information management, processes and compliance the problem, challenges and related research were reviewed and investigated in chapter 1 and 2. These chapters concluded that there are difficulties with how information management standards are validated and that there are no granular details or formal representations of the processes related to information management. There have been several attempts to undertake BIM maturity in the literature, but none specifically related to information management maturity or a framework outlining the requirements for understanding the status of a project from the related process. The BIM maturity frameworks that are currently in existence are related to either very high-level abstract levels (Succar, 2009), organisational related to a specific domain(Penn State University, 2012) or project-based not related to current information management standards (Arup, 2014). One of the significant challenges in information management compliance checking is the lack of standardised processes and guidelines. The absence of a formalised schema or framework for information management makes it difficult for organisations to ensure consistent and accurate compliance checking across projects and stakeholders. Without a standardised approach, organisations rely on manual methods to generate, review, and verify documents,

which is time-consuming, prone to errors and lacks efficiency (Sacks et al., 2010; Succar, 2009). This inconsistency and lack of uniformity in compliance-checking processes can lead to misinterpretation, miscommunication, and non-compliance with industry standards and regulations. Consequently, it hampers the overall quality of information management and can result in costly rework, delays, and compromised project outcomes.

Another issue lies in the generation of compliant documents within the information management process. The absence of a formalised schema for document generation and compliance checking complicates the task of ensuring that the generated documents meet the required information standards. Manual document creation and verification are labour-intensive, resource-draining, and subject to human error. It becomes challenging to maintain consistency, accuracy, and completeness in document content and structure across different projects and stakeholders. Moreover, the lack of automated tools or systems to facilitate compliance checking exacerbates the problem, as organisations struggle to efficiently validate the compliance of documents against information requirements. This leads to inefficiencies, increased costs, and potential non-compliance issues that can have negative implications for project delivery, stakeholder collaboration, and overall project success.

These chapters highlight the lack of a formalised schema for information management processes and document generation, along with the absence of automated compliance checking systems, which poses significant challenges in ensuring consistent and accurate compliance with information requirements. These issues hinder effective information management, increase the risk of non-compliance, and introduce inefficiencies in the construction industry. Addressing these challenges through the development of standardised processes, automated tools, and robust compliance checking systems is essential to improve the quality, efficiency, and compliance of information management practices in the industry

The contents of these chapters answer question 1 which is:

“What does existing literature reveal about the challenges and potential solutions for understanding maturity and enhancing collaboration and information management in the

construction industry, particularly in the context of complex processes involving multiple actors? "

Step 3 – Research methodology

The need for explaining the research methodology stems from the importance of selecting and utilising appropriate methods to address the research objectives effectively. Analysing different research methods enables the identification of the most suitable approaches to be employed in this thesis. By thoroughly exploring and understanding various research methodologies, it becomes possible to align the chosen methods with the specific requirements of the study. This alignment ensures that the research process is rigorous, systematic, and capable of generating reliable and valid results. Moreover, explaining the research methodology allows for transparency and clarity in the research process, enabling readers to understand the steps taken and the rationale behind them. By providing a clear explanation of the research methodology, this thesis aims to establish a solid foundation for the subsequent research chapters and ensure the credibility and integrity of the study.

Step 4 – Critical analysis for BIM Governance

In order to define the requirements and develop a comprehensive framework for effective information management in the construction industry, a detailed assessment of existing standards was conducted through manual reviews, interviews, and questionnaires. This rigorous process aimed to gain insights into the challenges faced by industry practitioners in meeting the requirements set by these standards. By engaging with professionals from various organisations and roles, valuable feedback and perspectives were gathered to understand the specific issues and pain points related to information management practices. Based on the findings from the assessment, a database design was implemented to establish a structured and centralised repository for information management. This design considered the specific data requirements, relationships, and functionalities identified through the analysis of industry standards and stakeholder feedback. The database design served as a foundational component of the comprehensive framework, providing a structured approach to store, manage, and retrieve information throughout the lifecycle of a project.

Furthermore, the identified processes were formalised into a Business Process Model and Notation (BPMN) schema. This formalisation allowed for a visual representation of the information management processes, depicting the flow of information, tasks, and interactions among stakeholders. The BPMN schema provided a standardised notation to clarify the sequence and dependencies of activities, facilitating a better understanding of the information management processes and their integration with other organisational workflows.

To create a flexible and scalable system for the comprehensive framework, a microservices environment was implemented using Docker. Docker containers provided a lightweight and isolated runtime environment for each individual service within the information management system. This approach allowed for modularisation and decoupling of functionalities, making it easier to develop, deploy, and manage the different components of the framework. The use of a microservices architecture meant the information management system was broken down into smaller, independent services that could be developed, tested, and deployed separately. Each service performed a specific function within the framework, such as data processing, information retrieval, or compliance checking. Docker containers encapsulated these services along with their dependencies, ensuring consistency and portability across different environments. The microservices architecture, coupled with Docker, offered several advantages for the comprehensive framework. It enabled scalability, as additional instances of a particular service could be easily created to handle increased demand. It also allowed for better fault isolation, as issues with one service would not affect the overall system. Furthermore, updates and changes to individual services could be made independently without disrupting the entire framework.

Through the combined efforts of manual reviews, interviews, questionnaires, database design, BPMN formalisation, and microservices implementation with Docker, the development of the comprehensive framework aimed to enhance information management

practices, promote collaboration, provided a formalised framework which was used to answer question 2:

Q2. What are the challenges facing industry in implementing and complying with the information management standard ISO19650-2:2018*?*

Step 5 – System design and process automation

The design and development of the AutoBIM platform involved leveraging the established database structure to store and manage information, as well as integrating the formalised BPMN process map into a process engine to monitor information management processes. Additionally, the platform incorporated a user task assignment feature to streamline task management. One of the notable features of the AutoBIM platform was its built-in simple approval system. The simple approval system within the AutoBIM platform played a crucial role in ensuring compliance with information management standards. As users progressed through the information management processes, certain checkpoints required approvals before proceeding to the next stage. This approval system provided a structured workflow, where stakeholders had to obtain appropriate approvals at each stage to ensure the accuracy, completeness, and compliance of the managed information.

The approval process was seamlessly integrated into the platform, allowing designated individuals or teams to review and provide their consent or feedback. Once approval was obtained, the system allowed the information management process to proceed to the next step. This simple approval system served as a quality control mechanism, ensuring that the required checks and balances were in place before advancing further. By incorporating the approval system, the AutoBIM platform promoted accountability and enhanced the reliability of information management practices.

This work answered questions 3 and 4:

"Q3. How can a comprehensive framework and standardised processes be developed to facilitate effective information management and enable seamless collaboration across organisations in the construction industry?"

"Q4. What are the potential approaches and technologies for automating information management processes in the construction industry?"

Step 6 – Compliance document generation and checking

The design and development of the document generation engine in the BIMComply platform focused on providing users with the ability to select the specific documents required for their roles, streamlining the document creation process. By allowing users to choose only the necessary documents, the platform eliminated unnecessary clutter and improved efficiency. Once the documents were generated, they underwent a compliance checking process that employed the concept of "level of checking." During the compliance checking process, the documents were scanned for various elements, including their contents, section titles, and document titles. This thorough scanning ensured that the documents met the required standards and contained the appropriate information. After scanning all the documents, the compliance checking engine presented the results to the user using a ranking system.

The ranking system played a crucial role in the compliance checking process. It compared the expected document type, such as an Exchange Information Requirement (EIR), with the actual content of the document. If the content aligned with the expected document type, the compliance checking engine would indicate a successful match. However, if the content did not match the expected type, the engine would provide feedback to the user, such as "You said this was an EIR, but based on the contents, it appears to be an Asset Information Requirement (AIR)." By implementing this ranking system, the BIMComply platform ensured that the compliance checking process was more than a binary pass or fail assessment. It provided users with detailed feedback regarding the document type and its alignment with the expected standards. This feedback helped users identify any discrepancies or inconsistencies and take appropriate corrective actions.

The design and development of the AutoBIM platform incorporated a comprehensive compliance-checking process that involved scanning the documents for their contents, section titles, and document titles. The ranking system utilised in the compliance checking engine enabled users to receive detailed feedback about the document type and its alignment with the expected standards. This approach ensured that the platform provided accurate and informative assessments, empowering users to address any non-compliance issues effectively.

The work answered questions 5 and 6:

"Q5. How are documents currently produced and can the contents be created in a structured format? "

"Q6. Can documents be checked for compliance with international standards? "

Step 7 – Demonstration and validation

AutoBIM platform's development process focused on the demonstration and validation of its capabilities. This phase involved utilising the platform to monitor the progress of a real-world case study within the construction industry, showcasing how it could effectively support information management practices and compliance. A limitation of the testing and validation due to time constraints meant that only section 5.1 of the ISO 19650 was implemented although the fundamental aspects of transferring a standard into the BPMN process through a process engine are still valid.

During the case study, the AutoBIM platform served as a centralised hub for managing and tracking information management processes. It provided a user-friendly interface that allowed project stakeholders to input and update relevant information, ensuring that the documentation and compliance requirements were met. The platform enabled seamless collaboration and communication among stakeholders, facilitating a streamlined workflow and efficient sharing of information. The ability to monitor progress was a key highlight of the demonstration and validation phase. It provided a comprehensive overview of the project's

information management practices, tracking the completion status of various activities and highlighting any deviations from the defined standards. This real-time visibility allowed for accurate and up-to-date information allowing stakeholders to make informed decisions and optimise project delivery.

To validate the compliance-checking capabilities of the platform, a real-life document from a BSI-audited source was introduced into the system. The document underwent a rigorous analysis using the platform's compliance checking engine, which leveraged BERT NLP-based scanning techniques against the template schema. This advanced analysis scanned the document for its contents, section titles, and document titles, comparing them against the expected standards. The compliance checking engine then generated a detailed report indicating the level of compliance for each aspect of the document. The results of the compliance checking process were presented to the users through a ranking system. This system allowed the platform to provide meaningful insights such as, "You specified this document as an EIR (Employer's Information Requirement), but based on the contents, it appears to be an AIR (Asset Information Requirement)." By highlighting such discrepancies, the platform enabled users to identify and rectify potential errors or inconsistencies in their documentation, ensuring that the information management practices aligned with the intended standards. The demonstration and validation phase played a crucial role in assessing the performance and effectiveness of the AutoBIM platform. By applying it to a real-world case study and subjecting a BSI audited document to analysis, the platform's capabilities in information management and compliance checking were thoroughly tested. The feedback and insights gained from this phase provided valuable inputs for further refinement and improvement of the AutoBIM platform, ensuring that it met the industry's requirements and delivered tangible benefits to construction projects.

This work answered question 7:

“Can the proposed platforms provide status information in relation to process and document compliance? “

Chapter 4 Critical analysis for BIM governance

This chapter provides the initial requirements to provide the framework for information management and quality assurance of both process and documentation generation and compliance. In order to define the requirements, this chapter is split into several sections in order to answer question 2.

"Q2. What are the challenges facing the industry in implementing and complying with the information management standard ISO 19650? "

Industry Engagement Justification

The decision to engage with the industry and involve local authorities in the research was driven by the fact that the Welsh government had not mandated the use of BIM in Wales (Welsh Goverment, 2022). Unlike some other regions or countries where BIM implementation is mandated by the government, Wales did not have such a requirement in place. This lack of a government mandate had significant implications, including the absence of dedicated government funding to support BIM implementation initiatives. Given this context, it was crucial to understand the industry's perspective and the challenges they faced in adopting BIM without the backing of a formal mandate. This study therefore gives the state of information management at the time. Engaging with local authorities, who play a key role in shaping construction practices and standards within their jurisdictions, provided valuable insights into the practical implications and considerations surrounding BIM and information management implementation in Wales. By involving local authorities, the research sought to capture their experiences, perspectives, and efforts in adopting BIM voluntarily, as well as their interactions with contractors and other industry stakeholders.

The absence of government funding for BIM implementation further underscored the need to explore the realities faced by industry practitioners. Without dedicated financial support, organisations had to rely on their own resources to invest in BIM-related technologies, processes, and training. Understanding the challenges and constraints arising from this funding gap was essential for identifying practical strategies and solutions that could help

organisations overcome financial barriers and effectively implement BIM and information management within their projects. Conducting the research within the context of a non-mandated BIM environment in Wales, the study aimed to provide insights and recommendations that could apply to other regions or countries where government mandates for BIM implementation may be absent. It sought to highlight the practical challenges faced by industry stakeholders, explore alternative approaches to driving BIM and information management adoption, and inform policymakers and industry professionals about the implications of non-mandated BIM for funding and implementation strategies.

The decision to focus primarily on contractors for the interviews was made due to their direct involvement in project execution and delivery, making their insights invaluable for understanding the practical challenges and successes in implementing standards like ISO 19650. However, this approach does have limitations. It may not fully encompass the views of other stakeholders like clients, architects, or consultants, and contractors may have inherent biases. Additionally, the findings may not be universally applicable to all stakeholders or project types due to varying roles and responsibilities. To address this, the research also engaged with local authorities and incorporated insights from industry workshops and questionnaires, providing a more holistic understanding of the challenges and opportunities associated with BIM implementation and information management across the construction industry

Industry Engagement Overview

Face-to-face interviews were conducted with the BIM managers of the main contractors. During these interviews, open-ended questions were utilised to encourage participants to provide detailed and personalised responses. Open-ended questions offer the advantage of allowing participants to express their thoughts, experiences, and challenges in their own words. This approach enabled a deeper exploration of the implementation issues and allowed participants to share their unique perspectives and insights. In addition to the interviews, the study involved attending BIM meetings conducted by the local authorities. Active participation in these meetings gave the ability to observe firsthand the discussions and issues raised by stakeholders concerning implementing BIM and adhering to the ISO 19650

standards. Detailed notes were taken during these meetings to capture the key points and insights shared by the participants.

To gather a broader perspective on the current implementation of BIM in Wales, a questionnaire was developed in collaboration with both the main contractors and the local authorities. The questionnaire was designed iteratively, considering the specific requirements and concerns raised by the stakeholders. The involvement of industry professionals in the questionnaire design process ensured that it captured relevant information and addressed key aspects of BIM and information management implementation specific to the Welsh context. The questionnaire was distributed to a wider group of contractors and consultants where respondents were asked to provide insights into their current practices, challenges faced, and the level of adherence to the ISO 19650 standards. The questionnaire provided quantitative data, which complemented the qualitative insights obtained from the interviews and BIM meetings.

The collected data from the interviews, BIM meetings, and questionnaires were analysed using a thematic analysis approach. This involved identifying recurring themes, patterns, and issues that emerged from the data. The organisation of the data into themes, provided a comprehensive overview of the implementation challenges faced by organisations and the common issues observed in the industry. The findings from the ethnographic study revealed several key issues in the industry's implementation of ISO 19650-2. These issues included a lack of awareness and understanding of the standards, difficulties in aligning existing processes with the requirements of ISO 19650-2, and challenges in managing and exchanging information effectively within project teams.

Based on the identified issues, the study explored potential strategies and interventions that could address these challenges. These included the need for increased awareness and training programs to enhance understanding and adoption of the ISO 19650-2 standards, the development of clear guidelines and best practices for aligning processes with the standards, and the use of technology solutions to facilitate effective information management and

collaboration. As work was already underway by the UK BIM Alliance to produce guidelines this was not explored further.

Industry Workshop and Interview Series

Local Authorities Workshops Overview

In this study, a series of 10 industry workshops were conducted with local authorities for 12 months to comprehensively explore the challenges and issues surrounding the implementation of BIM and the application of ISO 19650 within the construction industry as shown in

Figure 17.

Figure 17: Timeline of industry workshops/Interviews/Questionaries

While all workshops provided valuable insights, it is important to note that not all outcomes were directly relevant to the specific focus and objectives of the study. Therefore, the decision was made to report on four workshops that directly addressed the research questions and themes identified. These four workshops were selected based on their alignment with the study's objectives, the richness of data obtained, and the saturation of themes identified. Additionally, two workshops involved the integration of industry questionnaires, which provided additional perspectives and data to enhance the overall analysis. By transparently acknowledging the selection process and focusing on the relevant workshop outcomes, the study ensures a rigorous and targeted analysis while acknowledging the full range of data sources involved in the research process. This extended timeline provided ample opportunity

to engage with various stakeholders and gain in-depth insights into their experiences and perspectives while also adhering to research undertaken to understand the implications of ethnographic research and that it should be undertaken for a duration that captures enough data to be valid (Hammersley, 2006).

During the workshops, which involved active participation from local authorities, discussions were held to understand the practical implications of implementing BIM and adhering to the ISO 19650 standards. These sessions served as a platform for knowledge sharing, collaboration, and problem-solving, allowing participants to openly express their concerns, raise issues, and exchange best practices. The workshops not only facilitated a deeper understanding of the challenges faced by local authorities but also fostered a sense of collective learning and cooperation among the participants. The workshop details are presented below.

Local Authorities' workshop details

The first workshop was held under the auspices of a construction framework (CF). Despite its comprehensive approach to construction procurement and delivering high-quality facilities, the CF initially did not have a specific building information modelling or information management policy. However, the absence of a dedicated policy within the framework did not deter its commitment to excellence and as such they agreed to participate in the study under the agreement that no individual would be identified during the study. One common reference in research ethics and confidentiality is the Belmont Report (Sims, 2010), which provides guidelines for ethical principles and guidelines for the protection of research participants. The report emphasises the importance of maintaining confidentiality and protecting participants' privacy throughout the research process while at the same time maintaining its principles, which also allows for more active participation by the research participants. For these reasons, the exact location of the CF and participants have been anonymised.

While the framework did not have a formalised policy, it remained adaptable and open to embracing emerging industry practices. As the construction industry recognised the potential

benefits of BIM and information management in terms of improved project coordination, cost efficiency, and enhanced asset management, the framework actively sought to incorporate the principles into its processes. By doing so, it aimed to align with the evolving industry standards and meet the demands of clients and stakeholders who increasingly valued the advantages offered by BIM and information management. Another important aspect to note with regards to the research undertaken is that 3 of the main contractors that were present during some of the workshops were also on the CF while the remainder of the contractors were located in other areas of Wales.

Simultaneously, the interview series with main contractors' BIM managers provided a more focused and personalised approach to gathering information. Conducting face-to-face interviews, gave the ability to establish a rapport with the participants and create a conducive environment for open dialogue. The use of open-ended questions in these interviews allowed participants to freely express their thoughts, experiences, and insights regarding the implementation of BIM and the application of ISO 19650. The open-ended nature of the questions encouraged participants to provide detailed and nuanced responses, enabling a deeper understanding of the complexities and nuances involved while being able to explore new avenues when they become relevant.

Workshop Overview

The initial workshop was held in November 2018 in North Wales. There was a range of participants which is detailed in Table 8 below

Participant	Local Authority /Organisation	Role
A	1	Procurement (RICS Member)
B	1	Procurement
C	1	Procurement (RICS Member)
D	2	Design (RIBA Member)
E	2	Design (RIBA Member)
F	2	Procurement
G	3	Facility Management (CIOB Member)
H	4	Facility Management
I	4	Procurement (CIOB Member)
J	4	Design (RIBA Member)

Table 8: Workshop 1 participants

At the time of the workshop, the CF was not mandating BIM under the PAS 1192 standard. PAS 1192 refers to the Publicly Available Specification that provides guidelines for the implementation of Building Information Modelling (BIM) in the construction industry which was the precursor to ISO19650. The research acknowledges that the ISO 19650 series, specifically ISO 19650-2:2018, is the successor to the PAS 1192 series of standards. PAS 1192 was a publicly available specification that provided guidelines for implementing Building Information Modelling in the construction industry. It served as a precursor to the ISO 19650 standard, which aimed to formalise information management practices and ensure consistency across projects. The evolution from PAS 1192 to ISO 19650 reflects the industry's growing recognition of the importance of standardised information management processes. ISO 19650 builds upon the principles and concepts established in PAS 1192, providing a more comprehensive and internationally recognised framework.

While both standards address information management in the context of BIM, there are notable differences, particularly in terms of documentation. ISO 19650 introduces a more structured and standardised approach to document management, emphasising the use of consistent terminology, formats, and metadata. It also places greater emphasis on the exchange of information requirements and the development of information delivery plans. These differences have impacted the research by necessitating a thorough analysis of the ISO 19650 standard and its specific documentation requirements. The researcher had to adapt the research methodology and tools to align with the new standard, ensuring that the developed framework and processes were compliant with ISO 19650. The transition from PAS 1192 to ISO 19650 also presented an opportunity to explore the practical implications and challenges faced by organisations in adopting the new standard. The research investigated the industry's understanding and implementation of ISO 19650, identifying potential barriers and areas for improvement. An important aspect of this setup was that in essence, the main contractors were driving BIM forward based on their own knowledge and potentially their own interests.

During the 1st workshop, the researcher gave a general introduction outlining the current state of BIM, information management and the current standard at the time whilst also acknowledging the upcoming standard and its implications having read through the Draft version which was released to the public for comment in February 2017, along with stating the principles of confidentiality for the research. A general discussion was then held around the room and notes about the topics being discussed were written down by the researcher.

The thematic approach used in this study involved going through the notes collected during the workshop sessions. The researcher carefully reviewed the detailed notes taken during the workshops and identified recurring topics, ideas, or concepts that emerged from the discussions. The analysis process began with the researcher familiarising himself with the workshop notes and then gaining a comprehensive understanding of the content and context of the discussions. The researcher then systematically read through the notes, highlighting and annotating sections that contained relevant information related to the research questions or objectives. Next, the highlighted sections were organised into initial themes or categories based on their content and relevance. Similar ideas or concepts were grouped and overarching themes were identified. This process involved iterative reading, comparing, and refining the themes to ensure their accuracy and coherence. Once the themes were established, the researcher further explored and analysed the data within each theme, extracting key points, examples, or quotes that best represented the participants' perspectives or ideas. The data within each theme were examined for patterns, connections, or variations, enabling a deeper understanding of the workshop discussions. Throughout the thematic analysis, the researcher maintained a systematic and rigorous approach to ensure the reliability and validity of the findings. The process involved careful documentation of decisions along with regular discussions with his supervisor for feedback and validation, and the use of clear criteria to guide the identification and interpretation of themes. The themes identified are listed in Table 9 below:

Main Theme	Sub-themes				
Implementation	Software	Project status	Training and Skills –	Lack of BIM Understanding	Standards

General comments	"Revit is expensive", "It's just a spreadsheet", "The cost of doing this is going to be high, we will get the contractors to pay for it", "...We got the contractors to pay for Revit..."	"Won't help me to see how a project is running",	"I don't understand what it is really"	"I don't have the time to do BIM it's too complicated"	"How do we use the standards", "They [SIC – the standards] don't really tell us how to do it", "The standards are good if you understand them…but I don't"
Managing BIM	Standards	BIM Meetings	Model quality	Clash detection	Contractors
General comments	"I've heard of IFC to manage BIM", "What is IFC about?", "...even once we've done it, we need to manage it and coordinate everything…"	"I think there'll be too many BIM Meetings", "We've had BIM meetings but it's just the contractor telling us what they will do"	"How do we check the model?", "The coordinates are always wrong"	"I've done clash detection; it saves a lot of issues"	"How do we know they're doing it right", "The contractor we had on the last project did it for us"
Facilities Management (FM)	Handover Data	Training & Skills	Understanding	Requirements	
General Comments	"I don't understand Cobie", "Cobie is just a spreadsheet…",	"…they still like to use paper so going to be hard to get them to use a computer", "...stuck in the old ways of doing things..."	"FM won't use it ", "waste of time", "BIM is no good for existing buildings as [FM] won't do it",	"How do we work out what information to give?", "I've heard that we need an asset document…detail the things we need…"	
Legal issues	BIM protocol				
General Comments	"Does this need to be included in the JCT contract?"				
Document production	Requirements	Templates	BEP		
General comments	"We don't have a good EIR", "Not sure of documents we need to do BIM",	"We have an EIR that we use on all our projects"	"…we don't need a BEP the contractor does that for us"		

Table 9: Themes identified during Workshop 1

For the next workshop of relevance, the organisers brought in a software development company to demonstrate how they could manage the integration of information received

from the contractors into a platform so that it could be used. This provided valuable insights into the industry's current practices and challenges. The focus was on the process of handing over asset data through COBie (Construction Operations Building Information Exchange). The participants consisted of fewer people overall, but the ones who were present were the same as workshop 1 and are shown in

Participant	Local Authority /Organisation	Role
A	1	Procurement (RICS Member)
D	2	Design (RIBA Member)
E	2	Design (RIBA Member)
F	2	Procurement
G	3	Facility Management (CIOB Member)
H	4	Facility Management
I	4	Procurement (CIOB Member)
J	4	Design (RIBA Member)
K	5	Software vendor

Table 10

Participant	Local Authority /Organisation	Role
A	1	Procurement (RICS Member)
D	2	Design (RIBA Member)
E	2	Design (RIBA Member)
F	2	Procurement
G	3	Facility Management (CIOB Member)
H	4	Facility Management
I	4	Procurement (CIOB Member)
J	4	Design (RIBA Member)
K	5	Software vendor

Table 10: Participants in workshop 2

The workshop began with a presentation by a software company that showcased their platform's capabilities in ingesting COBie data and utilising it effectively. This presentation provided insights into the potential benefits and challenges associated with COBie data management and the state of the industry at the time. Following the presentation, a discussion ensued among the participants regarding the practical aspects of obtaining

relevant data from contractors and defining the specific requirements for asset data handover. The participants shared their experiences, perspectives, and best practices related to data collection and management during the handover process. The discussion aimed to address the key issues and considerations involved in ensuring accurate, complete, and usable asset data within the COBie format. The workshop offered a platform for participants to explore the intricacies of COBie data handover and engage in a meaningful dialogue about the challenges and opportunities associated with this process. The presentation by the software company provided valuable insights into how technology solutions can streamline and enhance the utilisation of COBie data, while the subsequent discussion fostered knowledge sharing and collaboration among the participants to improve data collection and requirements definition practices. A thematic analysis was undertaken using the themes identified in a workshop concerning FM with an additional theme related to cost. The results of the workshop are shown in Table 11

(FM)	Handover Data	Training & Skills	Understanding	Requirements	Cost
General Comments	"…the software will make it much easier to use BIM", "..[I can] see that the problem is now getting the right information from the contractor but how do we do that?", "	"...not sure that this [software] will be just as easy as they showed, there's always problems with computers…", "…if they provide the training it will be useful"	"FM won't use it ", "waste of time", "BIM is no good for existing buildings as [FM] won't do it",	"…we need to identify what information we need for the framework as it's not going to be the same for everything",	"..it's not going to be cheap though…", "if it's a good as they say then we will save money…"

Table 11: Thematic analysis of workshop 2

For the third workshop, the primary agenda was a presentation delivered by a representative from an accreditation body. The project participants were the same as in workshop 1 with additional participants from main contractors.

Participant	Local Authority /Organisation	Role
A	1	Procurement (RICS Member)
B	1	Procurement
C	1	Procurement (RICS Member)

D	2	Design (RIBA Member)
E	2	Design (RIBA Member)
F	2	Procurement
G	3	Facility Management (CIOB Member)
H	4	Facility Management
I	4	Procurement (CIOB Member)
J	4	Design (RIBA Member)
L	6	Accreditation Body

Table 12: Participants in Workshop 3

The presentation centred around the benefits of implementing standards in the context of BIM. The presenter highlighted how adherence to standards can improve efficiency, consistency, and interoperability in BIM projects. Following the presentation, the workshop participants engaged in a discussion regarding the practical implications of implementing standards. They acknowledged the potential advantages of utilising standards but also expressed concerns related to understanding the requirements, ensuring proper implementation, and managing associated costs. The participants recognised that while standards can provide a framework for effective BIM implementation, there are challenges in comprehending and aligning with the specific requirements of each standard. The discussion during Workshop 3 allowed the participants to share their perspectives, experiences, and concerns regarding the adoption of standards in BIM projects. The exchange of ideas highlighted the need for clearer guidance, training, and resources to support organisations in implementing standards correctly. The participants also emphasised the importance of cost considerations and the need for practical solutions that balance the benefits of standards with the associated investments. A thematic analysis of the workshop was undertaken in the same context as before but the standards item in implementation has been replaced with costs and is presented in Table 13.

Main Theme	Sub-themes				
Implementation	Software	Project status	Training and Skills –	Lack of BIM Understanding	Cost
General comments	"..it would be great if there was some software to mange this as it looks complicated", "..so its not about Revit?",	"…the standards won't help in showing a project status ",	"..we haven't got time to do more training about this", ".if we can organisation	"..[it]makes sense now", "with regards to Revit then, that is not doing BIM?"	"..your saying that the standards will reduce our costs?", "..sounds like

			some framework training that would be useful.."		we need a consultant to understand this",
Managing BIM	Standards	BIM Meetings	Model quality	Clash detection	Contractors
General comments	"..this, it'll help us to mange projects better", "I can see how this brings everyone together", " i understand what your saying but how do we mange all this with the people we have?"	None	"Where to the BIM models fit it with this?",	" you said that clash detection is not in the standard but its useful, can we add extra bits in?", "is there a standard we can use for clash detection?"	" …apply the standards here would mean that [the contractors] would use the same standard. That makes sense"
Facilities Management (FM)	Handover Data	Training & Skills	Understanding	Requirements	
General Comments	"I get that there's a standard for handover data and software but don't see how it fits together"	None	".. the standards cover the whole project from start to finish…so we just give the models to the FM?"	".. by getting the requirements for assets right, we comply with the standard?", "...still unsure how we manage the requirements in relation to the standard….does the standard tell us how "	
Legal issues	BIM protocol				
General Comments	None				
Document production	Requirements	Templates	BEP		
General comments	"I understand that we need lots of documents now, I thought it was only the EIR", "…it makes sense what your saying…I can see problems with knowing what documents to produce let alone checking the contractors….", "...is there a standard about the requirements, that	" would be useful if the standard had a template we can use for this", "…as an alliance, we can make a universal one..", "..asset information requirements , or whatever you called them need to match up with the other ones?	NONE		

	would be useful", "…think that the documents will take a lot of time especially as we have lots of projects. " an EIR is hard to write, I started one but still don't understand it.."	How is that done"			

Table 13: Thematic analysis of Workshop 3

During Workshop 3 of the study, the overall outcomes indicated that there were more questions than answers regarding the standards and how to effectively manage and implement them within the framework. Participants expressed a lack of clarity and understanding regarding the standards, particularly concerning the management and implementation processes. Many of the comments centred around the challenges faced in using and producing the required EIR document and asset information.

To gain further insights into the implementation of the standards and to understand how other organisations had approached them, the subsequent focus of the workshops shifted. Workshops 4 and 5 were dedicated to developing a comprehensive questionnaire that would help gather a broad spectrum of understanding on the current state of standard compliance and the associated issues. The researcher sought the participants' willingness to collaborate in developing this questionnaire, recognising the importance of their expertise and diverse perspectives. During these workshops, the collaborative effort of participants and the researcher resulted in the development of a questionnaire specifically tailored to explore various aspects of standard compliance and implementation challenges. Workshop 10 was then scheduled to include a discussion centred around the questionnaire's results, enabling participants to reflect on and analyse the findings collectively.

This iterative process of involving participants in questionnaire development and subsequent analysis aimed to enhance the breadth and depth of the study's understanding of the current state of standard compliance and the associated issues. By actively involving the participants in shaping the research instrument, the study sought to ensure a comprehensive and nuanced

exploration of the challenges and experiences related to implementing the standards within the construction industry. The questionnaire is discussed further below.

Industry Interviews

To gain insights into the perspective of contractors regarding the implementation of standards, a series of interviews were conducted with BIM managers within different organisations. These interviews aimed to understand their experiences, challenges, and perceptions related to the adoption of standards in their respective projects. The interviews provided an opportunity to delve deeper into their specific contexts and gather valuable information about the practical aspects of implementing standards. Furthermore, one of the main contractors expressed a need for assistance in implementing the standards effectively and agreed to participate in a case study. This collaboration allowed for a more in-depth examination of the challenges faced by contractors and provided an opportunity to explore potential solutions and best practices. By closely working with the contractor, the research study could closely observe the implementation process, identify hurdles, and propose strategies for the successful adoption of standards. The interviews with BIM managers and the involvement of the main contractor as a case study offered a comprehensive understanding of the contractors' perspectives on standard implementation. This approach provided firsthand insights into the specific issues faced by contractors, their motivations for seeking assistance, and the potential benefits they anticipated from implementing the standards. The interviews and the case study collectively contributed to a more holistic view of the challenges and opportunities associated with standard implementation from the contractors' standpoint.

Interview with Contractor 1

During Interview 1 held in May 2019, the researcher initiated the conversation by posing an open-ended question to the contractor, setting the stage for a comprehensive exploration of their experiences and perspectives. The interview took place in West Wales and involved a tier 2 contractor who was actively engaged in the construction and development of leisure centres and schools in collaboration with the local authority. The open-ended question

allowed the contractor to share their insights, opinions, and experiences related to the implementation of standards in their construction projects. As the interview progressed, the researcher delved into various areas of interest, probing for additional details and seeking a deeper understanding of the contractor's perspectives on standard implementation. The flexible nature of the interview allowed for organic discussions and the exploration of diverse topics that emerged during the conversation.

The contractor's involvement in the development and construction of leisure centres and schools with the local authority provided valuable insights into the specific challenges, requirements, and opportunities associated with standard implementation in the context of these projects. The interview provided an opportunity to gather firsthand information about the contractor's experiences, including any barriers encountered, successes achieved, and lessons learned. Conducting the interview in West Wales and engaging with a tier 2 contractor working on leisure centres and schools, the research study could gain region-specific insights and capture the unique dynamics and considerations relevant to the local construction industry. The interview aimed to uncover the contractor's perspectives on standard implementation, shedding light on their understanding of the requirements, their experiences in meeting those requirements, and their overall perception of the benefits and challenges associated with standards adoption.

Contractors' understandings

At the time of the interview, the organisation had just completed what they termed their second implementation of BIM on a project. They had not as yet implemented either PAS1192-2 or ISO 19650-2. The first implementation was a school for a local authority while the second was the redevelopment of a leisure centre. The interview was conducted with their BIM manager who had been in post for 4 years. The opening question "Tell me about your experiences in implementing BIM and your understanding of BIM Standards?". The same initial opening question was used for all the interviews. Using the same opening question in open-ended interviews offers several advantages in research. Firstly, it provides a consistent starting point for all participants, ensuring that each interview begins on an equal footing. Secondly, it allows for a comparative analysis of responses, enabling researchers to identify

patterns, themes, and variations across different participants. Thirdly, it helps to establish a rapport with participants, as they are allowed to express their thoughts and experiences in their own words. According to (Kvale, 2018), using a standardised opening question in qualitative interviews can be beneficial in terms of research reliability and comparability. It allows for a structured approach while still maintaining flexibility for participants to elaborate and provide unique insights. By using the same opening question, the researcher can ensure that relevant topics are covered consistently across all interviews, enhancing the overall validity and reliability of the study.

The overall interview was recorded by way of written notes which were then analysed into themes. The results of the themes are presented in Table 14 below.

Main Theme	*General Comments*				
Implementation	No real understanding of standards.	We do what we can and try and make it work	Trying to follow the standards but it's confusing	Don't understand the clients' requirements it's like they don't understand it themselves	We did the first one using traditional methods and using BIM, the second BIM only.
Client	Not committed to PAS	Not confirming to PAS1192	Don't adhere to naming conventions	Their [Clients] EIR is rubbish	
Models	Clash Detection	Using BIM-Server on site but not working	Not always complete when we're building.	They haven't got sufficient detail	
Process	Brought external consultants in to develop BIM process	Supply chain don't have any standard process or if they don't align	I propose that PAS1192/ISO19650 is written in concise detail to I can use it.		
Documents	We only do a simple BEP but to be honest we don't adhere to is as the client doesn't understand it either	Theres a lot of assumptions made at tender stage, so our documents aren't always right			

Table 14: Thematic analysis of Interview 1

Interview with Contractor 2

Interview 2 was conducted with a main contractor based in North Wales in April 2019 who had already received certification from the BSI for their implementation of PAS1192. The contractor's current certification status and their considerations for renewing it based on PAS1192 provided a valuable perspective on the practical implementation and ongoing adherence to BIM standards. It is important to note that at the time of the interview, there were no UKCAS-accredited standards relating to the implementation of either the PAS1192 or ISO19650 standards. The United Kingdom Accreditation Service (UKAS) plays a critical role in ensuring the integrity and competence of certification bodies within the UK. As the sole national accreditation body, UKAS assesses organizations that provide conformity assessment services, including certification against standards like ISO 19650. UKAS accreditation signifies that a certification body operates with impartiality and adheres to recognized best practices, providing stakeholders with confidence in the validity of issued certifications. While UKAS did not directly certify auditors for ISO 19650 at the time of this research, it is important to acknowledge the evolving landscape of BIM certification. Alternative approaches may have been prevalent, such as certification bodies developing their schemes aligned with relevant accreditation standards like ISO/IEC 17065. It is also worth noting that UKAS undertook a pilot program to assess certification bodies for ISO 19650-2, which eventually paved the way for the accreditation of prominent bodies like BSI, BRE Global, and LRQA. This ongoing development in the BIM certification landscape highlights the increasing focus on ensuring competence and best practices within the field

The researcher began the interview by posing an open-ended question, allowing the contractor to share their experiences, insights, and reflections on BIM implementation within their organisation. Given their prior certification and commitment to PAS1192, the contractor's perspectives were particularly relevant in understanding the benefits, challenges, and considerations associated with maintaining and renewing certification based on BIM standards. Throughout the interview, the researcher engaged in a detailed conversation with the contractor, exploring their experiences with PAS1192 and their intentions regarding certification renewal. The contractor's insights shed light on the practical aspects of implementing BIM processes, their understanding of PAS1192 requirements, and

the impact of certification on their organisation's operations and project delivery. By focusing on a contractor who had already achieved certification and was contemplating its renewal, the interview provided valuable insights into the contractor's ongoing commitment to BIM standards and their experiences with the certification process. The contractor's perspective allowed for a deeper understanding of the benefits gained from certification, the challenges faced in maintaining compliance, and the considerations involved in the decision to renew their certification based on PAS1192.

At the start of the interview which was held with a Design/BIM Manager who had been in position for over 10 years, the same opening question was asked. They stated they had experience in both implementing BIM and implementing BIM standards using the PAS1192 series. At the time of the interview, they didn't express a willingness to undertake certification using the new standards as the old ones "work just as well". They had experience implementing the standards against 4 projects which were a mixture of both secondary schools and primary schools. This particular contractor has previously worked with the researcher's sponsoring university for a BIM project related to capturing of asset data from the site and placing it into a COBie format.

To keep consistency within the thematic overviews, it was decided by the researcher to categorise the answers into the same themes. The results of the interview with the contractor are presented in

Main Theme	*General Comments*			
Implementation	No issues with implementing BIM now we've done it so many times.			
Client	The EIR they give us is really poor.	I don't think they understand what is needed	We need the client to tell us what the outputs should be.	The client wants to use soft landings using BIM. We both don't really understand how that works
Models	Were still not doing the 4th dimension.	Not long been doing the 3rd dimension		

Process	We haven't really formalised our process we just do it. As a result, we sometimes miss steps.		Not sure how we manged to pass our certification as we don't always do what we have to	We don't have any formal process with our supply chain either	
Documents	Our BEP is OK.	A Lot of assumptions are made as the EIR is Poor.	We don't really use any other documents apart from the BEP	We have used Zones within the BEP for conventions	The documents aren't always numbered right

Table 15: Thematic analysis of interview with contractor 2

Interview with Contractor 3

In Interview 3 held in February 2019, the researcher followed a systematic research design while engaging with a main contractor based in North Wales. The contractor specialised in the construction of educational facilities and expressed a strong interest in understanding and implementing the new ISO 19650-2 standard. Unlike the previous interviews, this contractor had limited knowledge of standards such as PAS1192-2 and how to implement and get 3rd party accreditation but demonstrated a proactive attitude towards adopting industry best practices. The research design involved the same semi-structured interview approach, starting with an open-ended question to explore the contractor's perspectives on BIM and their readiness to implement ISO 19650. The interview was conducted in a face-to-face setting, providing an opportunity for the researcher to delve deeper into the contractor's experiences, challenges, and aspirations related to information management and collaboration. Through a series of probing questions, the researcher aimed to uncover the contractor's current practices, their understanding of the ISO 19650 standard, and their specific areas of concern or interest. The contractor's willingness to participate in a case study between February 2019 and August 2019 further enriched the research design, allowing for a more in-depth exploration of the implementation process and potential outcomes. At this point, only the initial interview is discussed further, although the standard implementation is covered later on in process and document development.

The results of the thematic analysis for this contractor are detailed below

Main Theme	*General Comments*			
Implementation	"We don't have an understanding of implementing standards yet, but we need to get there"	"Competitor has already got certified but the old standard, getting the new one would boost our potential"	"[audit organisation] has already given us a price……expensive but worth it"	
Client	"Our main client doesn't understand bim but we are working together"	"Looking at what standards are required by our client for handover"	"The actual handover requirements are really poor"	
Models	"We don't really do any modelling"	"Would be great to have more iPads to view plans on-site"		
Process	"need to setup processes but they there confusing esp. as they're so new"	"[name withheld] has some experience in this area but not for standards	"handover is done with paper manuals it's a long process as contractors don't always engage"	
Documents	"the client EIR is poor, we sent it back with request for more details"	"Using a BEP but it's not great…. copied from the internet"	"Using BIM360 to manage documents but we need more training"	"a proper understanding of the document contents would be useful"

It is important to note that at the end of the interview, a discussion took place where the process of gaining certification would be followed by the researcher. This enabled the researcher to gain access to the organisation's documentation requirements as well as the processes that were implemented overall. Workshops were held with this organisation over the next 5 months, these workshops included the development of the required documents, implementation of process and implementation of a common data environment. Working with the researcher over this duration ultimately led to a successful external audit along with a suite of compliant documents which could then be used for the later part of the research.

Interview with Contractor 4

In Interview 4 held in June 2019, a main contractor based in South Wales was interviewed regarding their construction projects, which encompassed schools, leisure centres, hospitals, and housing developments, including multi-story apartments. The purpose of the interview was to gather insights into their experiences and perspectives on information management practices, specifically focusing on their plans to implement the new ISO 19650 standard. Based on their existing external audit confirming their compliance with PAS 1192, the contractor had already established a foundation in information management standards. However, due to the size of their organisation and the scope of their projects, they decided to undertake the implementation of the new ISO 19650 standard independently. The interview aimed to explore their motivations, challenges, and strategies for this implementation process.

Following a structured research design, the interview covered various aspects related to their previous experiences with PAS 1192 and their preparations for transitioning to ISO 19650. The researcher inquired about their understanding of the new standard, their assessment of the potential benefits, and their plans for aligning their existing information management practices with the requirements of ISO 19650. The interview sought to uncover their perspectives on the feasibility, challenges, and anticipated impacts of implementing the new standard within their organisation. Additionally, it aimed to identify their strategies for training and upskilling their staff, as well as their intentions for engaging with external stakeholders, such as clients, consultants, and subcontractors, to ensure a smooth transition.

The results of the thematic analysis are presented below:

Main Theme	*General Comments*			
Implementation	*"See no major challenges with our current implementation of standards"*	*"The benefit of being certified far outweighs the costs as clients trust us more"*	"..we will implement the new standard but its being done at head office first"	" quite mature in our understanding of the standards"
Client	*".,,comprehensive of our offering to clients… as we*	*"soft landings is something*		

	understand they don't understand what is required"	*we aim to do better – bim will help us"*		
Models	"…in house modelling capabilities"	"..we're looking into 4D BIM",	"we currently have a VR facility to view models which clients love"	"still issues with regards to tolerances on clash detections"
Process	*"Were still immature with regards to classification process"*	*"we don't really have a defined process or reporting functions"*	*"no do not have a method or alike to tell us the project stage information requirements, but it would be useful"*	
Documents	"…one set of templates which we customise depending on the project"	*"..our templates include a client EIR as they don't also give us one"*	*"the reality is we still have to manually check our documents "*	

Industry Questionaries

The development of the questionnaire for the research study was a crucial step in gathering quantitative data to complement the qualitative insights gained through interviews and industry workshops. According to (Gall et al., 2007) designing a well-structured questionnaire involves careful consideration of the research objectives, target population, and desired data outcomes. In this study, the questionnaire was developed iteratively in collaboration with both the main contractors and the local authorities involved in BIM implementation in Wales. This participatory approach ensured that the questionnaire was tailored to the specific context and needs of the industry. The input and feedback from the stakeholders helped to refine the questionnaire, ensuring its relevance and validity. The questionnaire was designed to assess the current state of BIM implementation in Wales, capturing information about the participants' perceptions, experiences, and challenges. It consisted of a combination of

closed-ended questions, such as multiple-choice and Likert scale items, as well as open-ended questions to allow participants to provide additional comments or insights.

A copy of the questionnaire is included in Appendix B

Results of the Local Authority Workshops

The workshops highlighted the need for clarity and guidance in implementing the standards, specifically concerning the production documentation and understanding and implementation of the standards along with the required processes. The questionnaire development process aimed to address these challenges by capturing a broad spectrum of understanding regarding the current state of standard compliance and associated issues within the construction industry.

Results of the Contractor interviews

The themes from the open-ended start question all fit within the codification system used. Although several times the statements identified could have been placed in more than one area, the context in which the discussion and subsequent answers were allocated took precedence. For example, during the interview with Contractor 4, the discussion at the time was centred around the clients and how they were viewed. The context of the interview was talking about the standard of the required documentation, so although the category of the theme was documentation, the bigger picture was talking about the client.

Based on the interviews conducted with contractors, the thematic analysis focused on the standards, specifically examining the process, implementation, documents, and clients. Regarding the overall process theme, the results showed the following:

1) Processes are not defined:

    - Contractors reported that there is a lack of clear and well-defined processes in place.

- This indicates that there may be a lack of standardised procedures or guidelines for carrying out tasks and activities.

2) Processes are defined but not followed:
    - Contractors mentioned that although processes are defined, they are not consistently followed in practice.
    - This suggests a gap between the documented procedures and the actual implementation of those processes.
3) Current progress on processes could not be identified:
    - The analysis showed that it is difficult to determine the current progress or status of the processes.
    - This indicates a lack of visibility or tracking mechanisms to assess the extent to which processes are being followed or improved upon.

Moving on to the issues with clients, the thematic analysis revealed the following:

1) The client doesn't understand their requirements:
    - Contractors expressed that clients have difficulties understanding their own requirements for the project.
    - This suggests a potential lack of clarity or communication between the contractors and the clients regarding project specifications.
2) The client does not understand how to write the documents:
    - Contractors reported that clients struggle with composing or formulating the necessary project documents.
    - This indicates a potential need for guidance or support in the document preparation process.
3) The client does not understand the BIM process:
    - Contractors mentioned that clients have a limited understanding of the Building Information Modelling process.
    - This suggests a gap in knowledge or awareness regarding BIM and its potential benefits or implications.

Regarding the implementation theme, the thematic analysis identified the following issues:

1) Certification is a positive step towards negotiating contracts:
    - Contractors expressed that obtaining certification is seen as a positive factor in negotiating contracts.
    - This suggests that certification can enhance the contractors' competitiveness in securing contracts.
2) The cost of implementing was a factor but offset by gaining contracts:
    - Contractors mentioned that while there may be costs associated with implementing the standards, the benefits of gaining contracts outweigh these expenses.
    - This indicates a perceived trade-off between implementation costs and potential business opportunities.
3) ISO19650-2:2018 and its predecessor are hard to interpret:
    - Contractors reported difficulties in interpreting the ISO19650-2:2018 standard and its predecessor.
    - This suggests challenges in understanding and applying the requirements outlined in these standards.
4) Once certified, it's easier to maintain than implement:
    - Contractors mentioned that after obtaining certification, maintaining compliance with the standards becomes easier compared to the initial implementation phase.
    - This indicates that once established, the processes and practices required by the standards become more routine and manageable.

These findings provide valuable insights into the issues faced by contractors concerning the process, clients, and implementation aspects of the standards. They further demonstrate that as shown in Chapter 2, there is a lack of available resources concerning process definition and maturity framework relating to information management in BIM at a granular level.

Results of the questionnaires

As discussed, the questionnaires were designed using an interactive approach in consultation with construction or client organisations. The design and structure of a questionnaire play a crucial role in gathering valuable data and insights for research purposes. In this study, a carefully designed questionnaire was developed to explore the implementation of either the PAS1192 or ISO19650-2:2018 standard within organisations. This section provides an overview of the questionnaire design. The questionnaire was designed based on established principles of survey research and best practices in questionnaire design. Extensive literature review and consultation with experts in the field of construction industry standards informed the development of the questionnaire. The aim was to ensure that the questionnaire would yield reliable and valid data to address the research objectives.

Section 1: Responder Qualifications

The first section of the questionnaire focuses on gathering information about the qualifications and background of the respondents. This includes their professional experience and roles within their organisations. These questions aim to establish the expertise and knowledge of the participants, ensuring that the responses are relevant and informed.

Section 2: Implementation of the ISO 19650 Standard

The second section of the questionnaire investigates whether the participants have implemented either standard within their organisations. The responses obtained in this section will help categorise the participants into two groups: those who have implemented the standard (proceeding to Section 3) and those who have not (proceeding to Section 4).

Section 3: Implementation Experience (For Participants Who Have Implemented the Standard)

For participants who have implemented the either standard, Section 3 delves deeper into their implementation experience. This section includes questions related to the challenges

faced during the implementation process, the benefits observed, and the effectiveness of the standard in improving project delivery and compliance. The Likert scale questions in this section provide a structured format for participants to rate their experiences on a scale of 1 to 5, with 1 indicating a lower level of agreement or satisfaction and 5 indicating a higher level.

Section 4: Reasons for Non-Implementation (For Participants Who Have Not Implemented the Standard)

Participants who have not implemented the ISO 19650 standard proceed to Section 4. This section focuses on exploring the reasons behind their decision not to implement the standard. It includes Likert scale questions that assess the perceived challenges, barriers, or limitations hindering the adoption of the standard within their organisations. Participants are also provided with an open-ended question to elaborate on their reasons, allowing for qualitative insights into the barriers faced.

The carefully designed questionnaire aimed to gather comprehensive data on the implementation of either standard, considering the perspectives and experiences of different participants. The use of established questionnaire design principles based on those described by (Dillman et al., 2014; Fowler Jr, 2013) was also used where it has been shown not an iterative approach to design yields improved results.

To maximise the response rate and gather a comprehensive set of data, a two-fold method was employed in this study. Initially, the researcher reached out to all contractors who were part of a construction framework within Wales. The purpose of this initial contact was to introduce the research project and seek permission to distribute the questionnaire among their members. This approach not only helped in establishing a rapport with the potential respondents but also ensured that the research was conducted in collaboration with relevant industry stakeholders. In adherence to ethical principles, the questionnaire was designed to maintain the anonymity of the respondents. No user details or identifying information were collected or linked to the questionnaire responses. This approach aimed to create a safe and

confidential environment for participants to freely express their opinions and experiences. It also aligns with the principles of confidentiality and data protection, providing reassurance to the respondents regarding the privacy and security of their responses. The survey was sent out to a total of 29 Contractors identified on the frameworks and handed out to 19 of the local authorities in Wales during a conference workshop. In total, all 19 questionnaires from the local authorities were filled out and 23 contractors' surveys were returned.

Results of Section 1

Ensuring the validity and reliability of research findings is essential when studying a specialised field like the construction industry. One aspect of validating expertise is examining the professional qualifications and memberships of the respondents. From the total number of returned questionnaires, it was found that 76% of the respondents possessed professional memberships within the construction industry shown in Figure 18 and that all bar 1 respondent had been in the construction industry for more than 5 years. This high percentage indicates a significant level of expertise and involvement of professionals who are actively engaged in the field. Professional memberships serve as indicators of individuals' commitment to their respective disciplines, their continuous professional development, and their adherence to professional standards and codes of conduct. From the respondents, there was also a nearly 50/50 split in terms of clients and contractors.

The survey results gain further credibility and can be seen as a reflection of the insights and experiences of qualified professionals in the construction industry. These professionals bring a wealth of knowledge, expertise, and practical understanding to the research, enhancing the reliability and validity of the findings. The high percentage of respondents with professional memberships indicates a potential interest in or awareness of the importance of BIM standards. However, further research is needed to explore the specific motivations and drivers behind this correlation, including the role of industry body requirements and incentives for BIM adoption and certification. It demonstrates a proactive approach by professionals to stay informed, contribute to industry best practices, and ensure compliance with relevant standards. It is important to note that while professional membership is an indicator of expertise and commitment to the field, the survey also welcomed participation

from individuals who may not hold such memberships. The goal was to capture a diverse range of perspectives and experiences to gain a comprehensive understanding of the challenges and opportunities related to implementing either standard in the construction industry. It should be noted that the findings related to professional membership are based on the self-reported responses of the participants. The accuracy and validity of these responses are reliant on the honesty and accuracy of the respondents in providing information about their professional qualifications and memberships.

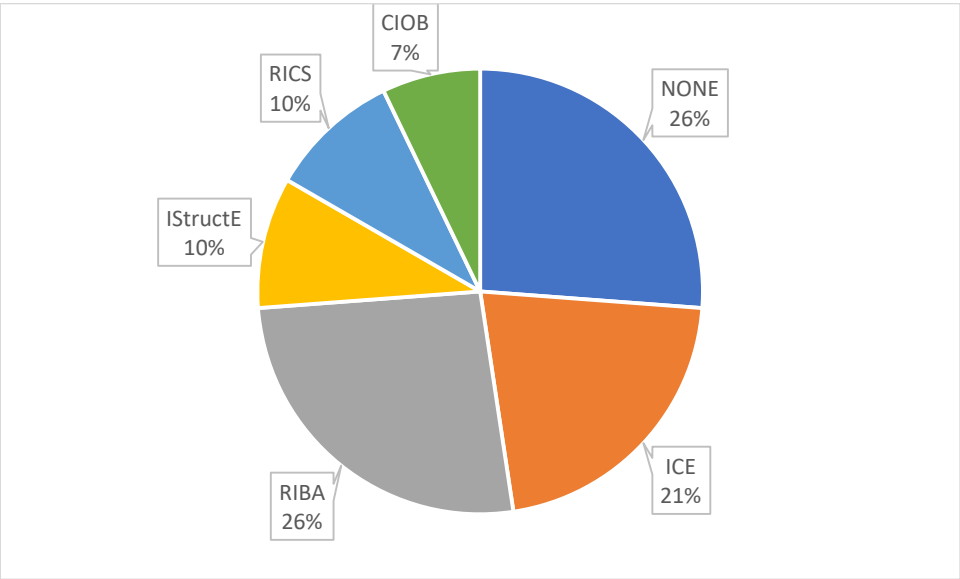


Figure 18: Result of Professional memberships

Results of Section 2

From the survey responses, an overwhelming majority of 88% of the participants stated that they currently utilise BIM in their construction projects. This finding aligns with the existing literature and corroborates the NBS survey, which has also reported a high adoption rate of BIM in the industry. The alignment between the survey results and the literature review, particularly the NBS survey, provides further validity to the findings. It indicates that the sample of respondents in this study is representative of the broader construction industry in

terms of BIM adoption. This strengthens the credibility and generalisability of the research outcomes.

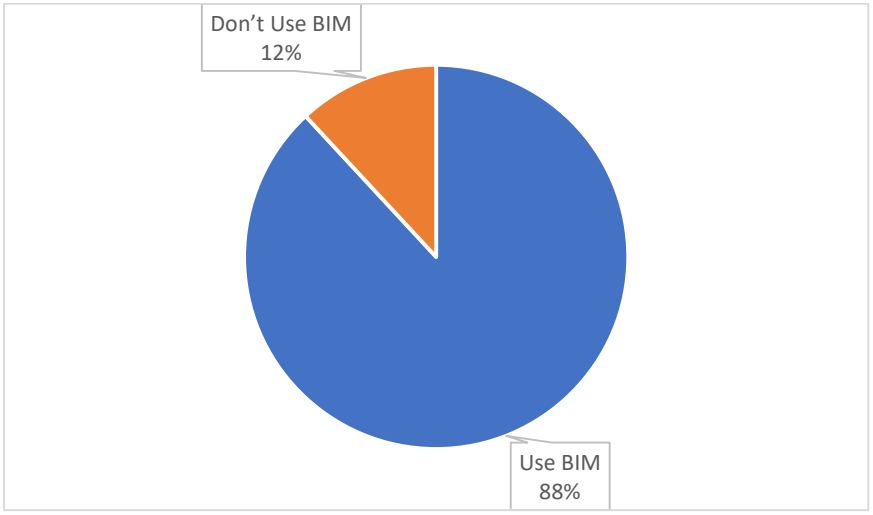


Figure 19: Results of BIM use in local authority and industry

The survey results indicate that none of the local authority respondents have adopted BIM standards. This finding suggests that there is a significant gap in the adoption and implementation of standardised digital information management practices within local authorities and agrees with the findings conducted throughout the workshops and interviews. Furthermore, among the contractor respondents, 50% reported having implemented BIM standards. This finding suggests that contractors, who are involved in the execution and delivery of construction projects, are more proactive in adopting digital information management practices. The high adoption rate among contractors highlights their recognition of the potential benefits associated with implementing BIM as shown in Figure 20.

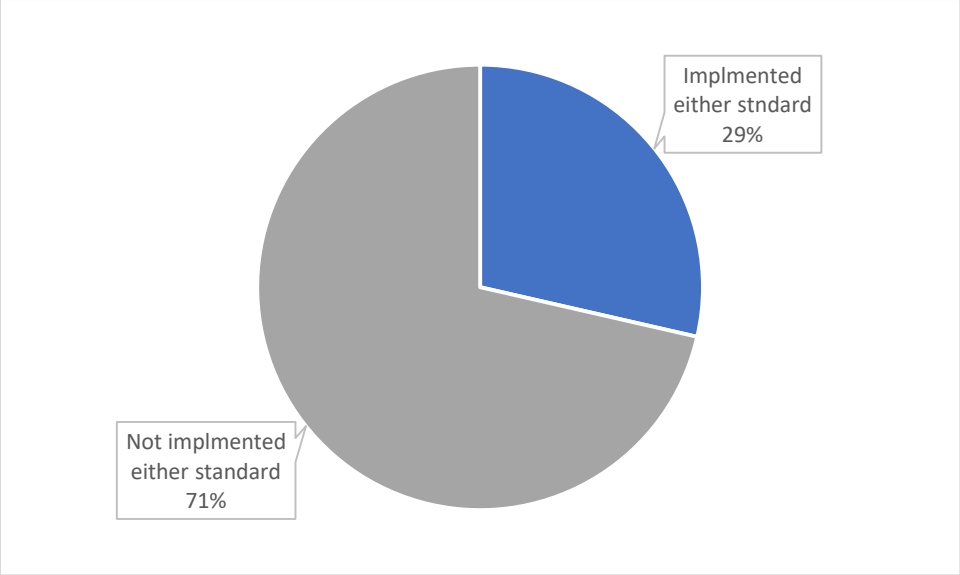


Figure 20: Result of BIM standards adoption

Results of Section 3

The section sought to gain an understanding of an organisations perception in relation to implementing either standard. The first question results showed an overall neutral or bias to perception. Among the respondents, 28% reported a high level of alignment, indicating that the implemented standard was perceived to align very well with their organisation's existing information management practices. These respondents likely found that the standard provided a comprehensive framework that effectively supported and enhanced their information management processes. On the other hand, 29% of the respondents indicated that the alignment between the implemented standard and their organisation's information management practices was not well-established. These respondents may have identified gaps or inconsistencies between their existing practices and the requirements outlined in the standard, suggesting the need for further adjustments or adaptations to achieve better alignment. A significant portion of the respondents, 43%, expressed a neutral stance, implying that they neither strongly perceived the alignment to be favourable nor unfavourable. These respondents may have found certain aspects of the standard to align well with their practices while encountering challenges or gaps in other areas. The varying perceptions of the standard alignment indicate the complexity and diversity of information management practices across

organisations within the construction industry. It underscores the importance of considering organisational context, needs, and capabilities when implementing and adapting standards like PAS 1192 or ISO 19650.

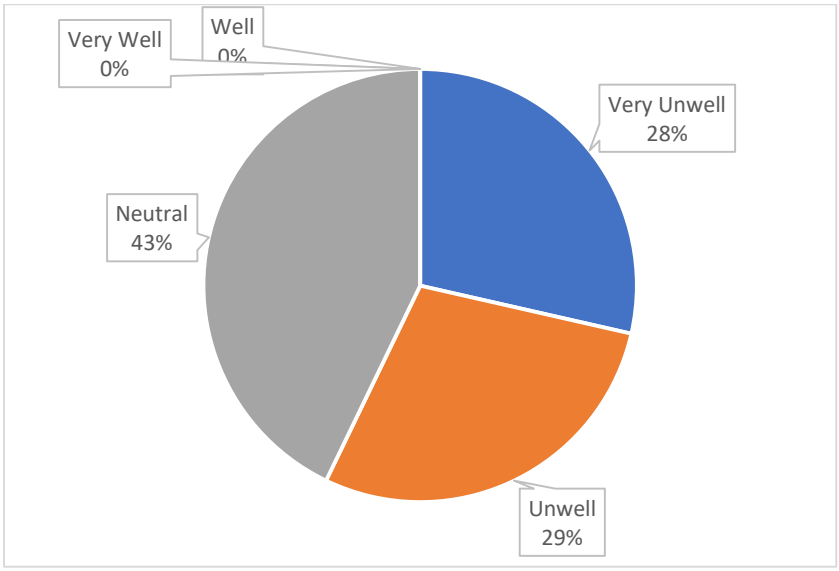


Figure 21: Results of Question 3.1 How well do you perceive the standard aligns with your organisation's information management practices?

Question 3.2 aimed to assess the satisfaction level of respondents with the support and guidance provided by the standard documentation. Participants were asked to rate their satisfaction on a Likert scale ranging from 1 to 5, with 1 representing very unsatisfied and 5 representing very satisfied. The results shown in Figure 22 revealed a range of perceptions among the respondents regarding the level of support and guidance offered by the standard documentation. Among the respondents, 50% expressed a high level of dissatisfaction, indicating that they were not satisfied with the support and guidance provided by the standard documentation. These respondents may have found the documentation insufficient, unclear, or lacking practical guidance, which hindered their implementation efforts and understanding of the standard. On the other hand, 29% of the respondents reported being satisfied with the level of support and guidance provided by documentation. These individuals likely found the documentation helpful in understanding the requirements and implementing the standard within their organisations. A notable portion of the respondents, 21%, expressed a neutral stance, implying that they neither strongly felt satisfied nor dissatisfied with the support and guidance from the standard documentation. These respondents may have found

certain aspects of the documentation useful while encountering limitations or gaps in other areas.

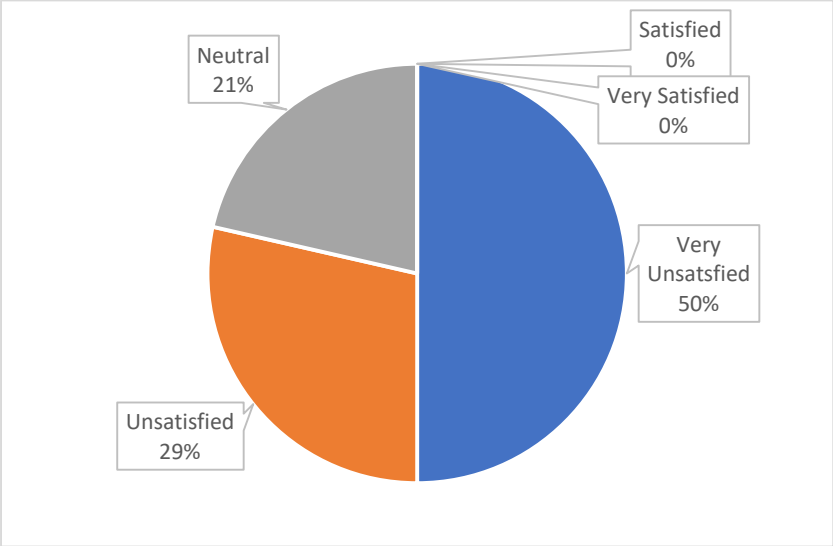


Figure 22: Results of question 3.2 How satisfied are you with the level of support and guidance provided by the ISO 19650 standard documentation?

Question 3.3 aimed to assess the respondents' perception of whether the implementation of the standard improved the efficiency of their organisation's information management processes. Participants were asked to indicate their agreement or disagreement on a Likert scale ranging from 1 to 5, with 1 representing strongly disagree and 5 representing strongly agree. The results revealed a range of perceptions among the respondents regarding the impact of implementation on the efficiency of information management processes within their organisations. 50% of the respondents expressed agreement that the implementation improved the efficiency of their organisation's information management processes. These respondents experienced positive changes in their information management practices. The standard's principles and guidelines likely contributed to more effective information management, resulting in improved efficiency within their organisations. 7% of the respondents strongly agreed that the implementation significantly improved the efficiency of their information management processes. On the other hand, 43% of the respondents

expressed a neutral stance, indicating that they neither strongly agreed nor disagreed with the statement. These respondents may have experienced mixed results or encountered challenges in fully realising the anticipated efficiency improvements. Factors such as organisational culture, resource availability, and implementation strategies could have influenced their perceptions. The findings suggest that while a significant portion of the respondents perceived improvements in efficiency resulting from, there is a need for further exploration and understanding of the specific factors that contribute to these outcomes. It is important to identify the success factors and best practices that organisations can leverage to maximise the efficiency gains from implementation.

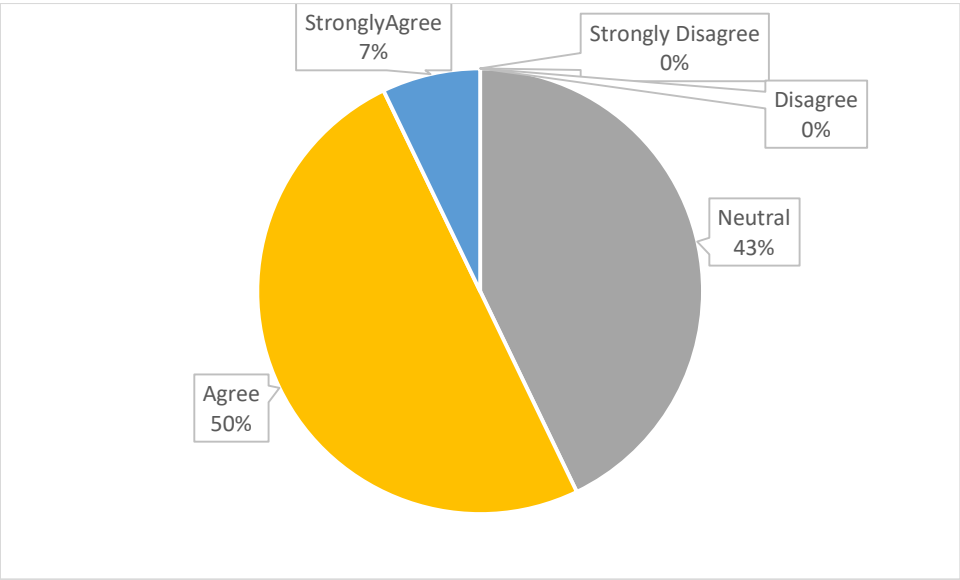


Figure 23: Results of question 3.3 The implementation of the ISO 19650 standard improved the efficiency of your organisation's information management processes.

Question 3.4 is shown in Figure 23 aimed to gauge the respondents' confidence in the accuracy and reliability of the information produced and managed using the ISO 19650 standard. The results revealed varied perceptions among the respondents regarding the accuracy and reliability of the information produced and managed although there was a bias towards positivity overall.

43% expressed confidence in the accuracy and reliability of the information produced and managed using the standard. These respondents reported that the implementation had positively impacted their organisation. The standard's guidelines, procedures, and

requirements likely contributed to the establishment of robust information management practices, resulting in greater confidence in the produced information. However, a significant portion of the respondents (57%) expressed a neutral stance, indicating neither strong confidence nor lack of confidence in the accuracy and reliability of the information produced and managed using the standard. These respondents may have experienced mixed results or encountered challenges in fully achieving the desired level of accuracy and reliability. Factors such as data quality, validation processes, and staff training could influence their confidence levels. The findings suggest that while some respondents have gained confidence in the accuracy and reliability of information through implementation, there is room for improvement in this aspect. Organisations need to focus on enhancing information governance practices, quality control measures, and continuous monitoring to further increase confidence levels. This result highlights the need for continuous improvement efforts to enhance data quality, validation processes, and overall information governance.

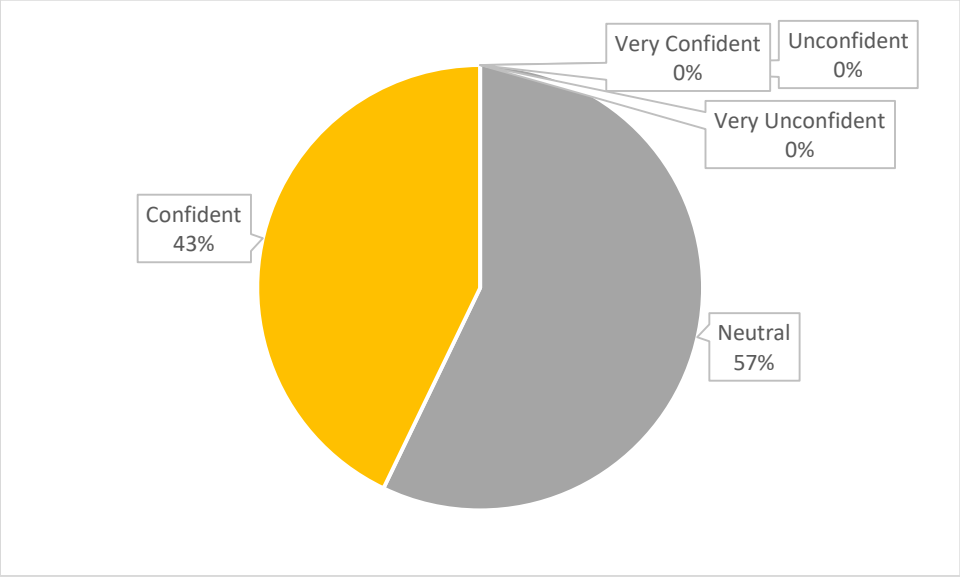


Figure 24: Results of question 3.4 How confident are you in the accuracy and reliability of the information produced and managed using the standard?

Question 3.5 aimed to assess the respondents' confidence in the ease of following and tracking processes outlined in the standard.

The results showed that 43% expressed a lack of confidence in the ease of following and tracking the processes outlined in the standard. These show the challenges in understanding and implementing the prescribed processes, possibly due to complexity, lack of clarity, or insufficient training. Difficulties in tracking the progress and compliance of these processes may have led to uncertainty and hindered effective implementation. A significant percentage of respondents (57%) expressed a neutral stance, indicating neither strong confidence nor lack of confidence in the ease of following and tracking the processes. This suggests that respondents may have experienced a mix of positive and negative experiences in terms of process usability and trackability. The findings suggest that there is room for improvement in making the processes outlined in the standard more user-friendly, intuitive, and easily trackable. Clear and concise guidance, training programs, and user-friendly tools can help organisations overcome challenges and enhance confidence in process adherence and trackability.

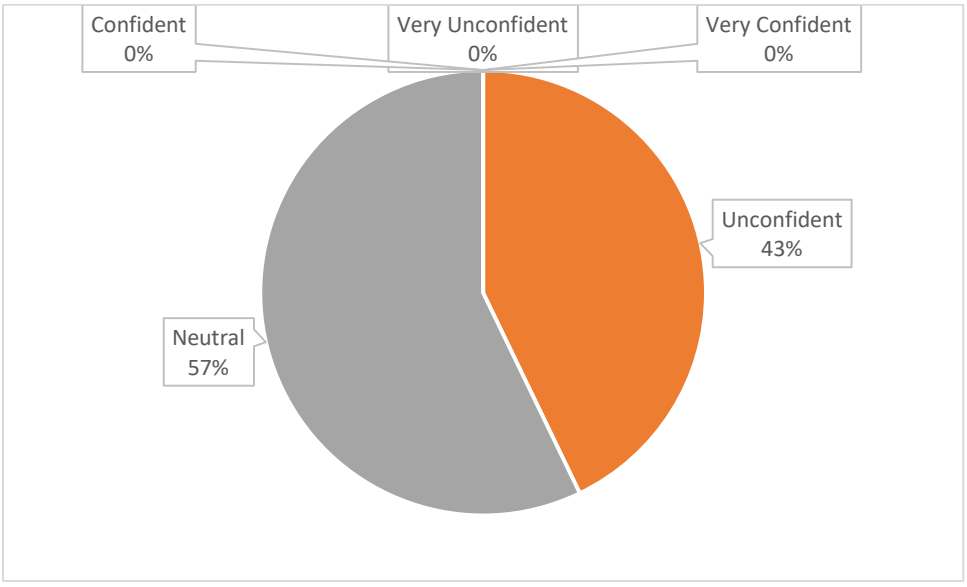


Figure 25: Result of question 3.5 How confident are you that the processes are easy to follow and can be tracked?

Question 3.6 aimed to assess the ease of producing the required documentation as outlined in the standards.

The results indicate that a significant majority of respondents (79%) found it very difficult to produce the required documentation. This suggests that the process of generating the necessary documents according to the standard poses' challenges and complexities for organisations. Respondents may have encountered difficulties in understanding the documentation requirements, aligning their existing practices with the standard, or lacking the necessary resources and tools to streamline the documentation process effectively. Furthermore, 21% of respondents reported finding the document production process difficult. Although a smaller percentage, it still indicates that a considerable portion of organisations face challenges in creating the required documentation. This may be attributed to factors such as the complexity of the standard. The findings highlight the need for improved guidance, training, and tools to facilitate the document production process under the standard. Simplifying the requirements and providing templates could help organisations overcome the difficulties and enhance their ability to produce the necessary documentation.

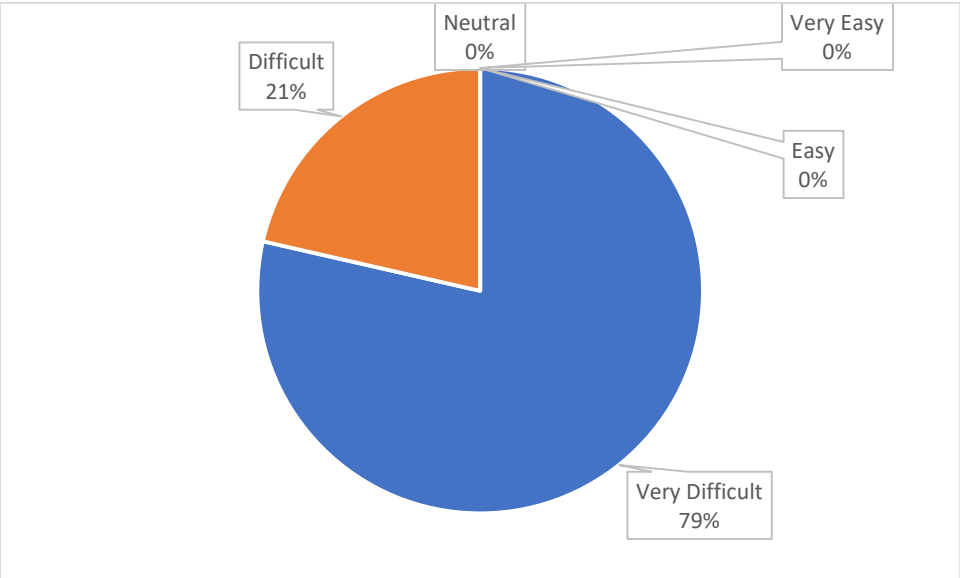


Figure 26: Results of question 3.6 How easy is it to produce the required documentation?

Results of Section 4

In Section 4 of the questionnaire, the focus shifted to understanding the challenges faced by organisations in implementing standards. The aim of this section was to gather insights into the difficulties, obstacles, and barriers encountered during the implementation process. A deeper understanding can be gained by exploring these challenges regarding the factors that

may hinder or impede successful adoption and compliance with the standard. The results from question 4.1 shown in Figure 26 show a bias towards the standard being complex.

- 39% of respondents expressed a neutral stance, indicating that they neither agree nor disagree that the complexity of the standard hinders their organisation's understanding of the required processes.
- 25% of respondents strongly agreed that the complexity of the standard hinders their organisation's understanding.
- 36% of respondents agreed that the complexity of the standard hinders their organisation's understanding.

These results highlight that a significant portion of organisations perceive the standard as complex, which poses challenges in comprehending the required processes. The complex nature of the standard can potentially impede effective implementation and hinder organisations' ability to fully grasp the intricacies and nuances of the processes outlined in the standard. Addressing this challenge may require efforts to simplify and provide clearer guidance on interpreting and applying the standard, ensuring that organisations can better understand and navigate the requirements. The findings from this question underscore the importance of providing adequate support and resources to help organisations overcome the complexity of the standard and enhance their understanding of the required processes

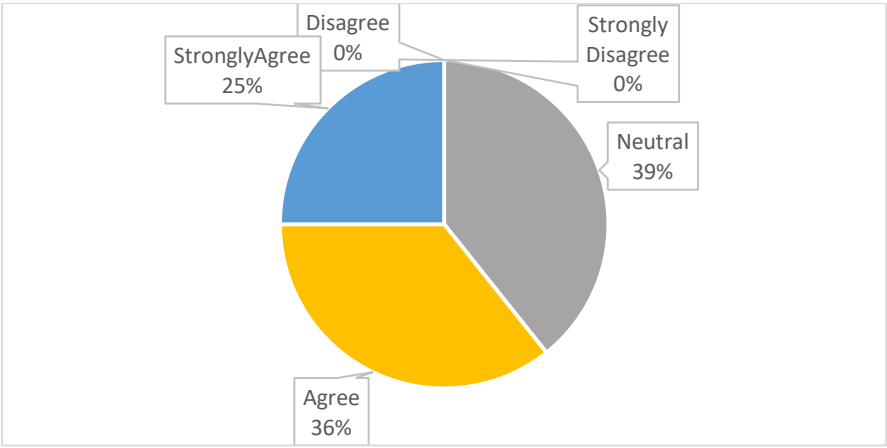


Figure 27: Results of question 4.1 The complexity of the standard hinders our organisation's understanding of the required processes

Question 4.2 asked respondents to rate the extent to which document production guidelines were impeding their implementation. The results indicate the following distribution among the respondents:

- 21% of respondents strongly agree that the lack of clear guidelines has impeded implementation.
- 43% of respondents agree that the lack of clear guidelines has impeded implementation.
- 36% of respondents had a neutral opinion regarding the impeding effect of the lack of clear guidelines.

These findings highlight that a substantial proportion of organisations perceive the absence of clear guidelines for document writing as a challenge in implementing the standard. The lack of guidance can lead to confusion and inconsistency in document preparation, hindering the smooth adoption and compliance with the standard's requirements.

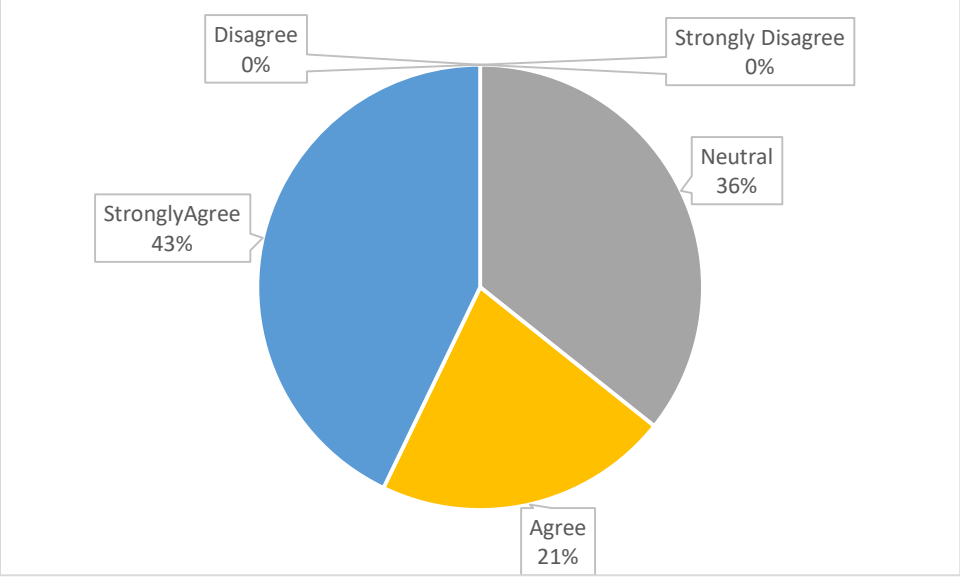


Figure 28: Results of question 4.2 Please rate the extent to which the lack of clear guidelines for document writing according to the standard has impeded implementation in your organisation

Question 4.3 is shown in Figure 29 and asked respondents to rate their level of agreement with the statement:

"Having a system that enables automation of processes and provides guidance would significantly help in implementing the standard in your organisation" The results indicated that:

- 25% of respondents had a neutral opinion regarding the statement.
- 39% of respondents strongly agree that having a system that enables automation of processes and provides guidance would significantly help in implementing the standard.
- 36% of respondents agree with the statement.

These findings highlight that a significant proportion of organisations recognise the value and potential benefits of having a system that enables automation of processes and provides guidance in implementing the ISO 19650 standard. Such a system can streamline workflows, facilitate adherence to standard requirements, and enhance overall efficiency and compliance.

The positive responses indicate that organisations perceive automation and guidance as crucial elements in successfully implementing the standard. Leveraging technology to automate processes and provide guidance will enable organisations to mitigate challenges related to complexity, lack of clear guidelines, and other implementation barriers. Implementing a system that combines automation and guidance can offer organisations a practical solution to navigate the intricacies of the standard, improve information management practices, and enhance overall project delivery within the AECOO industries. These results suggest that investing in a system that supports automation and guidance can be a strategic approach for organisations seeking to overcome implementation challenges and optimise compliance.

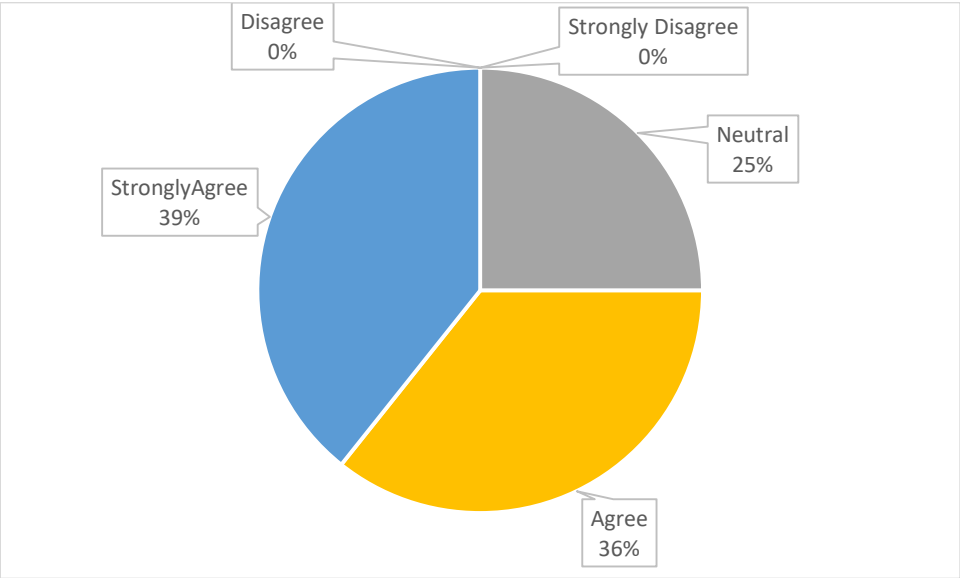


Figure 29: Results of question 4.3 Please indicate your level of agreement with the statement: "Having a system that enables automation of processes and provides guidance would significantly help in implementing the standard in your organisation."

An interesting observation from the results is the apparent disparity between the responses to Q3.2, which assessed satisfaction with the support and guidance provided by the standard documentation, and Q3.4, which gauged confidence in the accuracy and reliability of information produced using the standard. While 50% of respondents expressed dissatisfaction with the support and guidance, 43% expressed confidence in the information

produced. This suggests that while organisations may find the standard documentation lacking in clarity or practical guidance, they are still able to effectively implement the standard and produce reliable information. This could be due to several factors, such as relying on external resources, internal expertise, or a focus on practical outcomes rather than strict adherence to the documentation. This finding highlights an opportunity for the PoC approach proposed in this research. By developing a platform that offers enhanced guidance, automated processes, and quality checks, the PoC can address the shortcomings of standard documentation and further improve the efficiency and effectiveness of information management practices.

Summary

The results obtained from the questionnaire aligned with the discussions held during the local authority workshops and the industry questionnaires, highlighting consistent themes across the data. The main themes that emerged were:

Clients not understanding the requirements: The questionnaire responses, as well as the discussions in the local authority workshops, indicated that clients often struggled to grasp and comprehend the project requirements. This lack of understanding from the client's side could potentially lead to miscommunication, delays, and challenges in project execution.

Development of poor documentation: Both the questionnaire results and the industry questionnaires highlighted concerns regarding the quality and effectiveness of documentation produced during the implementation process. Contractors and stakeholders expressed difficulties in creating comprehensive and accurate documentation, which could impact project clarity, coordination, and overall success.

Process implementation: The questionnaire responses and industry questionnaires indicated a recurring issue with process implementation. Some participants reported that defined processes were not followed consistently, while others mentioned a complete lack of process implementation. These findings resonate with the challenges identified in the local authority

workshops, highlighting a gap between documented procedures and their practical application.

The alignment of these key themes across multiple data sources, including the local authority workshops, industry questionnaires, and questionnaire results, strengthens the validity and reliability of the findings. It provides a comprehensive perspective on the challenges faced within the industry regarding client understanding, documentation quality, and process implementation. By corroborating these themes through various data collection methods, the study establishes a robust foundation for understanding the common issues surrounding BIM implementation and ISO 19650 application.

Chapter 5 System Design and Process Automation

Overview

This chapter focuses on system design and process automation, specifically addressing the extraction of relevant clauses from ISO 19650 into a BPMN (Business Process Model and Notation) format. The following steps were undertaken to achieve this:

1) Comprehensive Development of BPMN Format: The study involved a thorough development process to extract and translate the relevant clauses from ISO 19650 into a BPMN format. This step ensured that the standard's requirements and guidelines were accurately represented within the BPMN model.
2) Definition of Database Schema: A comprehensive database schema was defined to capture the interaction between different components, including requirements, actors, work plans, information delivery plans, and projects. This schema facilitated the efficient storage and retrieval of data, enabling smooth process automation.
3) Implementation of BPMN Engine: A BPMN engine was implemented as part of the system design. This engine enabled the execution and management of the BPMN models, allowing for process automation and workflow orchestration based on the defined BPMN diagrams.

4) User Interface Design: A user interface (UI) was designed to provide a user-friendly interaction point for system users. The UI allowed users to interact with the BPMN models, view project-related information, and perform relevant actions as required by the ISO 19650 guidelines.
5) Integration of Microservices using Docker: The different elements, including the BPMN engine, database schema, and user interface, were integrated using Docker as a microservices architecture. Docker facilitated the deployment and management of these components as separate, scalable services, ensuring flexibility and efficient system operation.

By incorporating these elements, the study successfully developed a comprehensive system design and process automation framework. The extraction of ISO 19650 clauses into a BPMN format, coupled with the defined database schema, enabled the effective management and execution of the standard's requirements. The implementation of a BPMN engine, user interface, and the use of Docker as a microservices architecture further enhanced the system's functionality and usability.

ISO 19650 Process Discovery

Introduction to process discovery

Capturing the requirements of ISO 19650 involved a detailed analysis of the standard itself, which provided a comprehensive framework for information management in the construction industry. Reading through ISO 19650 allowed for a systematic understanding of the key principles, concepts, and requirements outlined in the standard. The process involved a thorough examination of each section and clause to identify the specific requirements that needed to be captured as shown in Figure 30 below.

Figure 30: ISO 19650 Activities, inputs and outputs

To capture the requirements in a structured format, one approach was to create a CSV (Comma-Separated Values) file. This file format allowed for the organisation and categorisation of the requirements based on different criteria, such as process areas, information exchanges, or roles and responsibilities. Each requirement was documented as a separate entry in the CSV file, along with relevant details, such as its description, associated clauses, and any additional notes or considerations.

In addition to the CSV format, a manual drawing of the requirements into BPMN (Business Process Model and Notation) was undertaken. BPMN provided a visual representation of the information management processes and workflows described in ISO 19650. The manual drawing involved mapping out the sequence of activities, decision points, and information exchanges specified in the standard using BPMN symbols and notation. This process helped to visualise the flow of information, the roles involved, and the interactions between different stakeholders in implementing the requirements of ISO 19650.

Both the CSV file and the BPMN diagrams served as valuable tools to document and communicate the requirements of ISO 19650. The CSV format provided a structured and easily accessible reference that could be shared and updated as needed. It allowed for easy sorting and filtering of requirements based on various parameters, facilitating analysis and

tracking of compliance. On the other hand, the BPMN diagrams provided a visual representation that enhanced the understanding of the information management processes and their relationships. The combination of these two approaches ensured a comprehensive and accessible representation of the requirements outlined in ISO 19650, aiding in the implementation and alignment of information management practices in accordance with the standard.

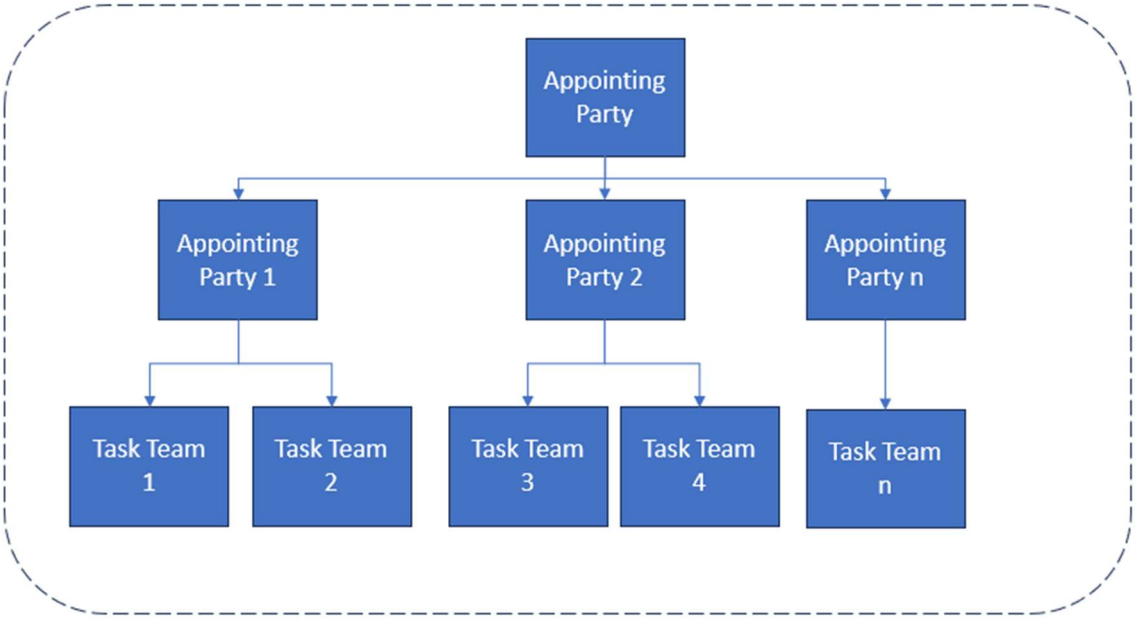


Figure 31: Arrangements of actors in ISO19650-1:2018

As stated, in order to develop the BPMN process maps, a manual trawl was undertaken of the ISO19650:2 standard. The standard itself is broken down into actors, with each actor allocated a part or parts within an activity. A project according to the standard can be only 1 appointing party followed by one or more appointing parties and tasks teams as shown in Figure 31 above. The standard itself identifies the use of a BPMN overview diagram of the high-level activities involved throughout each of the activities. These have been broken down and identified in Table 16 below. It is important to note that some of the high-level activities are controlled by 1 main actor although the activities within them are undertaken by 2 or more which shows the complexity of the standard and a need to understand the inter-relationships contained within it.

Section from ISO19650-2:2018	Description	Actors involved
5.1	Assessment and need	Appointing Party
5.2	Invitation to Tender	Appointing Party
5.3	Tender response	Lead Appointing Party
5.4	Appointment	Appointing Party/Lead Appointed Party
5.5	Mobilisation	Lead Appointed Party
5.6	Collaborative production of information	Task Team / Lead Appointed party
5.7	Information Delivery	Task Team / Appointing Party
5.8	Project Close Out	Appointing Party/ Lead Appointing Party

Table 16:High level activities identified in ISO19650-2018

The overall activities in section 1 are centred around the need for identifying the information required within a construction project. Within the section itself, there are further activities which are required to be undertaken at a high level which will affect the activities for the whole project duration and into the operational phase. As identified in the chapters above, these further activities and how they are both implemented and understood are some of the main issues in relation to implementing the standard.

BPMN Process maps

According to Dumas (Dumas et al., 2013) a BPMN model possesses three essential properties: mapping, abstraction, and purpose.

Mapping: BPMN models are designed to map or represent real-world phenomena. They aim to capture and model the relevant aspects of the object or process being analysed. By mapping the real-world phenomenon, BPMN provides a visual representation that helps stakeholders understand and communicate the process more effectively.

Abstraction: BPMN models focus on documenting and representing the essential or relevant aspects of the subject being modelled. They employ a level of abstraction that avoids unnecessary complexity or excessive detail. This abstraction allows for a concise and clear representation of the process, highlighting the key activities, events, and interactions.

Purpose: The purpose of the BPMN model influences the selection and inclusion of elements within the model. Depending on the specific purpose or goal of the mapping, certain elements may be emphasised while others may be omitted. The purpose of the model could vary, such as process analysis, process improvement, process automation, or communication among stakeholders. The model should also align with the intended purpose to fulfil its objectives effectively. In this particular case, it is to enable the standards to be described as accurately as possible while also being easy to use.

Taking these points into account individually, the first point about mapping the real world in this context relates to mapping the standard correctly. BPMN is represented by a mixture of symbols which should also represent to a variety of users what is meant to happen. The number of symbols used from the BPMN standard has been deliberately chosen to be as minimal as possible to aid those who are unfamiliar to understand the maps. The symbols used and their meaning is presented in below:

Swim lanes / Pools

These are used to visually represent different participants or organisational units involved in a business process. They serve several purposes, including role allocation, process ownership, separation of concerns, visualising handoffs and interactions, handling process variations, and enhancing readability and communication (Dumas et al., 2013). The assignment of swim lanes to specific stakeholders further enables responsibilities to become clear, promoting accountability and coordination and enabling responsibilities to become clear.

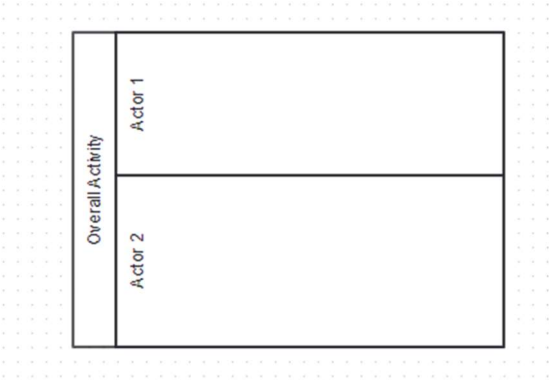


Figure 32: BPMN Swim Lane

Gateways

These are graphical elements used to model and control the flow of a process based on specific conditions or rules. They represent decision points within a process where different paths or alternative flows can be taken based on certain criteria and play a crucial role in modelling the behaviour and logic of a process. They're classified into different types based on their behaviour and purpose. For the research, only the ones used are explained further

Exclusive Gateway (XOR):

An exclusive gateway represents a decision point where only one outgoing path can be chosen. It is used to model mutually exclusive choices or alternative paths where only one condition is satisfied. The decision is based on evaluating the conditions associated with each outgoing sequence flow, and only the flow with a satisfied condition is taken.

Figure 33: Exclusive gateway

Inclusive Gateway (OR):

An inclusive gateway represents a decision point where multiple outgoing paths can be chosen. It is used to model inclusive choices or alternative paths where one or more conditions can be satisfied. The decision is based on evaluating the conditions associated with each outgoing sequence flow, and all flows with satisfied conditions are taken.

Figure 34: Inclusive gateway

Parallel Gateway (AND):

A parallel gateway represents a synchronisation or forking point where multiple concurrent paths are created. It is used to model parallel or concurrent activities that can be executed simultaneously. All outgoing paths from a parallel gateway are taken simultaneously, and the process flow continues along each path independently.

Figure 35: Parallel gateway

Activities

Activities are the fundamental building blocks used to represent work or tasks within a business process. Activities capture the actions or steps that need to be performed to achieve a specific outcome or goal. They can represent manual tasks performed by humans, automated tasks executed by systems, or subprocesses consisting of multiple activities.

- Task

  Represents a single unit of work that needs to be performed. It can be a manual task performed by a human or an automated task executed by a system.

Figure 36: Task gateway

- Subprocess

  Represents a collection of activities that form a smaller, self-contained process within the main process. It allows for the modelling of more complex processes by breaking them down into manageable subprocesses.

Figure 37: Subprocess

- Call Activity

  Represents the invocation of a reusable subprocess defined elsewhere in the process or in a separate BPMN diagram.

Figure 38: Call Activity

Events

These represent points in a business process where something significant occurs, triggering a change in the process flow or indicating a specific state. They can be used to model the start, intermediate, and end points of activities, as well as to capture external or internal occurrences that affect the process as well as help to define the control flow, synchronisation, and communication within a process. Only the ones used in the research are described in more detail;

- Start Events

  Represent the beginning of a process or subprocess. They indicate the initiation of the process flow and can have various triggers such as a message, timer, or signal.

Figure 39: Start Event

- End Events

  Represent the completion or termination points of a process or subprocess. They indicate the successful or unsuccessful completion of the process flow.

Figure 40: End Event

- Message

  Triggered by the arrival of a message from an external source or another process.

Figure 41: Message event

ISO 19650:2 Section 5.1 outlines a series of requirements that an appointing party must implement, encompassing seven distinct sections with various decision points associated with each. Notably, Section 5.1.1 mandates the appointment of a prospective information manager. The selection of an information manager can involve the choice between an internal candidate, a prospective lead appointment, or a third-party manager. Within the Business Process Model and Notation (BPMN), such decisions are typically represented using an XOR gateway.

The UK BIM Framework guidance, particularly Guidance Part 2, provides a high-level overview of information management processes through process maps. While these maps offer a valuable starting point, they lack the granularity needed to assign specific responsibilities for each activity within the ISO 19650-2 framework. To address this, the process map design in

this research goes a step further by incorporating a detailed breakdown of tasks and assigning clear ownership to each activity. This granular approach ensures accountability and facilitates effective coordination among project stakeholders, aligning with the principles of ISO 19650-2. This also provides a way of validating the process maps at the level of the UKBIM Framework.

The subsequent steps following the appointment of an information manager are contingent upon whether the selected manager is internal or external. If an internal manager is chosen, their role is assigned directly. Conversely, if an external manager is selected, they must carefully consider critical factors such as task requirements, competency, knowledge, and skills. To account for these considerations, a comprehensive BPMN model has been developed, considering all the pertinent points for effective implementation and decision-making as specified by ISO 19650:2 Section 5.1 as shown in Figure 42 below.

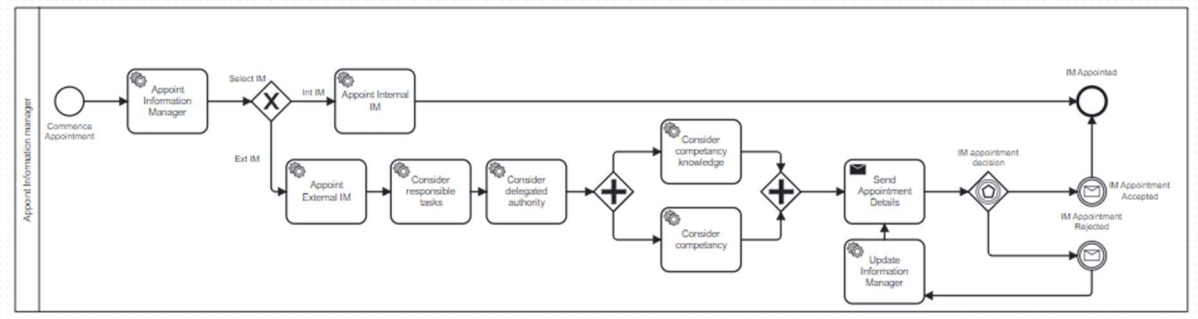


Figure 42: ISO19650:2 Section 5.1.1

In this research, due to time constraints, the focus has been placed on modelling Section 5.1 of the ISO 19650 standard in order to demonstrate its underlying concept. While the modelling efforts have been limited to this section, it is important to note that the elements and principles outlined within Section 5.1 are representative of the broader content and requirements found throughout the standard. Furthermore, the aim of modelling Section 5.1 is to showcase the applicability and significance of the concepts within this specific section, with the understanding that similar principles and elements will be present across the entire standard. This focused approach allows for a deeper examination of the core concepts related to information management planning, which can provide valuable insights into the overall implementation and adherence to ISO 19650. Section 5.1 high level is shown

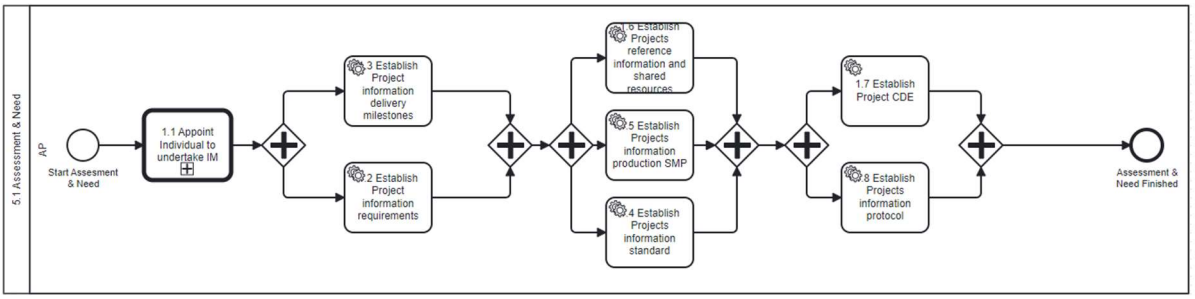


Figure 43: ISO 19650:2 Section 5.1

In this research, process maps have been created for each of the associated activities and subsections within ISO 19650:2 5.1. The process maps serve as visual representations of the step-by-step procedures and workflows involved in implementing the specific activities. To develop these process maps, Camunda Modeller, a popular BPMN modelling tool, has been utilised.

Undertaking the mapping out of processes using Camunda Modeller, it becomes easier to visualise and understand the sequence of activities, decision points, and interactions within the context of ISO 19650. They offer a comprehensive overview of the required steps, responsibilities, and dependencies associated with each activity and subsection of the standard. This approach allows for a more systematic and structured understanding of the implementation process, facilitating better communication, analysis, and optimisation of the procedures involved in adhering to ISO 19650.

The next subsequent step in the research process encompassed two primary aspects: the creation of a user interface and database, utilising Django to develop the models as discussed in the forthcoming section, and the development of the Camunda process engine. This phase aimed to integrate the process maps generated earlier into an operational system. To begin, a user interface was designed to provide a user-friendly platform for interacting with the Camunda process engine. Django, a high-level Python web framework, was employed to develop the necessary models and establish the underlying database structure. By leveraging Django's capabilities, the researcher was able to efficiently manage, and store relevant data associated with the process execution and user inputs. Simultaneously, the Camunda process engine was developed to execute the process maps created previously.

The relationships between the process engine, user interface, and developed process maps were comprehended through the utilisation of Maven, with specific emphasis on creating a Project Object Model (POM) model(Xiong & Yang, 2014). The POM model facilitated the seamless integration of these components by automatically updating interdependencies. Maven's POM model served as a fundamental building block in the project's development and integration process. Configuring the POM, enabled not only the structure and dependencies to be specified but also the management of the overall build and deployment process. Maven's ability to handle dependencies and automatically resolve conflicts significantly simplified the integration of the Camunda Engine, user interface, and process maps.

The decision to employ Maven was primarily driven by the fact that the Camunda Engine is based on Java, and Maven is well-suited for managing Java-based projects. Maven's familiarity and compatibility with Java-based systems ensured a smooth integration process, enabling efficient collaboration between the different components of the research. Within the integration process, the Camunda API was utilised to establish the necessary endpoints for communication between the user interface and the process engine. This allowed for the exchange of data, execution of process steps, and retrieval of relevant information. Furthermore, the system was designed to record and store user inputs at each decision point within the process, ensuring that the captured data accurately reflected the decision-making process.

Database Design Overview

Designing a database to accommodate the activities detailed in ISO 19650 involved careful consideration of the standard's requirements and the data elements associated with each activity. The goal was to create a robust and flexible database structure that could effectively store and manage the relevant information in a structured manner.

The first step in designing the database was to identify the key entities and their relationships based on the activities described in ISO 19650. This involved analysing the standard's sections and clauses to extract the relevant entities, such as projects, stakeholders, documents,

information exchanges, and roles. The relationships between these entities were determined to establish the data connections and dependencies. Next, the attributes and properties associated with each entity were identified. These attributes represented the specific data elements required to describe and characterise the activities in ISO 19650. For example, attributes for a project entity included project name, description, start date, end date, and classification. Similarly, attributes for a document entity could include the document name, version, author, creation date, and associated information requirements. Based on the identified entities and their attributes, a database schema was designed. The schema defined the tables, fields, and relationships necessary to represent the activities outlined in ISO 19650. It was structured to ensure data integrity, minimise redundancy, and support efficient data retrieval and manipulation. To implement the database design, the object relationship model was utilised with the Django framework. This framework provided the necessary tools and functionalities to create the tables, define the fields and data types, establish the relationships, and enforce data integrity constraints. The database design was translated into the appropriate SQL (Structured Query Language) statements to create the necessary database objects.

Once the database was set up, data population and validation were performed. The relevant information from existing projects and processes was captured and entered into the database. Data validation checks were implemented to ensure the accuracy and consistency of the entered data, in alignment with the requirements of ISO 19650. This provided a structured and organised repository for storing and managing the activities while also allowing for efficient data retrieval, searching, and reporting, enabling stakeholders to track and monitor the progress of projects, information exchanges, and compliance with the standard.

User interface

The development of the user interface in this research was carried out utilising the Django framework. This choice provided several advantages, including the ability to implement the required models and utilise the Object-Relational Mapping (ORM) feature to interact with the underlying database, in this case, PostgreSQL as shown in Figure 44 below

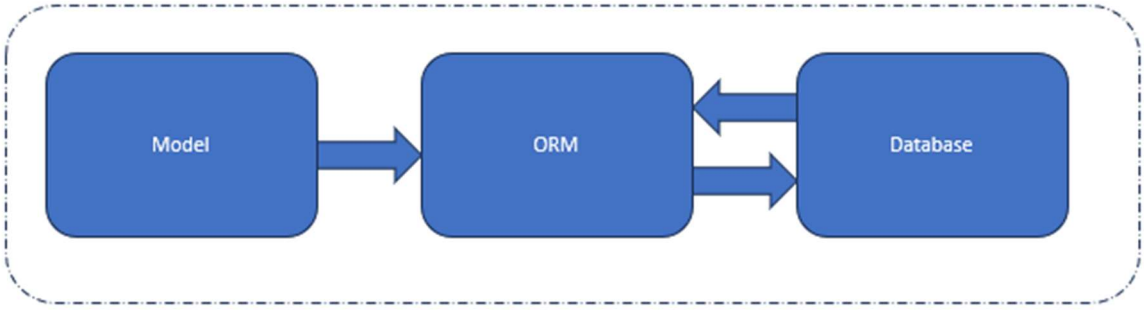


Figure 44: Relationships between models, ORM and database

Model Development

The user interface development process began with the creation of the actor model, which served as the basis for representing various entities in the system. From the actor class, derived models like the organisation and person models were developed. The organisation model could incorporate a hierarchical system to adhere to ISO 19650 standards, which require a single appointing party and multiple appointed parties. Implementing a hierarchical structure accurately depicted the relationships and responsibilities among different organisations. Similarly, the person model enabled the assignment of individuals to specific departments, facilitating a clear organisational structure and efficient personnel management within the system. The organisation, department and user models and their relationships are shown below in Figure 44.

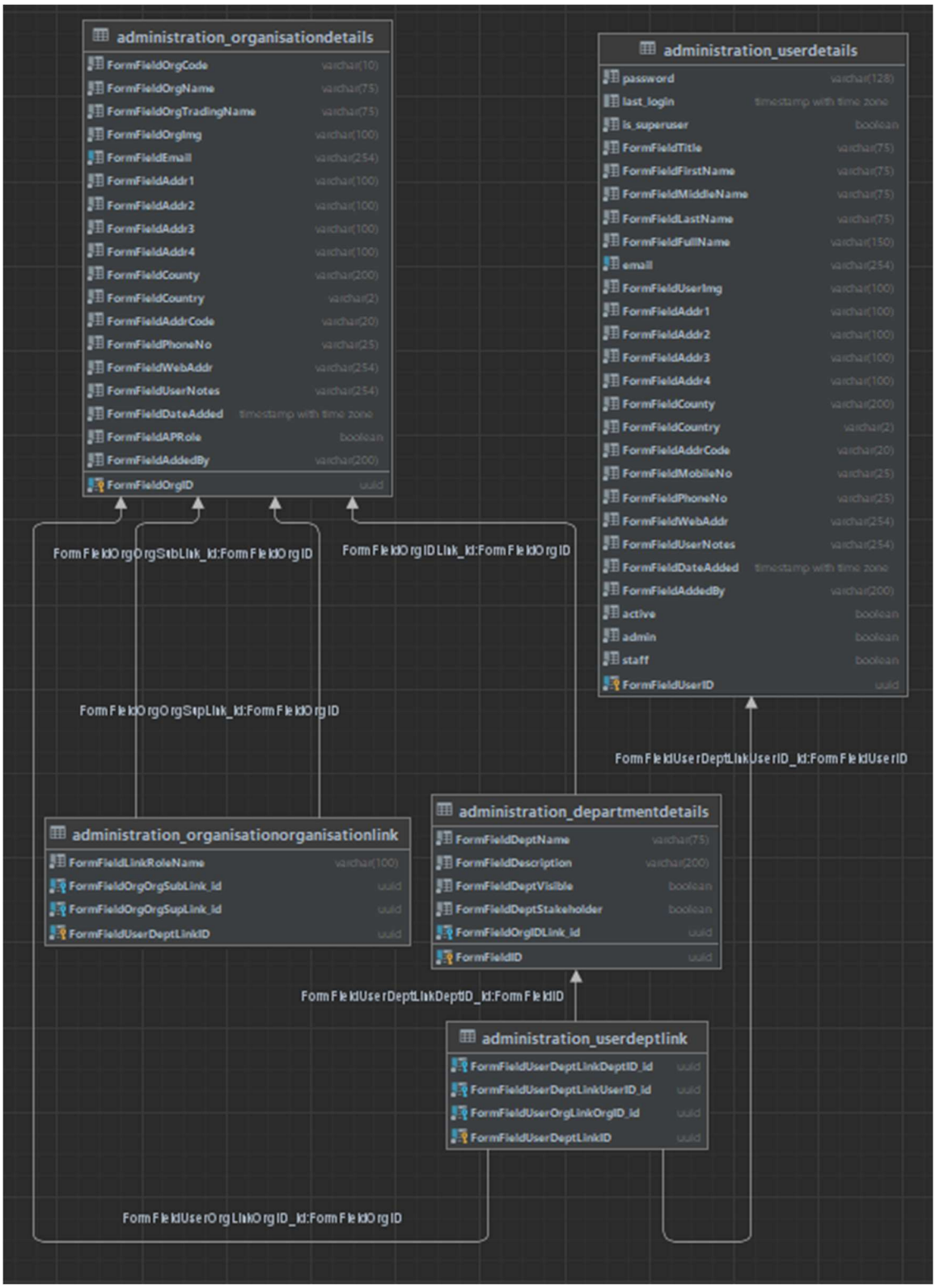


Figure 45: Relationships and dependencies between actors

After establishing the base models for actors, the next step involved developing the information requirements framework for both organisations and projects within the research

context. At the time of this development, there were no specific guidelines or standards available for writing linked information requirements. Therefore, as part of the research process, a framework was created to address this gap and provide a structured approach. The information requirements framework took into consideration the guidelines outlined in ISO 19650 Part 1,

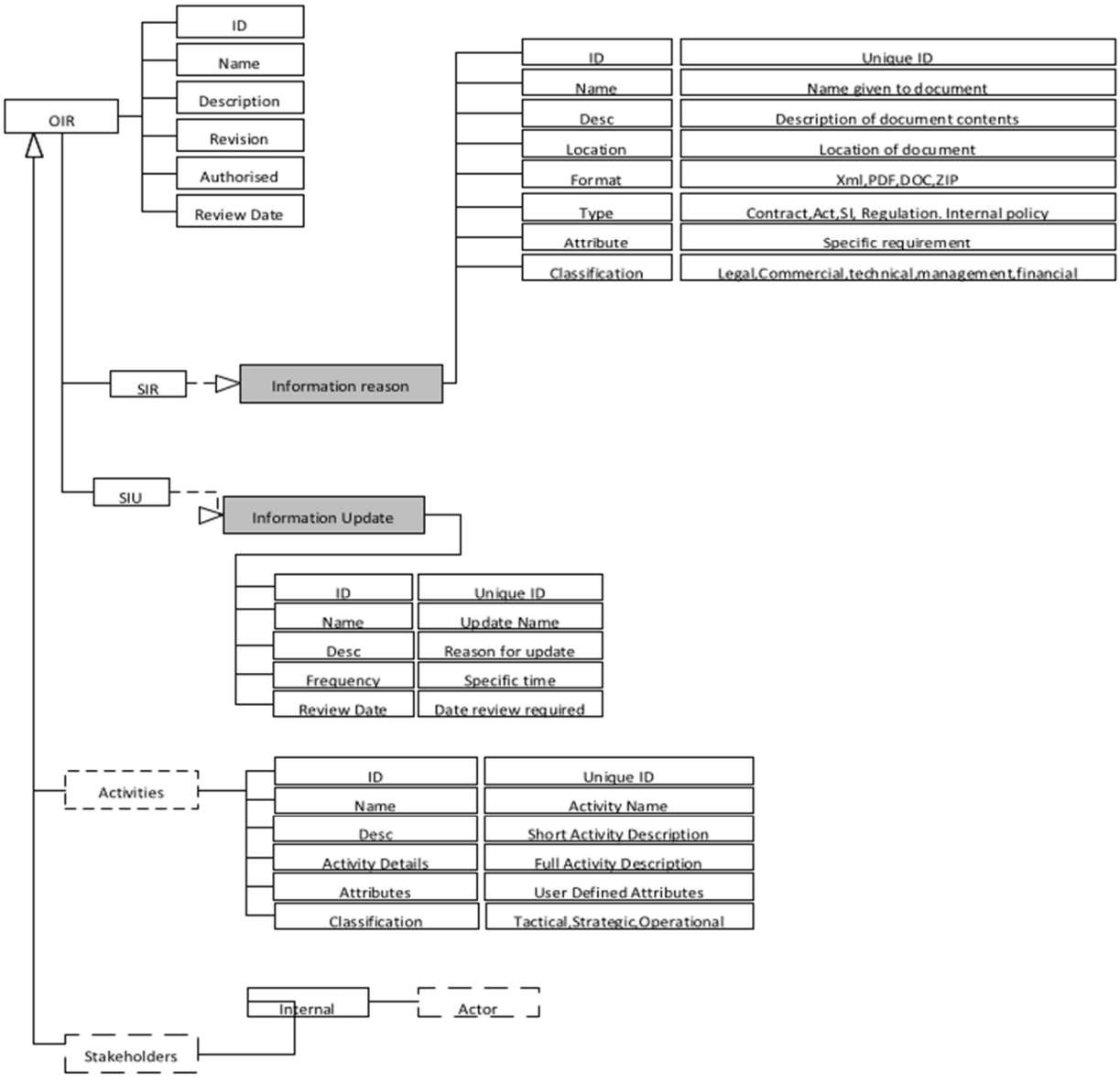


Figure 46: Framework for organisation information requirements

which emphasises the alignment of information with various aspects such as operation, strategic, tactical, technical, and commercial objectives. These aspects serve as categories for organising and classifying the required information. To translate these guidelines into a tangible model, the developed framework incorporated these categories as attributes or fields within the model. This allowed for the structured capture and representation of information requirements based on their respective alignment with the operational, strategic, tactical, technical, or commercial aspects. The organisation of the information requirements in this manner also enabled the possibility to effectively manage and communicate the specific information needs within the research project. The framework developed for the organisation's requirements includes a capability to capture activities within the business process.

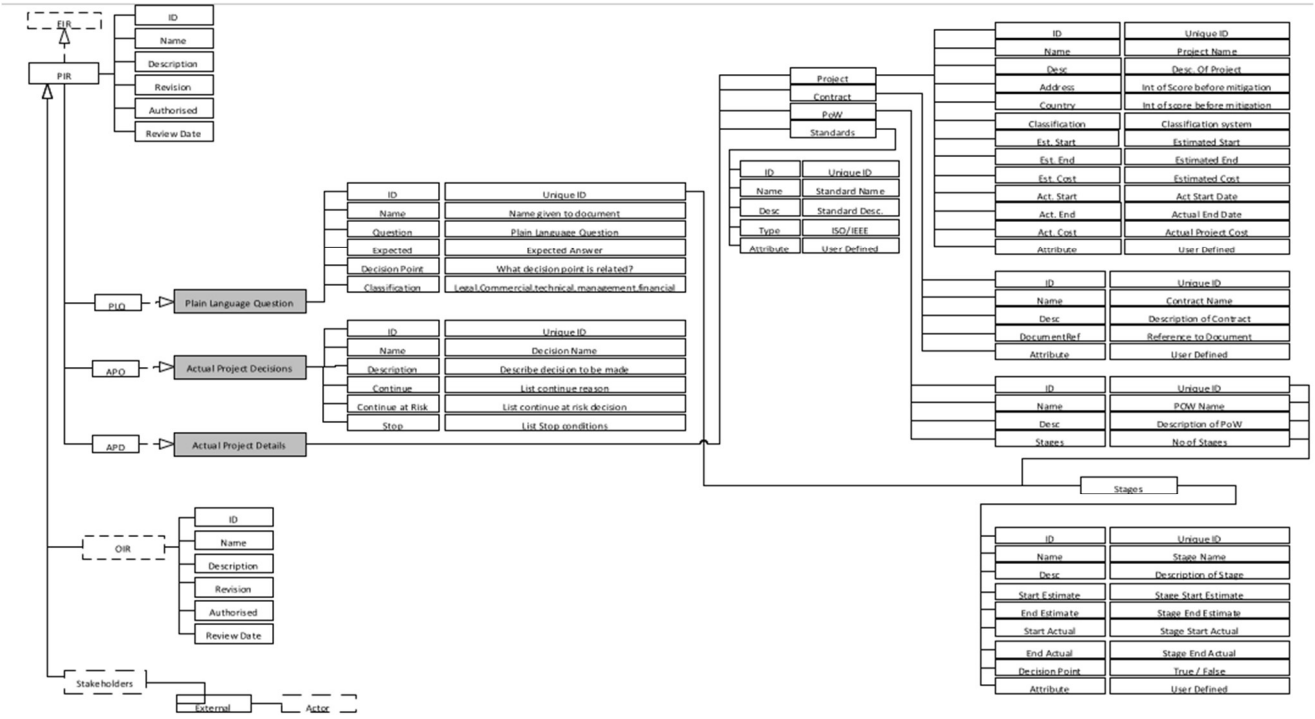


Figure 47: Project information requirements

This capability enables the identification and documentation of specific activities that take place within the process and builds upon previous work by (Cavka et al., 2017) where the need for rigorous information requirements was outlined. The activity-based framework allows for a more detailed understanding of the process flow and facilitates the analysis and

improvement of individual tasks. Furthermore, the framework also enables the specification of information requirements specifically associated with each activity. This means that for every captured activity, the necessary information inputs, outputs, and data dependencies can be identified, documented and appropriately utilised during the execution of each activity. A high-level overview of the organisation framework is shown in Figure 46 above whilst its implementation in the model is shown in Figure 48 below. Following the development of the information requirements framework, the next model to be developed was the project model itself. Extensive reading of all published parts of the standard, along with relevant information from BuildingSMART documentation, informed the inclusion of specific attributes within this model. The project model and its interrelationships which are detailed in Figure 49 below encompassed various essential attributes, including the project code, name, and description, providing a clear identification and description of the project. The plan of work, which outlines the project's scope, tasks, and timeline, was also included as a crucial attribute within the model. Additionally, the location attribute provided information regarding the geographical location

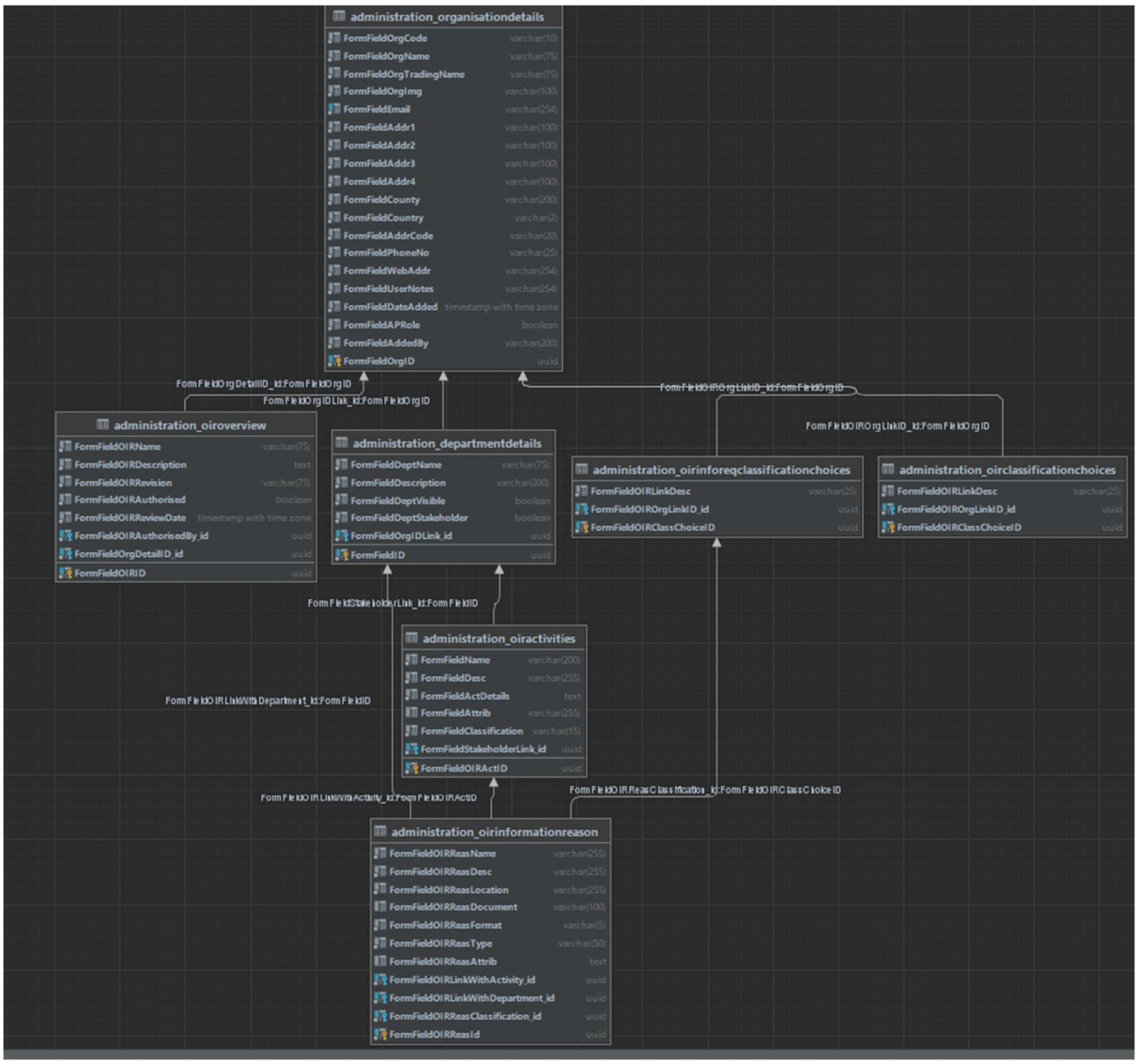


Figure 48: Relationship and dependencies on organisation information requirements

of the project. To ensure compliance with relevant standards, the classification system attribute was incorporated into the project model. This attribute enabled the categorisation and classification of the project based on an established system, facilitating efficient organisation and retrieval of project data. Furthermore, additional fields were included to support quality assurance and auditing processes. These fields captured information related to the user who added the project, as well as the date of project addition or updates. By including these fields, the system facilitated the tracking of project changes and provided accountability for user actions.

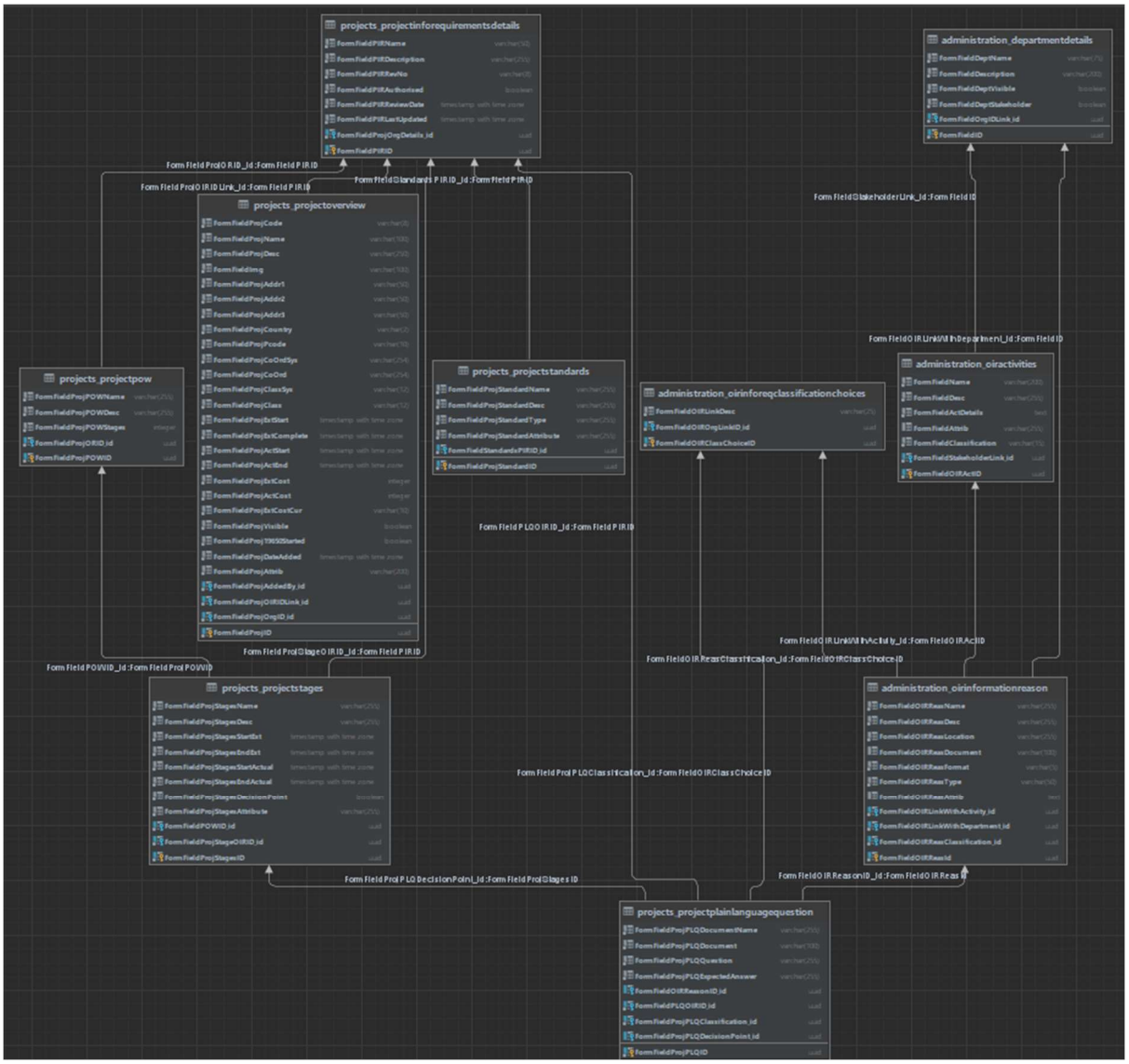


Figure 49: Relationship and interdependencies of the project and requirements

The subsequent model developed was the approval model, which focused on the approval process for specific items within the organisation. This model introduced a hierarchical structure to ensure that approvals were obtained in a structured manner. The approval process was broken down at different levels, such that the approval of certain activities was dependent on the approval of associated activities or the approval of specific questions within the project requirements. At the activity level, an activity could only be approved if its associated activities had already been approved. This ensured that all necessary dependencies were met before granting approval to individual activities. Linking the

approvals of related activities, the model enforced a logical and sequential progression of approvals within the process. Similarly, at the project level, the approval of the overall project requirement was contingent upon the approval of specific questions within the project requirements. If any of the required questions were not approved, the project requirement as a whole would not be approved. This approach maintained consistency and ensured that all necessary criteria were met before approving the entire project requirement. Once all the systems model schemas were set up, the user interface was designed which incorporated the development of the login interface and the associated process to allow a project to be setup.

Platform Workflow

Given that the platform was developed solely as a proof of concept for the purpose of this research, it was decided not to invest resources into implementing an automated setup process. As a result, when running the platform for the first time, a series of manual steps needed to be carried out before its execution. The initial step involved creating a user manually using the command line interface. This process typically requires providing necessary user information such as username, password, and any additional details relevant to the user profile. By manually creating a user, the platform could establish a unique identity within the system. Once the user was created, the subsequent steps involved setting up the organisational structure. This included manually creating an organisation entity within the platform. The creation process entailed defining the organisation's name, contact details, and any other pertinent information required for identification and differentiation. Following the establishment of the organisation, departments needed to be configured within the system. This involved manually creating each department and assigning it to the corresponding organisation. Departments could be designated based on specific functional areas or hierarchical divisions within the organisation. Lastly, the user created in the first step was assigned to the appropriate department. This step ensured that the user's role and responsibilities were aligned with the department's objectives and scope of work. Linking the user to the relevant department meant the platform could effectively manage access rights, permissions, and functional assignments. Although these manual steps were necessary for the initial setup, they were performed to facilitate the functioning of the proof-of-concept platform. This approach allowed the platform to be utilised for research purposes, despite

the absence of an automated setup process. In future iterations or production versions of the platform, it may be advisable to implement an automated setup procedure to streamline the initial configuration and improve user convenience. In order to add additional users to the platform, a user interface was developed enabling ease of access for other users. Following an internal review involving other researchers, the possibility of users switching between organisations and departments, as well as the potential for organisational separation, was taken into consideration. Recognising the need for flexibility and adaptability within the platform, adjustments were made to accommodate these scenarios. To address the requirement for users to switch between organisations and departments or the ability to belong to more than one department, the original models were enhanced. Specifically, the link between organisations was dissociated, enabling users to transition seamlessly between different organisations as needed. This dissociation allowed for greater flexibility and facilitated the movement of users across organisational boundaries within the platform. Furthermore, the platform was designed to account for situations where organisations may separate from the original parent organisation. This consideration acknowledged the dynamic nature of organisational structures, such as mergers, acquisitions, or spin-offs. By allowing for the dissociation between organisations, the platform could accommodate such changes and support the continued functioning of the separated organisations as independent entities within the system.

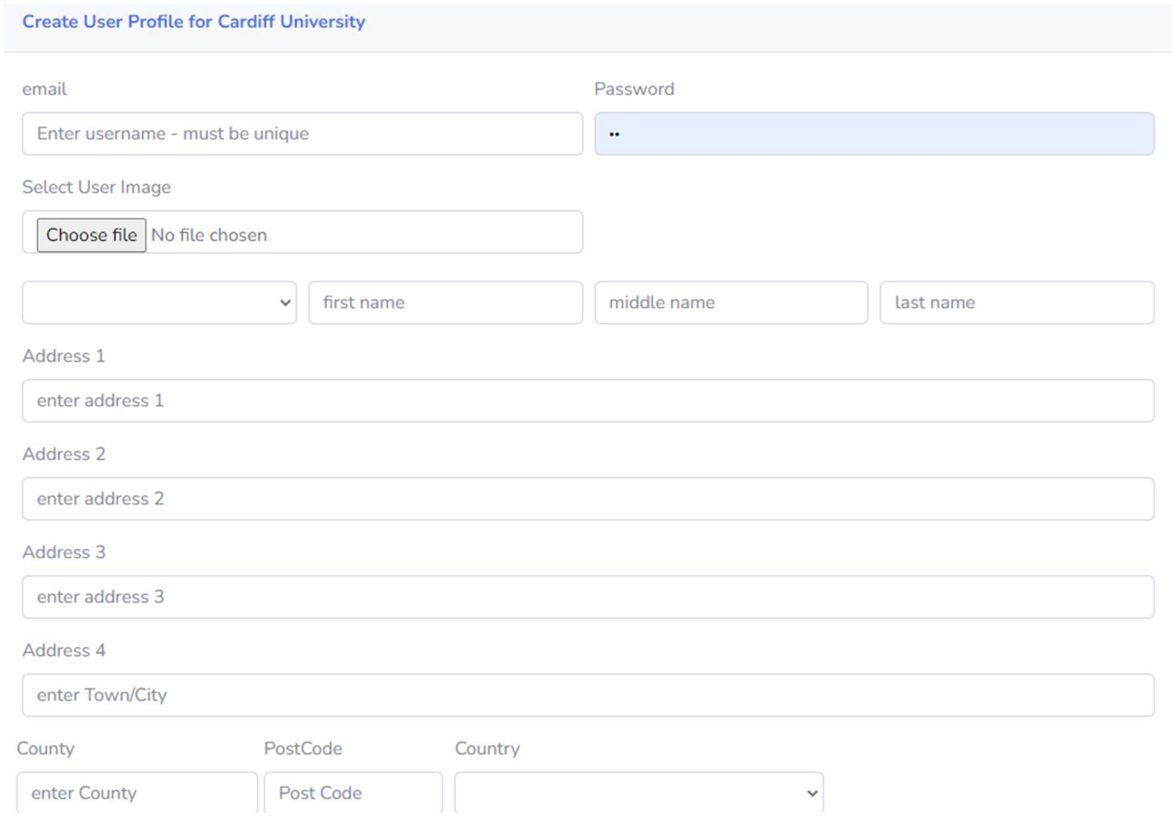


Figure 50: User interface for creating new users

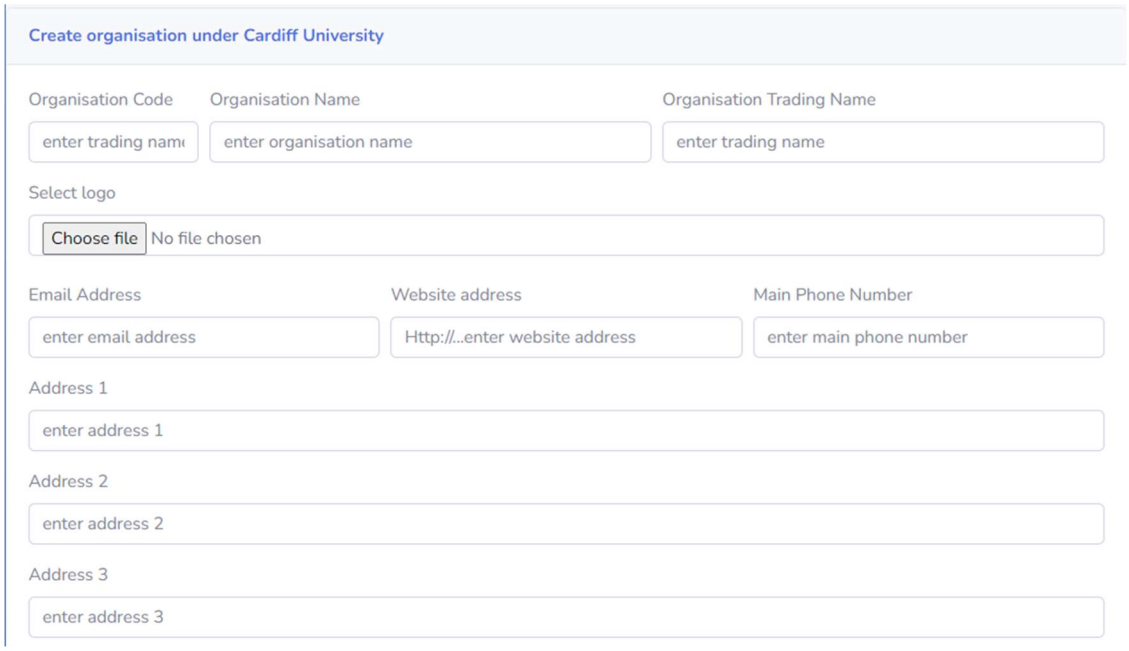


Figure 51: User interface for creating new organisations

Once the actors had been configured within the system, the users are prompted to initiate the setup of an OIR following the established framework as shown in Figure 52 below. This crucial step allows users to define and specify the information requirements necessary for the effective functioning of their organisation. The setup process for the OIR begins by guiding users through a structured framework that ensures comprehensive coverage of information needs. Users are presented with a series of prompts and guidelines that help them articulate their specific requirements based on the organisation's objectives, activities, and industry standards. Users are encouraged to identify the key information elements required for their organisation's operations, decision-making processes, and compliance obligations. This may include project-specific data, technical specifications, regulatory documentation, communication protocols, or any other relevant information deemed essential for organisational success. The framework assists users in mapping the identified information requirements to different stages of the organisation's lifecycle, such as planning, design, construction, operation, and maintenance. It encourages users to consider the various stakeholders involved, their roles, and the specific information needs associated with each stakeholder group. In following the outlined framework, users can ensure that their OIR captures the necessary information requirements in a structured and comprehensive manner. This helps in promoting effective communication, collaboration, and information management within the organisation, facilitating better decision-making processes and overall operational efficiency.

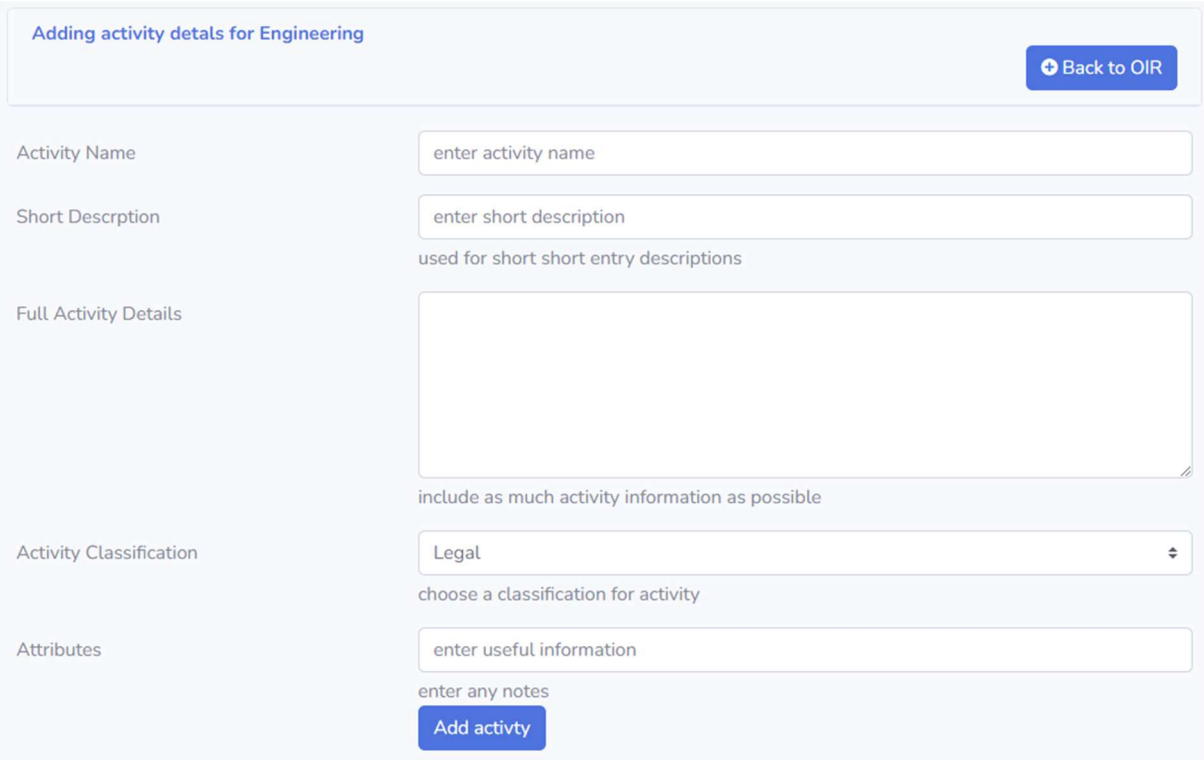


Figure 52: Creation of activity for OIR

Only at this point are they able to start a project. This again follows the requirements within the standard that an organisation should have an OIR available. A project is commenced by selecting the relevant menu within the platform where they are prompted to enter all the required details. At this stage, on completion, the process engine receives input from the platform which then starts the relevant linked processes.

Following the development of the process engine and its associated process maps, a series of user interfaces were created to facilitate the interaction between users and the process engine at each stage of the workflow. These user interfaces were designed to effectively communicate the current state of the process engine and provide access to the required information. Each user interface corresponds to a specific stage in the process workflow and aims to present the relevant information and options to the users. For example, at the initial stage of the workflow, the user interface would display the available options for appointing an information manager, allowing users to decide based on their specific requirements. The

user interface would provide clear indications of the current state of the process engine, such as highlighting the appointed manager or indicating the decision points yet to be addressed. As the workflow progressed, the subsequent user interfaces would dynamically update to reflect the evolving state of the process engine and present the necessary information and actions required at each step. This enabled users to make informed decisions and provide inputs based on the context and requirements of the specific stage.

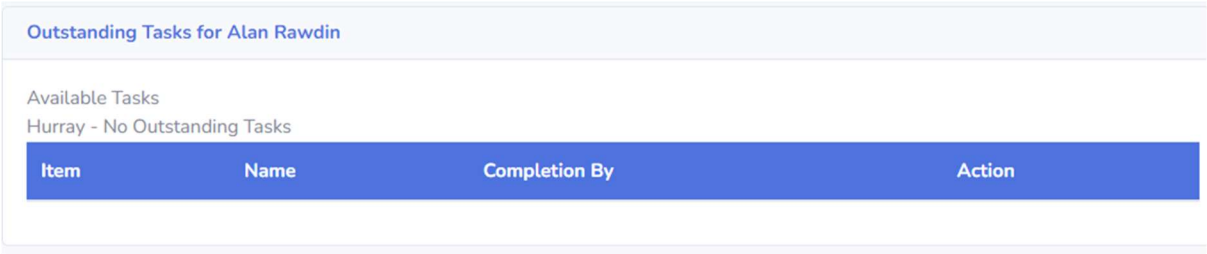


Figure 53: user interface for display of user tasks

The design of each interface within the system was undertaken by the researcher. To ensure the usability and effectiveness of the interfaces, an agile approach was employed, emphasising collaboration and feedback from fellow researchers and the researcher's supervisor. The design process commenced with the researcher taking the lead in designing the initial interface designs based on their expertise and understanding of user requirements. These designs served as prototypes, embodying the intended functionality and visual representation of the interfaces. Subsequently, active efforts were made by the researcher to seek input and validation from the local authorities and contractors outlined above. Through collaborative discussions, the interface designs were shared, allowing for valuable insights and perspectives from different stakeholders. This iterative process of sharing and gathering feedback enabled refinements and improvements to be made to the initial designs. This includes changing the menu items to allow for the separation of external, internal and user-based tasks as shown in Figure 54.

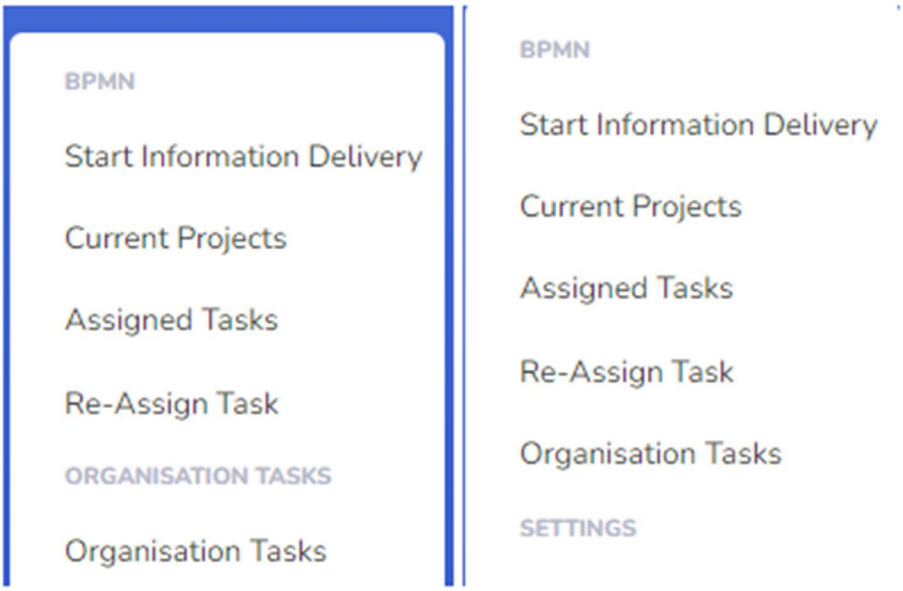


Figure 54: Examples of changes through agile approach and engagement with stakeholders

However, not all aspects could be included due to time constraints. This included as an example stakeholders asking for a live view from the process engine to be included in the platform, allowing for translations into the Welsh language and detailed descriptions from the standard for the relevant section. Through this agile approach of collaboration and validation, the researcher aimed to incorporate diverse viewpoints, expertise, and user-centred considerations into the interface design process. The iterative nature of the agile methodology allowed for swift adjustments, iterations, and enhancements based on the feedback received.

Microservice Design Overview

This section explains the development of the microservices architecture along with brief details about each of the technologies which have been implemented above. Microservices architecture, the underlying platform development approach, partitions an application into discrete, loosely coupled services that can operate independently. Each service can be developed, deployed, and scaled autonomously, granting the platform greater flexibility and agility. By embracing this microservice architecture, the platform capitalises on the unique

capabilities offered by each service, thereby augmenting the overall performance and adaptability of the system. Docker, the specific microservice framework selected, played a pivotal role in facilitating the integration of the various services. It enables the creation, deployment, and management of lightweight, self-contained containers that encapsulate each service. These containers operate in isolation, ensuring that any changes or updates to one service do not impact the functioning of others. This isolation mechanism allows for seamless integration and coordination of the services, contributing to the overall robustness and reliability of the platform. The overall architecture developed is shown below in Figure 55 below

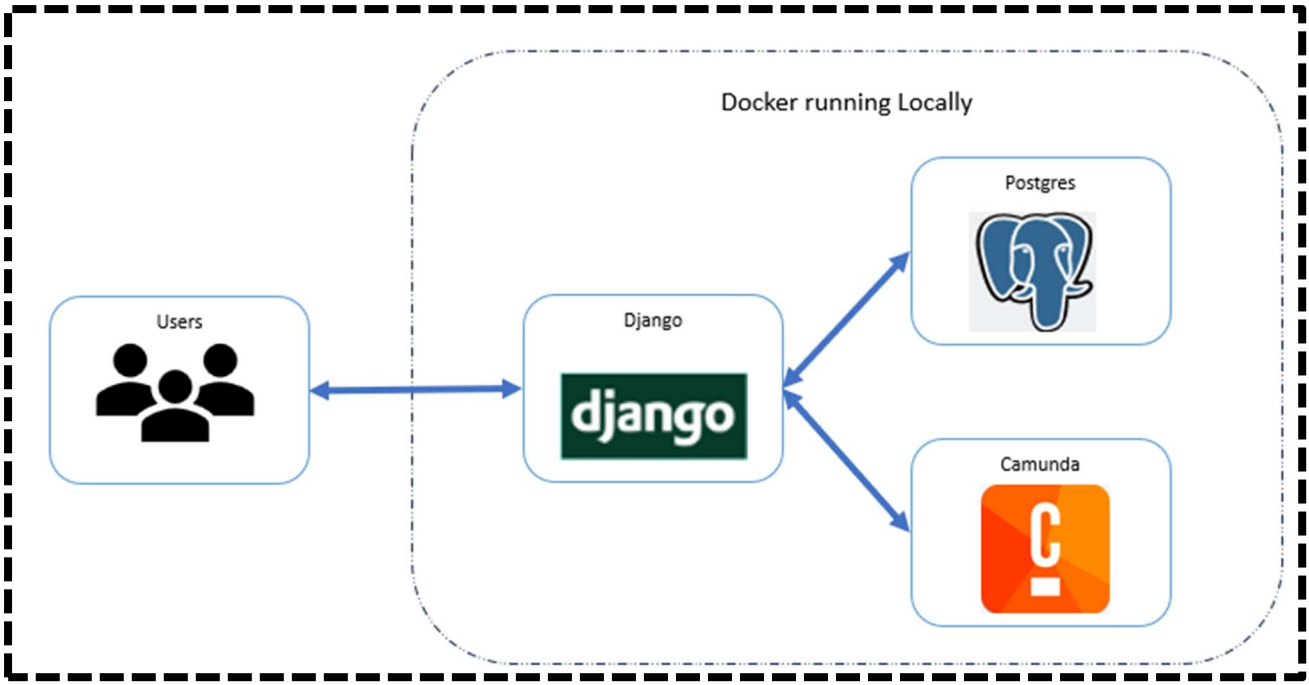


Figure 55: Overall architecture of containerisation

In a microservice environment, before a service can be executed, it must undergo the process of development and building. Once this process is completed, the service becomes available to be invoked within a compose script. For example, when building the Django script for the platform, all the necessary dependencies required by the platform are containerised. Containerising the dependencies involves packaging them within a Docker container, which encapsulates the service and its dependencies into a self-contained unit. This containerisation process ensures that all the necessary components and dependencies are included, enabling

the service to run consistently and reliably across different environments. One significant advantage of using Docker is the availability of pre-packaged systems developed by vendors. These pre-packaged systems, often referred to as Docker images or containers, contain all the required components and configurations to run a specific service or application. These vendor-provided containers can be readily called upon in a Docker compose script, simplifying the deployment and integration of external systems into the platform.

```yaml
version: '3.7'

services:
  autobim:
    build: ./app
    command: python manage.py runserver 0.0.0.0:8000
    volumes:
      - ./app/:/usr/src/app/
    ports:
      - 8000:8000
    env_file:
      - autobim.dev.env
    depends_on:
      - db
      - camunda

  db:
    image: postgres:10
    env_file:
      - db.dev.env
    volumes:
      - postgres_data:/var/lib/postgresql/data
    ports:
      - "5432:5432"

  camunda:
    build: ./camunda
    ports:
      - 8080:8080
    env_file:
      - camunda.dev.env
    depends_on:
      - db
    restart: always

volumes:
  postgres_data:
```

Figure 56: Docker compose script used in the AUTOBIM platform

Django is a powerful high-level Python web framework and served as the foundation for constructing the web-based user interface of the platform. One key feature offered by Django is URL routing. This feature enabled the platform to map URLs to specific views or functions, allowing for effective navigation and handling of user requests. Defining the URL patterns meant the researcher could easily direct users to the appropriate pages or resources within the platform, ensuring smooth and intuitive user interactions. Another significant capability provided by Django is template rendering. Django's built-in template engine allowed for the separation of presentation logic from business logic. This enable the creation of dynamic and visually appealing web pages which leveraged Django's template language, enabling the insertion of dynamic content and the reuse of common design elements. This separation of concerns further streamlined the development process, enhanced code maintainability. Django's request handling mechanism was also instrumental in simplifying the development process. With its powerful request/response framework, Django efficiently processed and handled user requests. The researcher could easily define the logic for handling incoming requests, access and manipulate data, and generate appropriate responses. This streamlined approach reduced the complexity of healing the user requests. An example of this was the development of user pages which had multiple requests available to it. Routing the request to the correct view in the correct context streamlined the development.

```
from django.conf import settings
from django.conf.urls.static import static

from django.contrib import admin
from django.urls import path, include

urlpatterns = [
                path('', include('welcome.urls')),
                path('administration/', include('administration.urls')),
                path('projects/', include('projects.urls')),
                path('processmanagement/', include('processmanagement.urls')),

            ] + static(settings.MEDIA_URL, document_root=settings.MEDIA_ROOT)
```

Figure 57: Example of high-level routing in the platform

```
urlpatterns = [

                path('processmanagement', views.start_information_delivery, name='start_info_del'),
                path('processmanagement/projects/current', views.list_current_projects, name='list_current_projects'),
                path('processmanagement/projects/gettask/<uuid:pk>', views.list_current_task,
                     name='list_current_task'),
                path('processmanagement/projects/assigntask/<uuid:pk>', views.assign_task, name='assign_task'),
                path('processmanagement/users/tasklist', views.task_list_user, name='list_user_task'),
                path('processmanagement/users/task/start/<uuid:pk>', views.task_start_user, name='task_start_user'),

                # path related to organisation based activities / tasks
                path('processmanagement/organisation/task/organisation',
                     views.task_organisation_list, name='task_organisation_list'),
                path('processmanagement/organisation/task/organisation/<uuid:pk>',
                     views.task_organisation_view_detail, name='task_organisation_view_detail'),
```

Figure 58: Example of a granular view

Postgres, a powerful open-source relational database management system, was selected as the database backend for the AutoBIM platform. It offered excellent data storage and retrieval capabilities, ensuring the integrity and reliability of the system's data. Postgres supported advanced features like data indexing, transaction management, and concurrency control, which were essential for handling the complex information management requirements of the platform.

Camunda, an open-source workflow and business process management (BPM) platform, played a crucial role in orchestrating the information management processes within the platform. It provided a flexible and scalable environment for modelling, executing, and monitoring business processes. Camunda allowed the platform to define the sequence of activities, decision points, and information flows in a graphical notation (such as BPMN) and automate their execution. This streamlined the information management workflows, reduced manual effort, and ensured consistent compliance with the defined standards.

The microservice architecture facilitated the seamless integration of these services within the platform. Each service could be developed, deployed, and managed independently, allowing for modular development and easier maintenance. Additionally, the scalability and fault-

tolerance offered by the microservice architecture ensured that the platform could handle increasing user demands and provide a reliable experience even during peak usage periods.

The adoption of a microservice architecture, with Django, Postgres, and Camunda as connected services, provided numerous benefits to the design and functionality of the platform. It enabled the platform to leverage the strengths of each service, enhance performance, scalability, and flexibility, and effectively support the information management processes within the construction industry.

Summary

Chapter 5 of the thesis focused on the implementation of the proposed framework for quality assurance in Building Information Modelling. The chapter began with an overview of the assessment and validation process, highlighting the need for a systematic approach to ensure the quality of BIM processes and deliverables.

The chapter then delved into the development of BPMN process maps for ISO 19650, a standard that outlines requirements for the management of information throughout the life cycle of a construction project. The researcher explains how the BPMN process maps were designed to capture the various activities and information requirements specified by ISO 19650. The chapter also discusses the development of an approval model within the framework. This model allows for the approval or rejection of specific items, ensuring that associated activities and project requirements are met before granting approval. The author emphasised the importance of this model in maintaining compliance with standards and ensuring the overall quality of the BIM processes. This chapter also highlighted the use of an agile approach in the development and validation of the framework. The researcher described how interface designs were shared with industry and local authorities involved in earlier project research for feedback and validation. This iterative process allowed for continuous improvements and adjustments based on the input received. The implementation of the microservice architecture using Docker is another significant aspect discussed in this chapter. The author explains the benefits of adopting a microservices approach, such as flexibility, scalability, and the ability to leverage the strengths of each service. Docker was selected as

the microservice architecture, facilitating the integration and deployment of Django, Postgres, and Camunda services. Overall, Chapter 5 provided a comprehensive account of the implementation of the quality assurance framework for BIM. It covered various aspects, including the development of BPMN process maps, the approval model, the agile approach to interface design, and the utilisation of Docker for the microservice architecture. The chapter highlights the researcher's efforts in ensuring the quality and compliance of BIM processes while incorporating flexibility and efficiency into the framework's implementation.

Chapter 6 – Compliance document generation and checking

In the construction industry, the generation of compliant documentation that aligns with the ISO19650-2:2018 standard poses significant challenges. As highlighted in Chapter 2 and 4, the accurate production of documentation and ensuring its adherence to industry standards remains a critical concern. This chapter delves into the process of generating compliant documentation and explores the subsequent checking of these documents using natural language processing (NLP) techniques. Leveraging NLP, the aim is to address the difficulties associated with documentation generation, comprehension, and verification, ultimately improving implementation efficiency and quality assurance. The chapter focuses on two interrelated aspects:

1) The generation of compliant documentation and the subsequent checking process. Firstly, the researcher acknowledges the challenges faced in determining the specific documentation requirements for each process outlined in the ISO19650-2:2018 standard. Understanding the information needs and responsibilities of different stakeholders is vital to developing a comprehensive documentation framework. By mapping the documentation requirements to the appropriate processes, the researcher seeks to provide clarity and guidance in generating accurate and standardised documentation whilst also recognising that the framework is high-level and will require further enhancement.
2) The importance of checking the produced documentation for compliance. The traditional manual checking process can be time-consuming and prone to errors. Therefore, the application of NLP techniques offers an innovative solution to automate the verification process. Utilising NLP algorithms and methodologies, the researcher aims to enhance the efficiency, accuracy, and consistency of document checking, thereby ensuring the documentation aligns with the ISO19650-2:2018 standard. The integration of NLP in the checking process not only saves time but also contributes to overall quality assurance. The ability to align the documented processes with the actual implementation reduces the risk of errors, non-compliance, and rework.

Consequently, this chapter emphasises the importance of leveraging NLP techniques to streamline the documentation generation and checking processes, promoting improved implementation efficiency and enhanced quality assurance.

Document Generation

This section presents the development of a comprehensive documentation framework designed to facilitate the creation of documents in compliance with the ISO 19650 standard. Drawing upon the knowledge acquired in the previous chapter, the researcher conducts an in-depth analysis of the standard's information requirements and identifies the parties responsible for generating the respective documents. Undertaking a close examination of the ISO 19650 standard, the researcher gains valuable insights into the specific information that must be incorporated into the documents in a structured format. This meticulous analysis serves as the groundwork for establishing a robust framework that ensures strict adherence to the standard's guidelines. Within this well-defined framework, the researcher assigns distinct roles and responsibilities to the relevant project stakeholders. A clear delineation of the responsibilities associated with document creation has enabled the researcher to ensure a smooth and coordinated process. This approach guarantees that each party comprehends their specific obligations and can contribute effectively to the generation of documents that align with the ISO 19650 standard. The primary objective of developing this documentation framework is to enhance overall compliance and elevate the quality of the generated documents. By adopting a systematic approach to document creation, the framework guarantees that all necessary information is captured and that the documents meticulously adhere to the specifications outlined in the ISO 19650 standard. Consequently, this systematic approach fosters effective communication, seamless collaboration, and streamlined information management across the project.

Framework generation

The development of the framework for compliant document generation in this chapter builds upon the previous chapter's work, which focused on developing the processes at a granular level. The following key steps were undertaken to establish the framework:

1) A model was developed to compile a comprehensive list of the required documents. This model serves as a reference for identifying the specific documents that need to be generated throughout the project lifecycle.

2) The process maps, created in the previous chapter, were linked to the document model. This linkage ensures that each process is associated with the relevant documents, enabling efficient documentation generation.

3) Document section models were developed to provide a structured framework for organising the content within each document. These models define the sections that should be included in the documents, ensuring consistency and completeness.

4) Content section models were developed to align with the previously defined section models. These models guide the inclusion of specific content within each section, ensuring that the necessary information is captured accurately.

5) A model was developed to align the plan of works with information delivery. This model ensures that the documents generated align with the project's defined plan of works, facilitating smooth information exchange and compliance.

6) Models were developed to align classifications such as Uniclass or Omniclass. These models enable the inclusion of standardised classification systems within the generated documents, promoting consistency and interoperability.

7) Models containing dictionaries of content information were developed. These dictionaries provide a repository of predefined content elements that can be utilised during document generation, ensuring consistency and accuracy.

8) The user interface was developed, building upon the work carried out in Chapter 5. The interface facilitates the user's interaction with the framework, allowing for intuitive and efficient document generation.

9) Project naming standards were established to ensure compliance. These standards define the naming conventions for documents, ensuring clarity, consistency, and ease of identification.

10) A common data environment (CDE) model was developed to hold the compliant information in document format. The CDE serves as a centralised repository for storing and managing the generated containers, ensuring accessibility, version control, and compliance throughout the project.

In addition to these elements and to streamline the project setup, data dictionaries were also developed where possible which further enhanced the user experience to ensure project standards and compliance were maintained.

High-Level Framework

The development of a high-level framework was developed which encompassed all of these attributes which were encapsulated at different levels as shown in Figure 59.

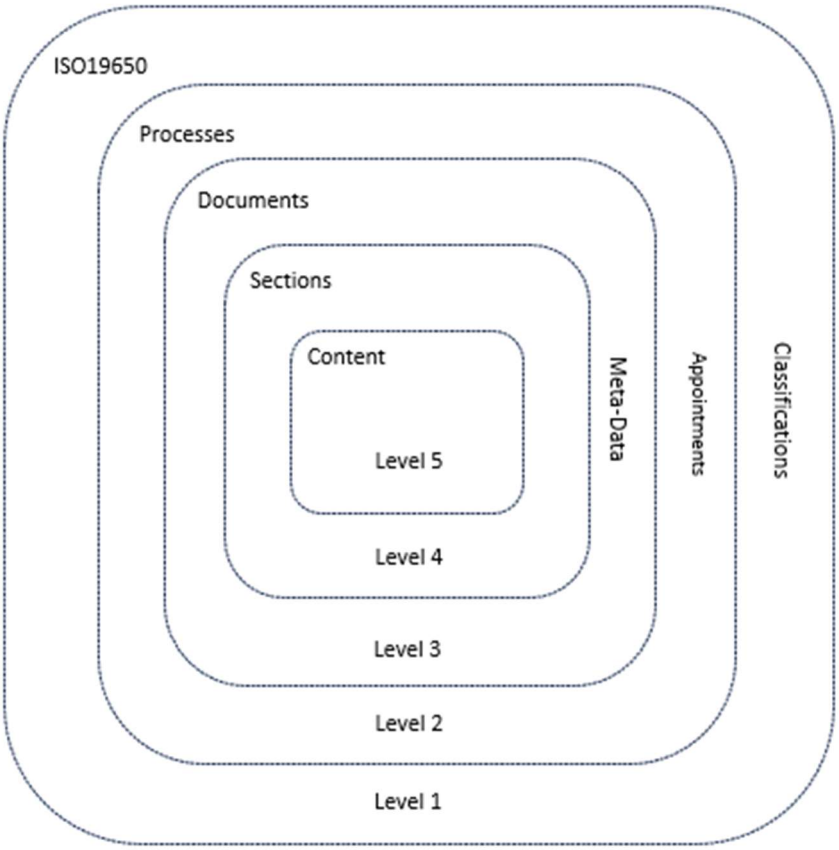


Figure 59: Document generation framework levels

This multi-dimensional framework encompasses all the requirements of the ISO 19650 standard at five different levels of maturity. Starting from the centre of the framework, Level 5 represents the highest level of compliance, requiring the fulfilment of specific attributes to successfully implement ISO 19650. These attributes serve as essential criteria for achieving Level 5 compliance and ensuring effective adherence to the standard.

At Level 5, the following attributes must be satisfied:

1) Alignment of All Content: All content within the documents must be aligned to the outer attributes defined in the ISO 19650 standard. This alignment ensures that content elements are properly linked to the relevant sections, documents, and processes specified in the standard.
2) Consistency with Classification Systems: Each content element must adhere to appropriate classification systems, such as Uniclass or Omniclass. This ensures consistent categorisation and labelling of information, promoting interoperability and standardisation across projects. As an example, the EIR has a specific classification code in Uniclass as PM_10_20_28.
3) Integration of Information Delivery Plans: Every content element should have an assigned information delivery plan. This plan outlines when and how the content is delivered and exchanged, ensuring the timely flow of information throughout the project lifecycle.
4) Inclusion of Required Meta-data: All content elements must include essential meta-data, such as authorship, creation dates, versions, and other relevant attributes. This meta-data enhances document management, version control, and tracking of changes, facilitating accurate and reliable information management.

The fulfilment of these attributes at Level 5 enables organisations to demonstrate a high level of maturity in implementing ISO 19650-2. This level of compliance ensures comprehensive alignment of content, utilisation of standardised classification systems, integration of information delivery plans, and inclusion of essential meta-data. Ultimately, it enables effective information management and facilitates seamless collaboration and interoperability

in construction projects. This has been achieved through the use of mapping applicable attributes of ISO16739 with the Models. As an example, the actor model is aligned with ifcActor, Classification is aligned with ifcClassification and the process is aligned with the ifcProcess class.

Model Development

To develop the required models for the multi-dimensional framework, the Django framework was employed once again. Leveraging the power of Django, the researcher could focus on designing and implementing the specific models required by the multi-dimensional framework, ensuring that they accurately capture the information and relationships outlined in the ISO 19650 standard. The flexibility and scalability of Django gave the ability to not only adapt but also refine the models as necessary, aligning them with the evolving needs and requirements of the framework. As defined above the development of the models required an iterative approach. The models outlined in the previous chapter were adapted to include new attributes such as classification, meta-data and naming standards along with improvements in the user interface. The overall architecture of the platform was also adapted to include automatic setup and loading of attributes including data dictionaries of classification structures, pre-defined plan of works such as RIBA and the pre-loading of all processes identified previously and their sub-clauses, decisions, and responsible parties.

The development of the required models for the multi-dimensional framework followed an iterative approach. Building upon the models outlined in the previous chapter, enhancements and adaptations were made to incorporate new attributes, such as classification, meta-data, and naming standards. These additions aimed to align the models with the comprehensive requirements of the ISO 19650 standard. The user interface of the platform was also improved, considering the feedback and insights gained from the previous chapter's development process. The user interface enhancements aimed to provide a more intuitive and user-friendly experience, facilitating seamless interaction with the platform's functionalities. In addition to refining the models and user interface, the overall architecture of the platform was adapted to introduce automation. This included the automatic setup and loading of various attributes, such as data dictionaries of classification structures, pre-defined

plan of works (e.g., RIBA), and the pre-loading of all previously identified processes, along with their sub-clauses, decisions, and responsible parties. This automation aimed to streamline the initial setup process and ensure the availability of comprehensive and relevant data within the platform.

Platform Setup

In the continued development of the platform, the existing microservice architecture, consisting of Docker, Django, Postgres, and Camunda, serves as the foundation for further enhancements. However, a notable addition to this architecture is the integration of the Redis server, which brings valuable capabilities to the platform. Redis, an in-memory data store, acts as a key-value cache, providing fast and efficient storage and retrieval of data. The incorporation of Redis into the microservice architecture further extends the platform's capabilities and enhances its performance. One of the key advantages of using Redis within the platform is its ability to facilitate the setup process. With the Redis server in place, the platform gains the capability to automatically import the required data dictionaries. These data dictionaries play a crucial role in defining and structuring important information, such as classification structures, pre-defined plan of works, and other relevant datasets as shown in Figure 60 and Figure 61 below.

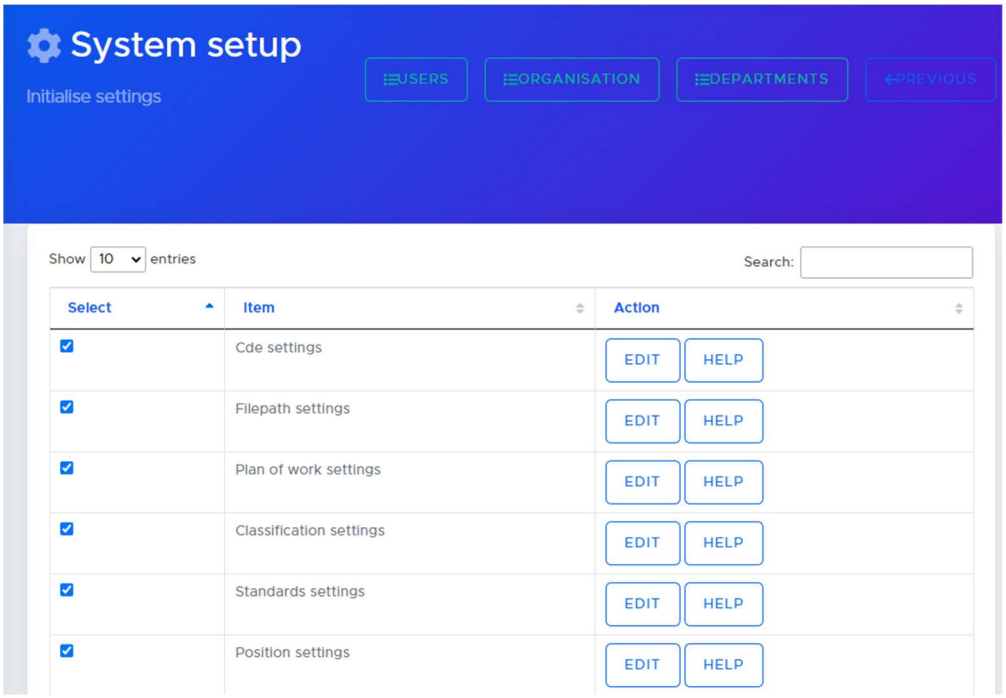


Figure 60: Automatic import of data dictionaries

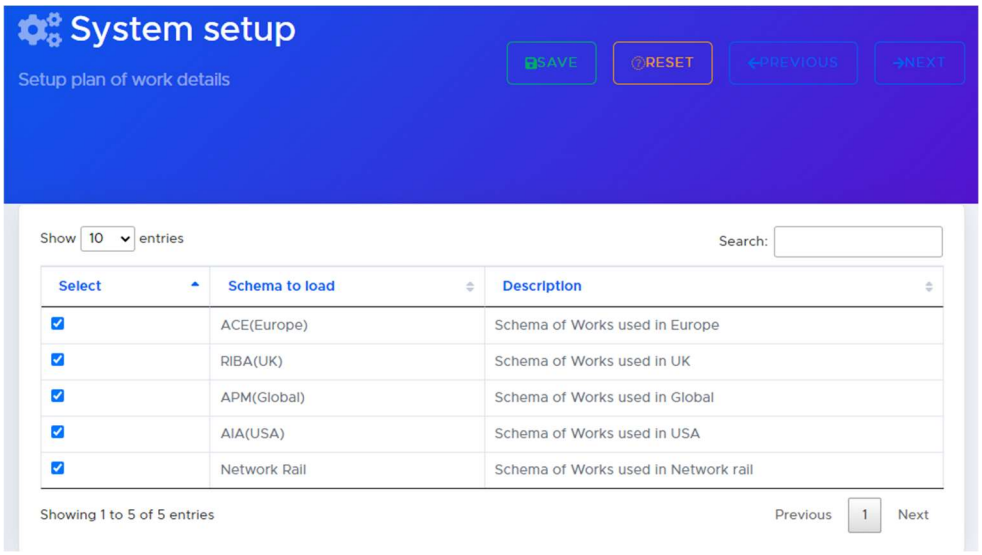


Figure 61: Plan of work setup

The automatic importation of these data dictionaries saves time and effort, eliminating the need for manual data loading and further reducing the chances of errors or inconsistencies. Furthermore, Redis offers features that enhance the scalability and reliability of the platform. With its ability to handle large volumes of data and support high read and write speeds, Redis

ensures that the platform can accommodate growing demands and maintain optimal performance. Additionally, Redis provides data persistence, ensuring that the imported data dictionaries are retained even in the event of system restarts or failures, thereby preserving the platform's stability and continuity. The additional component is described in Figure 62.

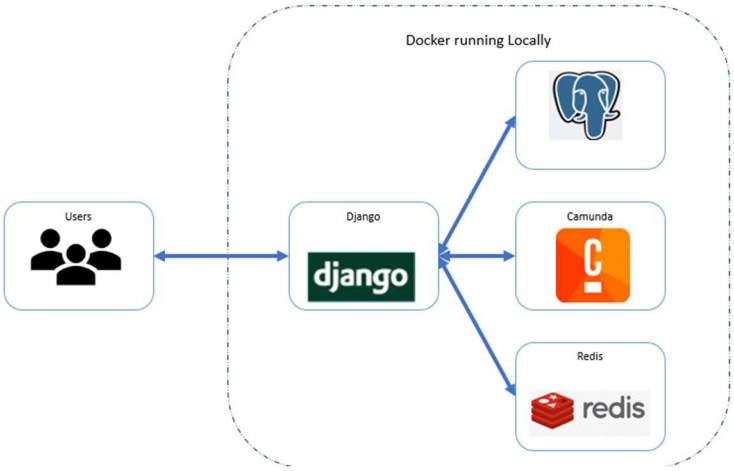


Figure 62: Document generation microservices

Platform setup models

To ensure the platform's compliance with international standards and user understanding, it was necessary to implement a suitable format for importing data dictionaries shown in Figure 63 below. Although many important data dictionaries were researched and formatted, only a few of the important ones are discussed further for brevity. The focus initially centred on the classification settings, which required the establishment of hierarchical structures within the models. The first step involved creating a classification group, which serves as the top-level entity for different classification structures. This group provides the flexibility to accommodate diverse classification systems as per industry requirements. Building upon this, the subsequent levels were defined as group, version, and reference, respectively. These levels were interconnected through primary keys, establishing a hierarchical relationship that ensures proper organisation and linkage of the classification data. Structuring the models in this hierarchical manner meant the platform could effectively capture and represent the intricate relationships within the classification settings. It enables users to navigate through

different levels, access relevant information, and understand the classification structures employed within the platform.

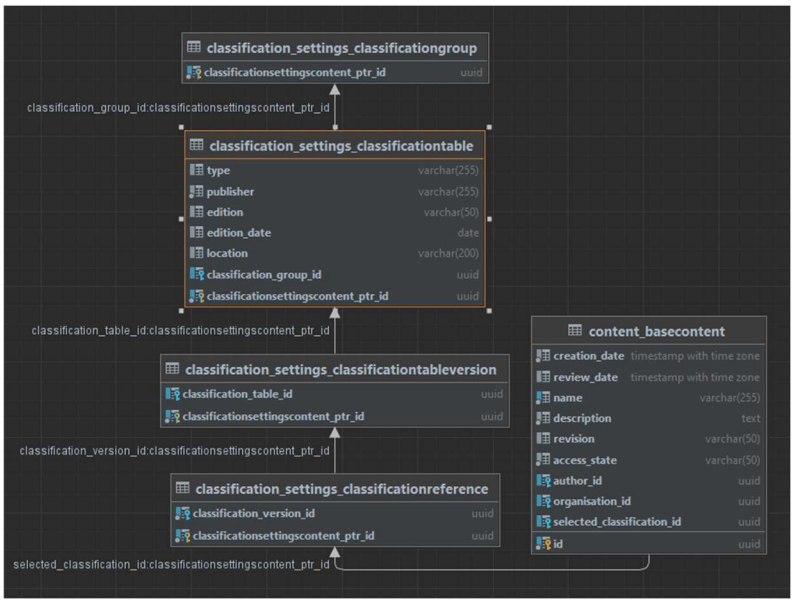


Figure 63: Classification data dictionary

In addition to the models discussed previously, Figure 63 also illustrates another essential model called "content_basecontent." This model plays a crucial role in maintaining a consistent structure across all models within the platform. By having all other models inherit from this base content model, it enables further flexibility and standardisation throughout the system. The "content_basecontent" model serves as a foundational structure that ensures uniformity in terms of attributes and relationships across different content-related models. It establishes a standardised template that includes key fields necessary for effective content management and control. Within the "content_basecontent" model, various attributes are defined to enhance the comprehensiveness and organisation of content. These attributes include classification references, author information, approval status, modification details, revision dates, and a relationship with the primary organisation. The inclusion of classification references allows for the association of content with specific classification systems, facilitating proper categorisation and retrieval. The author information field captures details about the content's creator or contributor, enabling traceability and

accountability. The approval status attribute indicates the current stage of approval for the content, providing transparency in the review process. The modification details field records pertinent information about any changes made to the content, aiding in version control and revision history. Lastly, the relationship with the primary organisation establishes a connection between the content and the relevant organisation, facilitating effective organisation and management of information. The standardising of the structure and attributes through the "content_basecontent" model enables the platform to ensure consistency and coherence across all content-related models. This approach enables efficient data management, improves searchability and retrieval, and allows for seamless integration and interoperability of different content elements within the platform. The utilisation of a base content model also provides a solid foundation for content-related operations and supports the platform's overarching goal of achieving compliance, flexibility, and scalability. It streamlines the development process, simplifies data maintenance, and ensures that all content models adhere to a standardised structure, enhancing overall system integrity and performance.

To establish standards for the CDE and naming conventions within the project, the platform implemented a data dictionary setup. This setup encompassed two key aspects:

1) A default schema import and the flexibility for complex naming systems. During the platform setup, a default schema was imported to provide users with a straightforward and readily available naming convention. This default schema served as a foundation and allowed for immediate usage without additional configuration. It ensured that basic naming requirements aligned with industry standards and compliance with the ISO 19650 standard. However, recognising the need for flexibility and customisation, the platform also provided the capability for users to set up complex naming systems. This feature empowered users to tailor the naming conventions according to the unique requirements of their projects. By allowing customisation, the platform ensured that the models and their associated data could conform to specific project needs, further enhancing compliance with the ISO 19650 standard.

2) The data dictionary setup included the ability to link these naming conventions to a project model. This linkage ensured that all relevant naming conventions and standards were automatically applied within the context of the specific project. By associating the naming conventions with the project model, the platform promoted consistency and compliance throughout the project's lifecycle. This comprehensive approach to data dictionary setup, encompassing default schema import, flexibility for complex naming systems, and project-specific linkage, allowed the platform to address the diverse requirements and standards related to CDEs and naming conventions. It provided users with the tools and flexibility needed to align their projects with industry best practices and regulatory guidelines, ultimately enhancing data management and compliance within the platform.

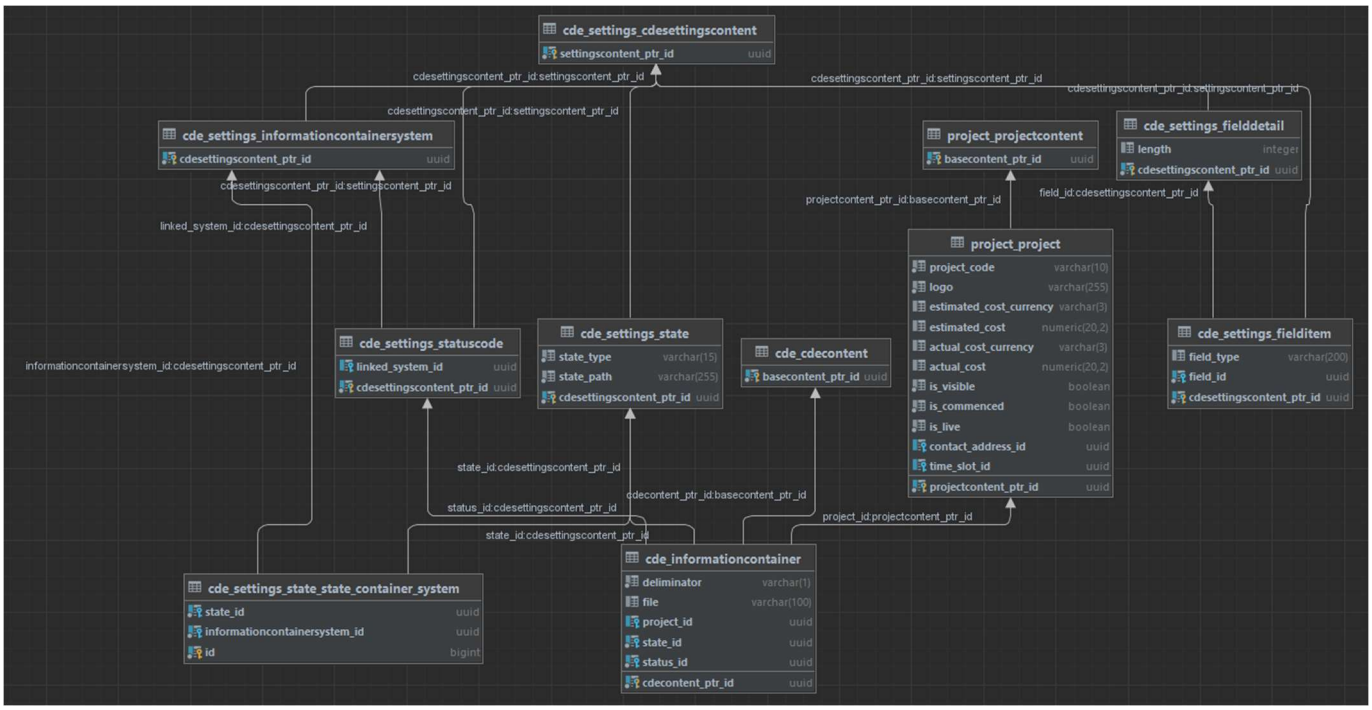


Figure 64: CDE and naming conventions models relationships.

The development of models for process, subprocess, and documentation linking was a significant step towards ensuring project compliance with the framework. A key requirement of the framework was that each project should have documents with well-defined sections

and content, accompanied by appropriate metadata, classifications, and workplan attributes. To achieve this, the platform introduced the document data dictionary model. The document data dictionary model played a crucial role in defining the structure and attributes of the documents created within the platform. It provided a standardised template for documenting project information, ensuring consistency and compliance with the framework's requirements. The model encompassed essential elements such as sections, content, metadata, classifications, and work plan attributes, enabling users to capture and organise project-related information effectively like the other models they all inherited from the base content model which ensured that classifications and other important attributes were controlled at both a high and granular level. Considering the process models first, additional attributes were encompassed for this section of the platform which included both predecessor and successor elements along with a description of the applicable section from the original standard. These elements are shown in Figure 65 below

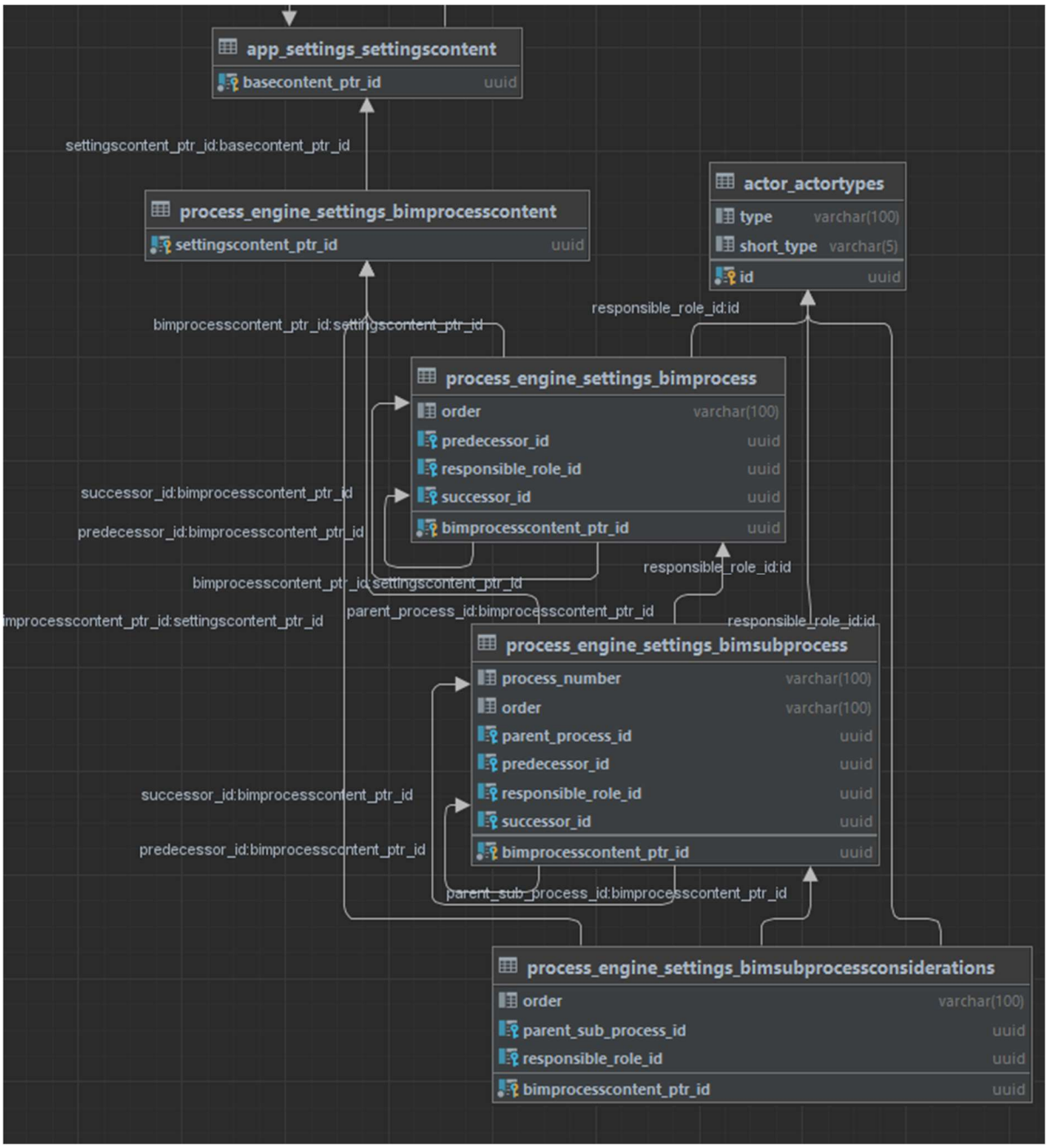


Figure 65: Process, sub-process and considerations; relationships with actors

When designing a document structure, several attributes are typically included to provide essential information about the document itself. These attributes often encompass details such as the author, creation date, and classification. These elements serve to identify the document's origin, provide contextual information, and ensure proper categorisation within the framework. Within the document structure, sections are created to organise and present specific content. Traditionally, sections do not allow for classification. However, incorporating

attributes in a similar format as at the document level fulfils the requirements of the framework while also enabling categorisation based on authorship, similar to the document level. This approach ensures consistency and adherence to the framework's guidelines while offering additional categorisation possibilities within the sections. Expanding further, extending the attributes to the content section level follows the framework's requirements and enables an additional level of granularity for data management. The inclusion of the same attributes within the content section enables the framework to allow for the linking of sections to other sections. This enables the reuse of content across multiple documents, streamlining the writing process and facilitating updates to the content section across various documents. This approach enhances efficiency and consistency in data management within the framework. Additionally, enabling the creation of a data dictionary with pre-defined content at all levels greatly aids users in generating the required documents. The data dictionary serves as a reference guide, providing standardised and predefined content elements for each level of the document structure. This assists users in ensuring compliance with the framework's requirements, reduces errors, and promotes consistency across documents. Overall, these design considerations for document structure, section attributes, content section attributes, and the inclusion of a data dictionary help align the documentation process with the framework's guidelines. They facilitate efficient data management, content reuse, and consistency while providing the necessary flexibility and structure required by the framework.

The document framework developed for compliance with the ISO 19650 standard incorporates various relationships and dependencies which are outlined in it. These relationships encompass the connections between the CDE, Plan of Work (PoW), actors, processes, and their associated sub-processes and interdependencies. The framework captures the intricate and complex nature of these relationships, offering a comprehensive representation of the project's documentation structure. This level of detail and complexity in representing relationships within the framework is a novel contribution not previously highlighted in existing literature. The framework provides a holistic view of the interconnected components within the document management process, enhancing

understanding and facilitating efficient documentation practices in compliance with ISO 19650.

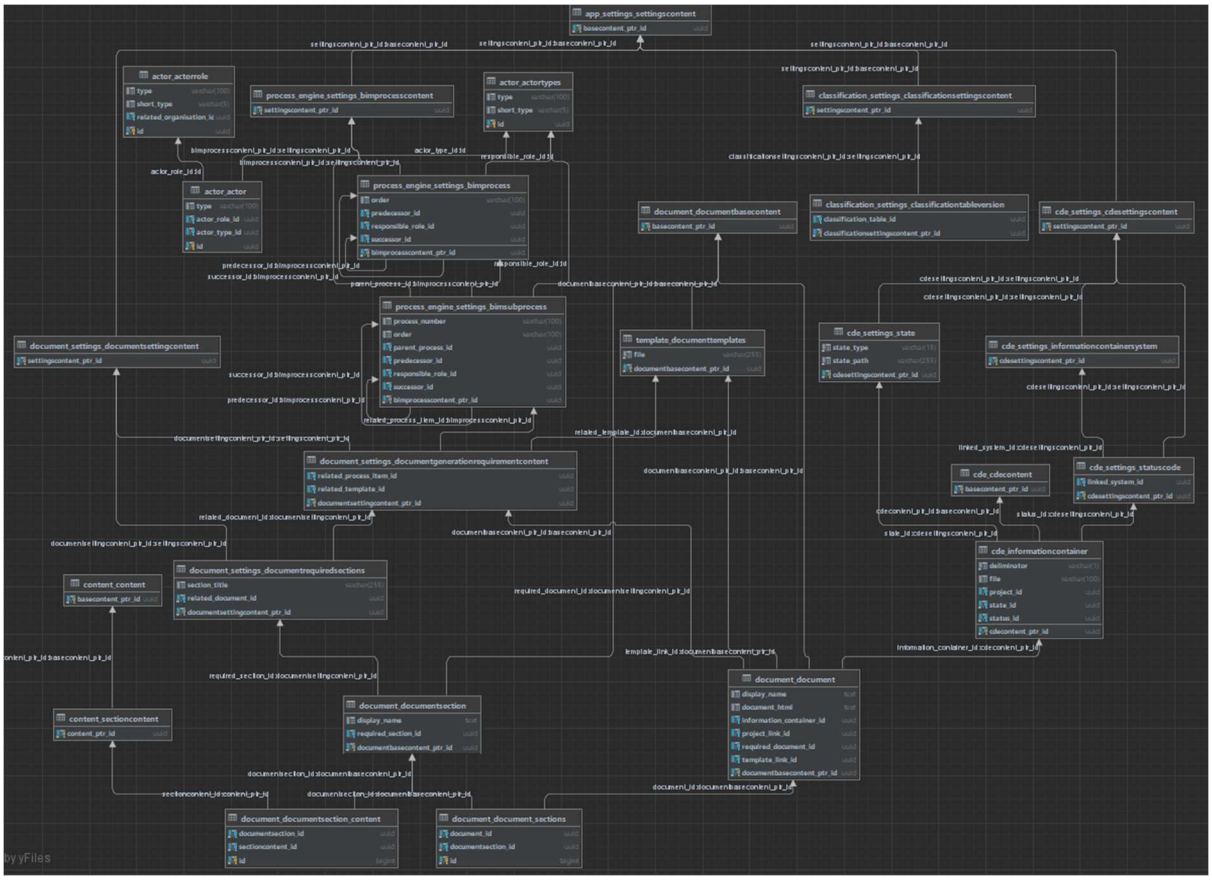


Figure 66: Holistic view of the relationships and interdependencies of ISO 19650.

The creation of the plan of work data dictionary model was a fundamental step in the framework development process. The model represented an overarching plan of work at a high level, establishing a connection between the project model and a specific plan of work schema. Defining the plan of work in a structured manner, the model facilitated the organisation and management of project activities and tasks according to the ISO 19650 standard whilst providing a standardised framework for aligning project goals, timelines, deliverables, and responsibilities, ensuring consistency and clarity throughout the project lifecycle. The plan of work data dictionary model can serve as a valuable reference for a project, enabling the efficient planning and execution of tasks while adhering to the

prescribed plan of work guidelines. Furthermore, the framework encompassed the ability to update the plan of work, ensuring that project decisions were aligned with the information exchange dates specified within the documentation. For instance, when creating the project information requirements, it was necessary to identify and update the information delivery dates accordingly. This meant that elements such as information requirements, which required decision-making, not only needed to be incorporated within a document but also had to update the information delivery plan. This dynamic integration between the documentation and the plan of work allowed for seamless coordination and synchronisation of project activities, ensuring that information exchange and delivery occurred as per the specified timeline and requirements. The models created for allowing this is shown in Figure 67.

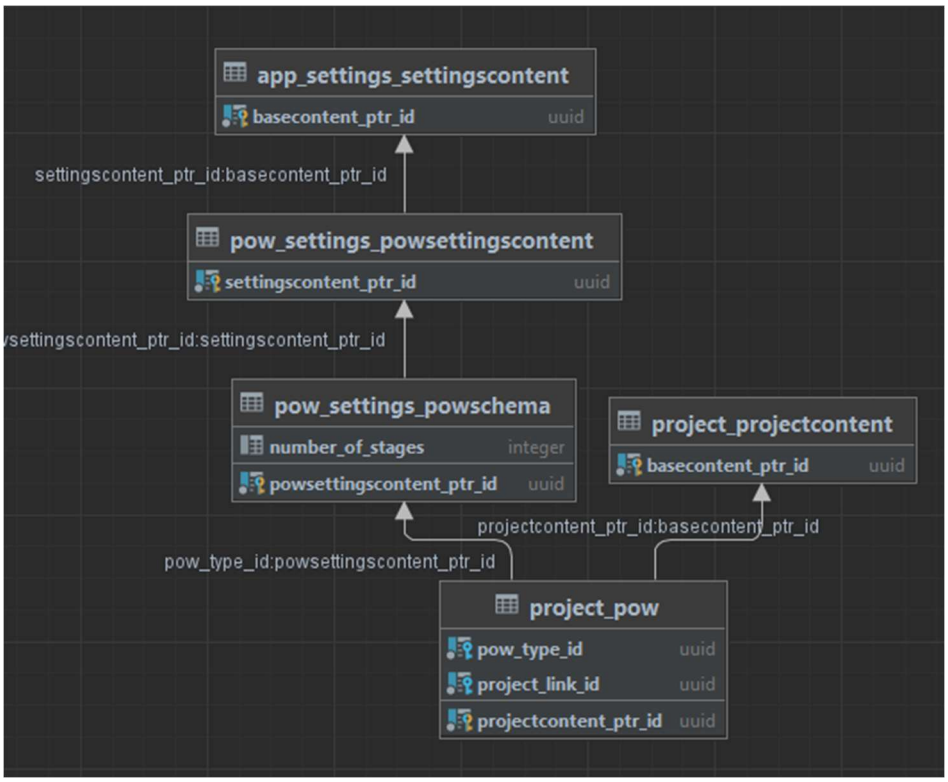


Figure 67: Relationships within a plan of work

The project model serves as the central entity within the framework, connecting and influencing all other models and allowing other models to influence it. It acts as a hub that

captures essential project-related information and provides the foundation for effective information management and compliance. Within the framework, the project model establishes relationships with various other models, forming a network of interconnected entities. For instance, the project model directly links to the document model, reflecting the project's requirement for compliant documentation. This connection ensures that all project-related documents are aligned with the project's objectives, classifications, and information delivery plans. It also connects to the classification model, enabling the categorisation and organisation of project information according to defined structures. This relationship ensures that project documents, sections, and content are classified appropriately, facilitating efficient information retrieval and management.

The project model also integrates with the plan of work model to allow capturing of the project's activities, timelines, and information exchange requirements. This linkage enables the project model to reflect the project's specific plan of work, ensuring that information delivery aligns with the project's milestones and stages. Additionally, the project model interacts with the CDE model, serving as a reference point for data storage and access within the project. The establishment of this model ensures that all project-related data is managed and shared through the designated CDE, promoting collaboration, version control, and data consistency. Decisions made within the project are captured and associated with the project model, creating a comprehensive record of key choices and their impact on project execution. This relationship allows stakeholders to trace decisions back to their origins and understand their implications on subsequent actions. Lastly, the project model can incorporate site locations, acknowledging the spatial context and specific requirements of different project areas. The association of site locations with the project model, although outside the scope of this research allows for future work in realising variations in information needs, regulations, or constraints based on physical locations.

Framework Structure

In order to achieve the desired level of maturity within the framework, each element must be incorporated at a sufficient level. This means that all the required documents, sections, and contents must be created and implemented as specified by the ISO 19650 standard. It is not enough to have partial compliance; all elements must be present and accurately aligned with the project requirements and classifications. For instance, if the framework dictates that a certain process necessitates the creation of 10 documents, the project must ensure that all 10 documents are generated and adhere to the specified structure, content, and metadata requirements. Additionally, each document should have its associated sections, reflecting the necessary granularity of information within the project context.

The proposed maturity framework includes various requirements at different levels related to classification, plan of work, and metadata. At the ISO 19650 level, the framework necessitates the establishment of a classification structure. This classification structure serves as a standardised framework for organising and categorising information within the construction project. It ensures consistency and enables efficient information retrieval and management throughout the project lifecycle. At the process level, the framework emphasises the implementation of a plan of work. The plan of work outlines the sequence of activities, tasks, and milestones involved in the project. It provides a roadmap for the project's execution, guiding the stakeholders through the different stages of the project. The plan of work ensures that the project follows a structured and coordinated approach, aligning the activities with the defined processes and deliverables. Moving down to the document level, the framework requires the inclusion of metadata. Metadata refers to additional information that describes or provides context to the document. This information includes details such as the author or creator of the document, the date of production, updates or revisions, approval status, and the document's name or title. Metadata enhances the understanding and management of the document, facilitating its identification, tracking, and retrieval.

In essence the levels are defined as

Level 1

- The focus is on the content level, where all content elements must align with the outer attributes, such as classification, meta-data, and information delivery plans. This ensures that the content is accurately categorised, properly documented, and follows the prescribed guidelines.

Level 2

- The emphasis shifts to the section level. Here, the sections within the documents should be organised and structured in a compliant manner. This includes considering attributes such as authorship, creation dates, updates, approvals, and names. These attributes provide essential contextual information and enable effective management of the document sections.

Level 3

- Pertains to the document level. At this stage, the focus is on the overall document structure and its alignment with the ISO 19650 requirements. Meta-data, such as authorship, dates, approvals, and classifications, play a crucial role in ensuring the integrity, traceability, and compliance of the documents.

Level 4

- This is the process level. Here, the emphasis is on the plan of work, which outlines the sequence of activities and tasks required to achieve compliance with the ISO 19650 standard. The plan of work provides a roadmap for implementing the necessary processes, procedures, and controls within a project.

Level 5

- This is the ISO 19650 level itself. This represents the highest level of compliance, where all elements at the content, section, document, and process levels align with the requirements of the ISO 19650 standard. Achieving this level demonstrates a comprehensive understanding and implementation of the standard's guidelines and best practices.

Framework User Perspective Development

To ensure effective documentation production, it is crucial to consider the user perspective and provide a user-friendly experience. Implementing the requirements outlined in section 4 of the framework involves simplifying the user experience and making the platform intuitive to use. The platform itself needs to leverage its knowledge and capabilities to guide users in aligning with the ISO 19650 standards by generating only the necessary documents and collecting the required information. The platform should also enable users to create the required documents without unnecessary complexities. It should offer clear instructions and prompts, ensuring that users enter the relevant information without overwhelming them with excessive or irrelevant data fields. This approach ensures that users provide the right amount of information and nothing more or less, reducing errors and enhancing efficiency. The platform should also incorporate intelligent features and decision-making logic to guide users through the document creation process. It can leverage the framework's knowledge and predefined templates to suggest the appropriate document types, sections, and content based on the project context and ISO 19650 requirements. This helps users navigate through the documentation process, ensuring that they address all the necessary aspects while avoiding unnecessary steps or omissions. The user experience should also reduce the learning curve, minimise errors, and enhance productivity, ultimately improving the overall user experience. Additionally, providing a user-friendly interface and incorporating user feedback in the platform's development ensures that it remains intuitive and continuously meets the needs and expectations of its users.

Guided Use

According to the ISO 19650 standard, and as stated, information delivery requires specific documentation related to organisations and project-specific information. The platform incorporates logic to ensure that the necessary documentation is created in the correct order. The user is not allowed to set up a project until the OIR and Level of information need documentation has been developed and approved. This is because the PIR and AIR are defined based on the OIR.

Once the OIR and level of information needed documents are created and approved, the project can be initiated following the defined process from the previous chapter. The next important document is the PIR, which includes information related to the information delivery plan, decision points, information exchanges, and questions needed to inform the decisions. The logic uses Python classes as shown in Figure 68.

```
class ProjectHomeView(DetailView):
    template_name = 'project/home.html'

    Alan Rawdin
    def get_object(self, queryset=None):
        queryset = Project.objects.get_project_by_access(self.request.session['organisation'])
        # set the project session
        if queryset.filter(id=self.kwargs.get("pk")).first():
            self.request.session['project'] = str(self.kwargs.get("pk"))
            project = Project.objects.get_project_by_id_access(self.request.session['organisation'],
                                                               self.kwargs.get("pk"))

            self.request.session['project_owner'] = str(project.organisation.id)
            logging.info("project-owner" + str(project.organisation.id))
        return get_object_or_404(queryset, id=self.kwargs.get("pk"))

    Alan Rawdin
    def get_context_data(self, **kwargs):
        context = super(ProjectHomeView, self).get_context_data(**kwargs)
        context['meta_content'] = meta_content
        context['title_colour'] = title_colour
        context['content_title'] = content_title
        context['content_sub_title'] = _('home'.capitalize())
        context['title_icon'] = 'fa-home'
        context['block_navbar'] = self.get_navigation()
        context['block_script'] = complete_script(form_function, form_id, 'x')
        context['project_document_list'] = self.get_project_documents()
        context['project_pow'] = self.get_project_pow()
        context['project_pow_stages'] = self.get_pow_stages()
        context['project_cde_system'] = self.get_cde_system()
        context['project_cde_states'] = self.get_cde_states()
        context['project_site'] = self.get_project_site()
        context['project_actors'] = self.get_project_actors()
        context['project_contracts'] = self.get_project_contracts()
        context['project_questions'] = self.get_project_questions()
        context['project_decisions'] = self.get_project_decisions()
        context['project_standards'] = self.get_project_standards()
        context['project_procurement_route'] = self.get_procurement_route()
        context['project_setup_status'] = self.get_setup_status()
        context['project_pow_setup_status'] = self.get_pow_setup_status()
        context['project_cde_setup_status'] = self.get_cde_setup_status()
```

Figure 68: Logic used in project presentation

The platform ensures that document production is only allowed after these elements have been produced. This is achieved through logic implemented at the model level, using access attributes, and through the view method logic within the Django framework. Collaboration among various actors, both internal and external, is essential for a project. To facilitate this, the platform includes the Contributing Actor model, which allows users to be added to the project at the lead appointing party or appointing party levels. This model serves three purposes:

1) It allows users to access the information shared with them, ensuring they have the necessary permissions.
2) It restricts them to creating documents at the appropriate level, ensuring compliance with the standard.
3) It grants them access to the CDE permissions specific to their organisation, enabling efficient collaboration.

```
def get_project_actors(self):
    project_actors = ActorMap.objects.get_actor_map_by_project_access(self.request.session['organisation'],
                                                                      self.kwargs.get("pk")).distinct()
    return project_actors
```

Figure 69: Logic applied for project collaboration

The project dashboard is a user-friendly interface that presents relevant information and features in a logical and streamlined manner. Behind the scenes, the platform incorporates various decisions and logic to ensure that the dashboard provides a cohesive and intuitive user experience. The logic applied within the platform ensures that the user is guided through the necessary steps and documentation creation process in compliance with the ISO 19650 standard. However, the user is not burdened with the technical details or complexity of the underlying logic. Instead, they are presented with a dashboard that abstracts away the intricacies, providing a simplified and user-friendly interface as shown in Figure 70 below.

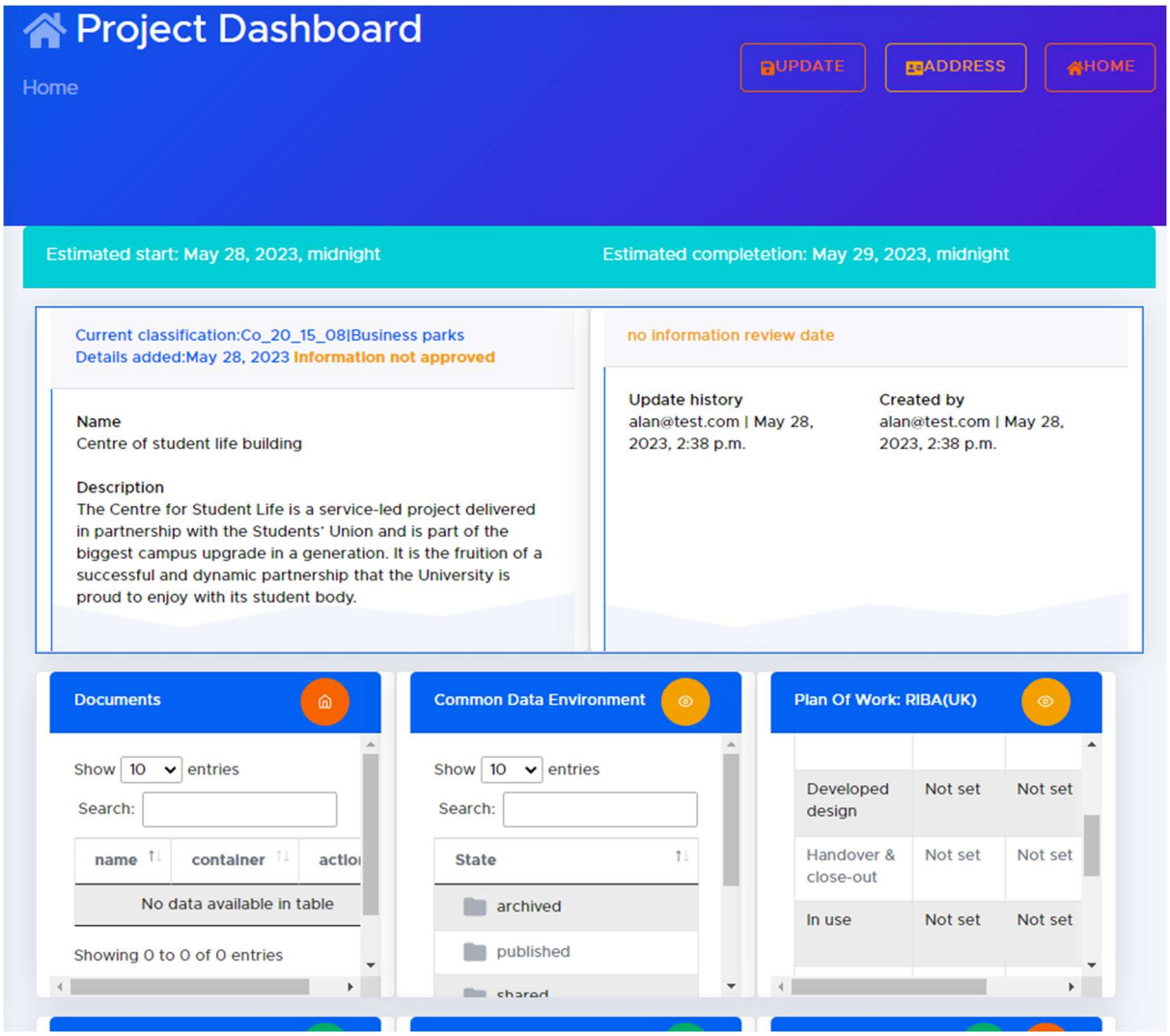


Figure 70: Snapshot of the project dashboard

Once all the required information has been entered for a project and the necessary prerequisites have been fulfilled, the user can proceed to the "Documents" menu within the platform. This menu provides the functionality to produce templates for the project based on the specified requirements and standards. When accessing the "Documents" menu, the user is presented with a selection of document templates that apply to the project based on its specific characteristics, scope, and requirements. These templates are pre-defined and aligned with the ISO 19650 standard, ensuring that the generated documents comply with the specified guidelines. The user can choose from a variety of document types, such as project information requirements, project execution plans, CDE & Naming conventions and

more. Each document template includes the necessary sections, content structures, and metadata fields as defined by the ISO 19650 standard.

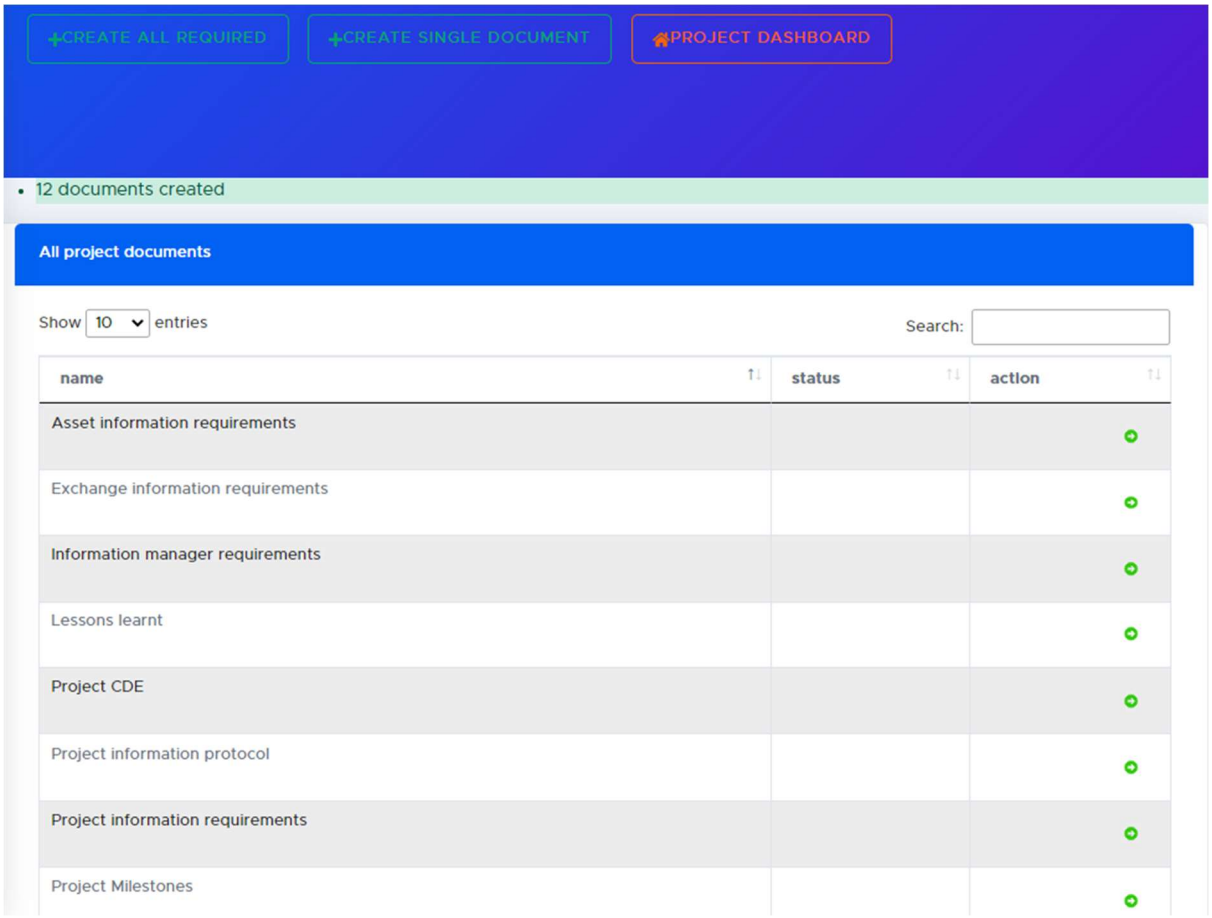


Figure 71: Required document templates available for editing

Indeed, while not all aspects of content generation were explored in this research due to time limitations, the primary goal was to demonstrate the concept of applying information management principles and logic within the platform. The aim was to showcase how the platform could facilitate the creation of project documentation in alignment with ISO 19650 standards, while also ensuring efficient information management practices. The implementation of the core functionalities and logic discussed earlier enabled the researcher to establish a foundation for the generation of project documentation. The focus was on demonstrating the ability to capture and integrate relevant information, apply classification structures, enforce document structure and metadata requirements, and enable collaborative workflows among project actors. While specific content generation features

may not have been fully implemented, the logic and principles applied within the platform remain valid and form a solid basis for further development and refinement. The research serves as a proof of concept, showcasing the feasibility of integrating information management principles into the document generation process and highlighting the potential benefits in terms of compliance, consistency, and streamlined project workflows.

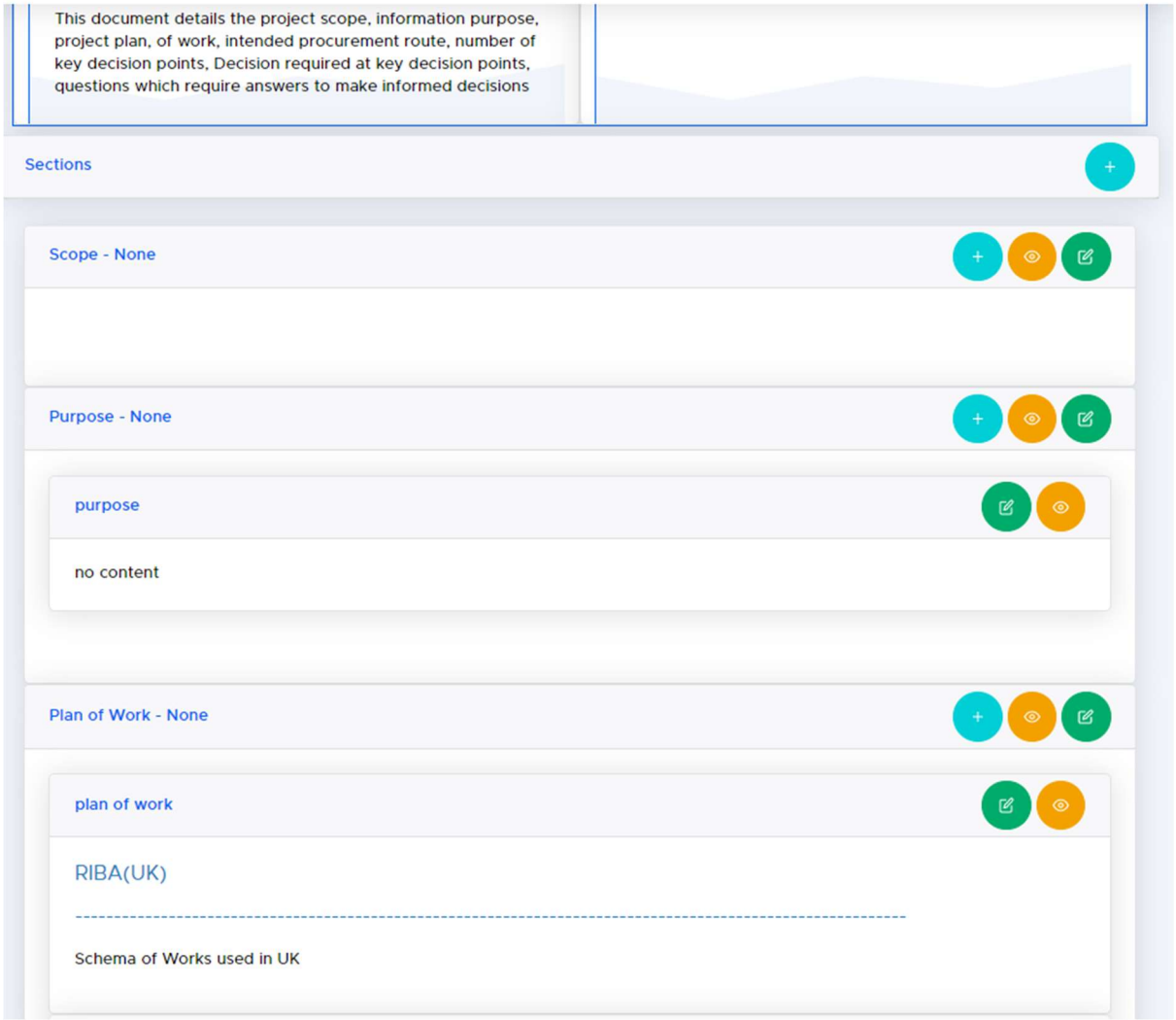


Figure 72: Elements contained on selection of the PIR document

Summary

The section demonstrates the implementation of document generation, document-linked processes, and project models within the platform. By developing and integrating these components, the platform enables the production of documents in a structured format that could align with the requirements of ISO 19650. Through the use of models and data dictionaries, the platform allows for the creation of document structures with appropriate sections, content, classifications, metadata, and other attributes. The models capture the relationships and dependencies between documents, sections, processes, and project entities, ensuring consistency and adherence to the ISO 19650 framework.

The platform's logic and functionality enforce the necessary steps and prerequisites for document production. For example, the creation of project-specific documentation is dependent on the completion of OIR and the Level of information need documentation. This logic ensures that users follow the defined processes and provide the required information before generating project-specific documents. The implementation also incorporates collaboration features by introducing the contributing actor model, which allows users to be added to projects at appropriate levels (lead appointing party or appointing party). This ensures that users have access only to relevant information, can create documents at the appropriate level, and are granted the necessary access permissions within the CDE. Integrating these features and functionalities, the platform facilitates the production of structured documents that adhere to ISO 19650 standards. It provides users with a streamlined and user-friendly interface where they can enter the required information, follow defined processes, and generate documents that capture the necessary content, classifications, metadata, and relationships. Overall, the implementation of document generation, document-linked processes, and project models within the platform enables the structured creation of documents, empowering users to meet the requirements of ISO 19650 and facilitating efficient information exchange and collaboration in the construction industry.

Compliance Checking

This section details how the platform utilises a combination of logic and BERT NLP to ensure compliance with the ISO 19650 standard. The compliance checking process involves comparing the content of documents, sections, and content against predefined rules and requirements specified in the data dictionary. The data dictionary, which contains information about the structure and attributes of documents, sections, and content, serves as an additional source for refining the BERT model. By leveraging this data, the platform enhances the accuracy and effectiveness of the compliance checking process. The compliance-checking logic is implemented in parallel with the BERT NLP model. BERT is a powerful deep learning model that has been pre-trained on a large corpus of text data. It can understand the contextual meaning of words and sentences, making it suitable for analysing and evaluating the content of documents. The compliance checking process involves several steps. First, the platform extracts the relevant text from the documents, sections, and content to be checked. This text is then passed through the BERT model, which processes and analyses it to identify any deviations or violations of the specified rules and requirements. The logic implemented in the platform complements the BERT NLP model by incorporating additional checks and validations. Each of these aspects, logic and the BERT model is discussed below.

Decision logic

The compliance checking platform offers users two options for collecting documents to undergo compliance checks:

1) In-built CDE

   If users opt for the in-built CDE, the platform retrieves documents associated with the selected project and state from the CDE repository. These documents are then added to the project's files, ready for compliance checking.

2) Manual document uploads.

   Users can choose to upload one or more documents directly from their local systems.

The platform creates individual records for each uploaded document, capturing relevant details such as file contents, name, and description. These documents are then included in

the list of files earmarked for compliance checks. Offering these two collection options, the platform empowers users to leverage the in-built CDE or upload documents, depending on their preference and convenience. This feature enhances the versatility and usability of the compliance-checking platform, ensuring a seamless and efficient compliance assessment process for users.

This is undertaken using a Python script called “compliance_check_start_scan. The following pseudo steps are taken:

1) The method begins with logging a message and checking if the request method is "POST", if not the
2) It retrieves the necessary data from the request, including the organization, user, and project information.
3) It checks if a compliance history exists for the given organisation and project. If not, it creates a new compliance history entry.
4) It creates a new entry for scanned files and a new compliance result entry.
5) It retrieves the scan type and file source from the request.
6) If the scan type or file source is missing, it returns an error response.
7) If the required data is available, it retrieves additional parameters such as similarity, and file source.
8) Based on the scan type and file source, it performs specific actions. For example, if the file source is a local CDE it retrieves files from the CDE. If the file source is a remote source, it connects to the remote CDE and retrieves the files. If the file source is "option3" or "option4," it retrieves the uploaded files from the request.
9) After obtaining the files to be checked, it performs further processing based on the file type. For example, if a PDF file is encountered, it converts it to a DOCX format before adding it to the list of files for checking.
10) Finally, it calls the loc_check_document function with the relevant parameters to perform the document checking. The result is then rendered into an HTML template and returned as a JSON response.

Document check

The loc_check_document function is responsible for performing a document check based on specified parameters. It begins by retrieving the actor's role and the required documents associated with that role. For each required document, the function iterates through the provided list of files. It attempts to load each file as a docx.Document object and then performs a section-level check on the document using the loc_section_check function. The results of these checks are stored in the document_results list. After processing all files for a

particular document, the function identifies the best match based on the score of the section check. The best document match and score are updated if the current document's match has a higher score than the previous best match. If the overall best match score meets the required similarity threshold, the information container (file) is added to the overall result. The function then creates a result_list to store the final results. It matches each result item with its corresponding required document and appends it to the list. Finally, the function records the processing time and returns the result_list, which contains information about the required documents, the result status (True or False), and the corresponding result item.

The pseudo step used to implement this are as follows:
The function starts by recording the current time and logging an info message indicating the start of the document check.

1) The similarity value is converted to a float by dividing it by 100.
2) An actor_map object is retrieved using the ActorMap.objects.get_actor_map_by_subordinate_actor_access method, which takes several parameters related to the request and project. The actor_map represents a mapping between actors and roles in a project.
3) The actor_role is extracted from the actor_map object, representing the role of the actor making the request.
4) The required documents for the actor's role are obtained using the DocumentGenerationRequirementContent.objects.get_document_generation_by_access method, which takes the subordinate actor's ID as a parameter. This retrieves a list of documents that are required for the given role.
5) Two lists, document_results and overall_result, are initialised to store the results of document checks and the overall results, respectively.
6) A loop iterates over each document in the required_documents list. It checks if the document's related process item's responsible role matches the actor's role.
7) Within the loop, there is another loop that iterates over each file in the files_list. It attempts to load the file as a docx.Document object using the file_input path.

8) The loc_section_check function is called with the request, document, and loaded doc object, along with the similarity parameter. This function likely performs some section-level check on the document and returns a result.
9) The result of the section check is appended to the document_results list as a dictionary containing information about the document, container result, container name, etc.
10) After iterating over all files for the current document, the best match is determined using the get_best_match function. The best match is determined based on the score of the match.
11) If the best score match is greater than or equal to the overall best score match so far, the overall best score and best document match are updated with the current values.
12) The result dictionary is updated with the overall best document match, best score match, information container, and raw result.
13) If the overall best score match is greater than or equal to the similarity threshold, the information container is added to the overall result.
14) The function then creates a result_list to store the final results. It iterates over the overall results and the required documents to match the required document with the result item.
15) Finally, the function records the processing time, if any, and returns the result_list containing the required documents, the result status, and the corresponding result item. If an exception occurs at any point, it is logged, and the exception itself is returned.

Document section and content check

The loc_section_check function is responsible for comparing the sections of a required document with the sections of a provided document. It takes in the request, the document_required object, the doc (document) object, and a similarity threshold defined by the user input. The function begins by creating an empty list called sections to store the sections extracted from the provided document. It iterates through the paragraphs of the document and extracts the text from each heading. If a heading contains a "|" character, it splits the text and takes the first part, otherwise, it uses the entire text. This is done as the researcher was unable to extract the score directly from the pytourch model. The extracted

sections are appended to the sections list. The required sections for the document are obtained using the DocumentRequiredSections model based on the related document and the session organisation. Next, the function initialises a SentenceTransformer model called 'paraphrase-MiniLM-L12-v2', which is used for embedding the sections for comparison. The function then iterates through each section_required in the sections_required list. For each section, it initialises an empty list called section_results to store the similarity results between the required section and each provided section. It also sets the max_result to 0, which will be used to track the maximum similarity score. For each provided section, the function computes the embeddings of the required section and the provided section using the SentenceTransformer model. It then calculates the cosine similarity between the embeddings using the util.pytorch_cos_sim function. The resulting similarity score is extracted and stored in the result dictionary along with the required section, provided section, and the result status. The function compares each result to the current maximum similarity score (max_result) and updates the max_result, best_match, and overall_result variables accordingly. If the maximum similarity score exceeds the similarity threshold, overall_result is set to True, indicating a successful match; otherwise, it is set to False.The function creates a section_match dictionary containing information about the required section, the matched section, the similarity score, and the overall result status. This dictionary is appended to the sections_required_list for each section_required. Finally, the function returns the sections_required_list, which contains information about the required sections and their corresponding matches in the provided document, along with similarity scores and result statuses.

Document Ranking in comparison to other documents

The get_best_match function aims to determine the best match among the document results obtained from the document analysis process. This part of the decsion logic is crucial in the analyis of the document score against other documents. In order to understand the logic further, it is broken down into psudeo steps:

1) The function begins by initialising variables, such as document (representing the required document) and total_score (representing the cumulative score for the best match).
2) The function iterates through each item in the document_results list, which contains the analysis results for each document.
3) Within each item, the function extracts the values for the keys 'document_required' and 'container_result'. 'document_required' represents the name of the required document, while 'container_result' contains the analysis results for the document sections.
4) For each section result in 'container_result', the function calculates the section's score. It iterates through the key-value pairs in each section result and accumulates the score based on the 'score' key. Additionally, the function counts the number of positive results ('True' values) and negative results ('False' values) within the section results.
5)Using the accumulated scores and section results, the function calculates the average score (av) per section and the weighting (weighting) based on the ratio of positive results to the total number of sections. A zero division error is handled by setting the weighting to 0 in case there are no sections.
6)The total score for the best match is calculated by multiplying the average score (av) and the weighting (weighting) and applying a multiplication factor of -1. The score is then multiplied by 100 to provide a percentage representation.
7)The function creates an overall_result dictionary containing the best matching document, the total score, and the raw document results.
8)The overall_result dictionary is returned as the output of the function.

The overall document ranking plays a crucial role in the decision-making logic of the system. It goes beyond simply comparing a document against a data dictionary and assigning a score based on the match. Instead, it enables a comprehensive analysis of all the documents presented within the platform. This logic is particularly valuable when dealing with a large number of documents of the same type. For example, consider a scenario where multiple documents claim to be a PIR . The system can analyse each document's content and compare it to the data dictionary. In some cases, it may identify that a document, although labelled as a PIR, bears more resemblance to an AIR based on its content. This highlights the ability of the system to look beyond document labels and assess the actual content to provide more

accurate rankings. Furthermore, the overall document ranking logic accommodates iterative improvements. If a document fails to meet the desired criteria, the system can provide detailed feedback on why it failed. This feedback empowers users to refine their documents and submit updated versions for analysis. Consequently, the ranking process becomes an iterative and collaborative effort, with users gaining insights into how to enhance their documents and achieve better results. The document ranking mechanism goes beyond a simple comparison against a data dictionary. It allows for the analysis of multiple documents, identifies the most suitable match based on content similarity, and provides valuable feedback on failures. This approach facilitates continuous improvement and ensures that the system accurately assesses and ranks documents within the platform.

NLP in document analysis

In the context of comparing documents, sections, and their content, the Sentence Transformer model with BERT plays a crucial role. The Sentence Transformer model is a powerful NLP tool that enables semantic understanding and comparison of textual data. When it comes to document analysis, the Sentence Transformer model is employed to transform the textual information into fixed-dimensional vector representations, also known as embeddings. These embeddings capture the contextual and semantic meaning of the document, section, or content by encoding them into numerical representations. Using BERT, the Sentence Transformer model considers the intricate relationships between words, phrases, and sentences within the text. It captures the nuances of language semantics, contextual cues, and the underlying meaning of the textual content. In the specific context of comparing documents and their sections, the Sentence Transformer model allows for a comprehensive analysis. It extracts the required sections from documents and converts them into embeddings. Similarly, it encodes the content of the document sections, generating embeddings that represent their semantic meaning. To determine the similarity between the required and actual document sections, the Sentence Transformer model calculates the cosine similarity between their respective embeddings. The cosine similarity measure quantifies the similarity between two vectors, providing a score that ranges from -1 to 1. A higher score indicates a stronger semantic similarity between the compared sections.

Chapter 7 – Validation

Within the AECOO industries, efficient information management and ensuring compliance with regulatory standards are paramount for successful project delivery. As projects become increasingly complex and data-intensive, there is a growing need to automate the process of information management to enable real-time insights into a project's current status and ensure compliance smartly and effectively. This chapter focuses on the validation of proposed methods and synthesises the results obtained through rigorous research and analysis. The chapter is broken down into three areas:

1) Hypothesis Evaluation:

In this section, the hypothesis stated earlier will be critically evaluated based on the empirical evidence and findings obtained throughout the research. The chapter will discuss whether the research results support or refute the hypothesis. The evaluation will consider the alignment between the research objectives, methodology, and the hypothesis itself. Any insights, patterns, or trends identified from the data analysis will be examined to determine the validity of the hypothesis.

2) Research Limitations:

This section will address the limitations and constraints encountered during the research process. It is essential to acknowledge and discuss these limitations as they provide context and boundaries to the study. Various factors, such as sample size, data quality, time constraints, or external factors, may have impacted the research outcomes. The chapter will transparently outline these limitations and their potential influence on the validity and generalisability of the findings. Suggestions for mitigating these limitations or considerations for future research will also be provided.

3) Research Contribution:

The final section will focus on highlighting the contribution of the research to the field of automated compliance checking and information management in the AECOO industries. The chapter will summarise the key findings, insights, and implications generated through the research process. It will emphasise how the research outcomes address the existing gaps and advance knowledge. Additionally, the section discusses the potential impact of the research on industry practices and policymaking.

Hypothesis Evaluation

In order to validate the work undertaken in this research, it is first necessary to look again at the original research hypothesis.

"There is a need to automate the process of information management to enable a projects current status to be interrogated and understand its current compliance in a smart way in order to improve project delivery within the AECOO industries, hence a smart way to automate compliance checking".

Process Automation validation

In order to validate to the hypothesis against the process automation platform, the platform will be set up to validate the different cases that could be presented to it. The first test is related to section 5.1.1 of ISO19650-2:2018 which states:

"The appointing party shall have regard to the effective management of information throughout the project and reflect the long-term asset information strategy, as described in ISO19650:1 by nominating individuals from within the appointing party's organisation to undertake the information management function on behalf of the appointing party"

To validate the hypothesis regarding the process automation platform, a specific test case will be conducted. This test case focuses on the appointment of individuals for the information management function, as outlined in section 5.1.1 of ISO19650-2:2018. The goal is to assess whether the platform effectively handles the selection of an external or internal information management role and carries out the necessary actions accordingly. During the validation process, the process automation platform will be configured to simulate user interactions and decision-making. The user will be presented with the option to choose between an external or internal information management role. If the user selects the external role, the platform will provide the required fields to capture relevant information for the external organisation, such as contact details, responsible tasks, authority, and necessary skills and knowledge. Once the user completes the information for the external organisation, the platform will initiate the process of sending the appointment request. Simulating a real-world scenario, the platform will handle the response from the external organisation. If the response is a rejection, the user will be notified and given the opportunity to resend the request. In the case of acceptance, the process automation flow will continue, involving task assignments, communication channel setup, and access provision to relevant information. Throughout the test case, documentation and reporting will be carried out to record the test execution details. This includes capturing the user's selection, the information collected for the external organisation, and the received response. Any deviations from the expected behaviour or encountered issues will also be noted for further analysis. By conducting this test case, the effectiveness of the process automation platform in managing the appointment of individuals for information management roles can be evaluated. It ensures that the platform adheres to the requirements specified in ISO19650-2:2018 and facilitates a smooth and efficient appointment process within the organisation. An overview of the test cases are presented below:

Test case 1	Sub-Scenario	Step to reproduce
External information manager	External organisation rejects	1) User sets up a project 2) User selects external information manager 3) Platform should prompt user to enter required information

		4) Sent to external organisation first for rejection then resend to organisation who should accept

Expected results			
1) Process engine should capture the requirements as defined in the standard.	2) Notification to external organisation who then reject the request	3) Original organisation should receive the notification to appoint another manager	4) Resend request recieved. Process engine should show next step as 5.1.3 and 5.1.2

Table 17: Evaluation of test case 1

Test Case 1 Results

The simulated user has entered the required details relating to the project as shown in Figure 73.

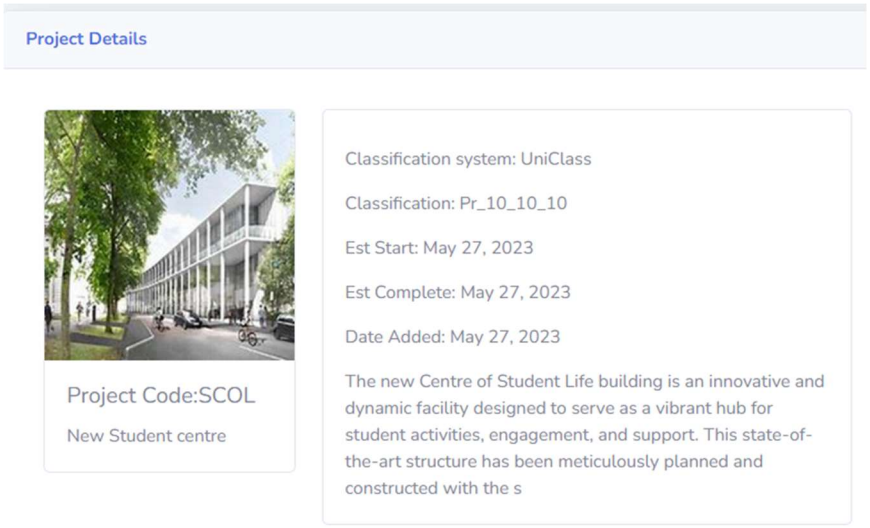


Figure 73: Project overview presented to user

The results from the process engine indicate to the user that the process has started and prompts the user to assign a user to undertake the task as shown in Figure 74and Figure 75 respectively.

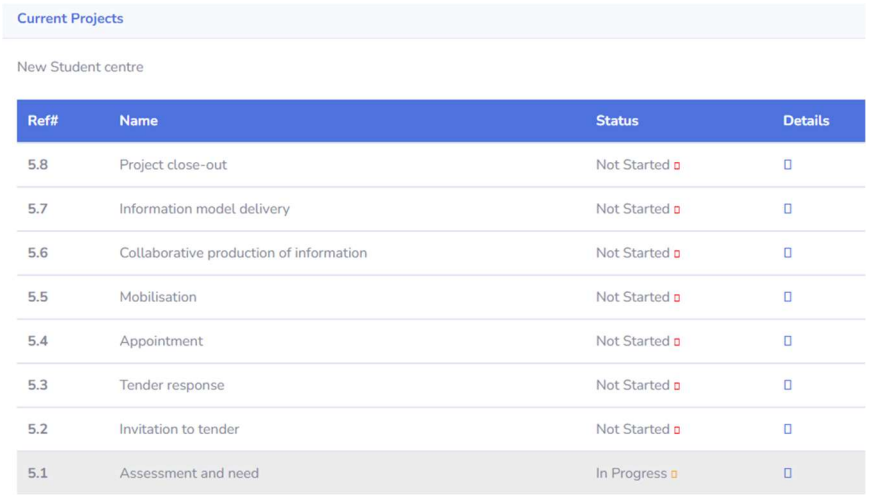


Figure 74: Current process state presented to user

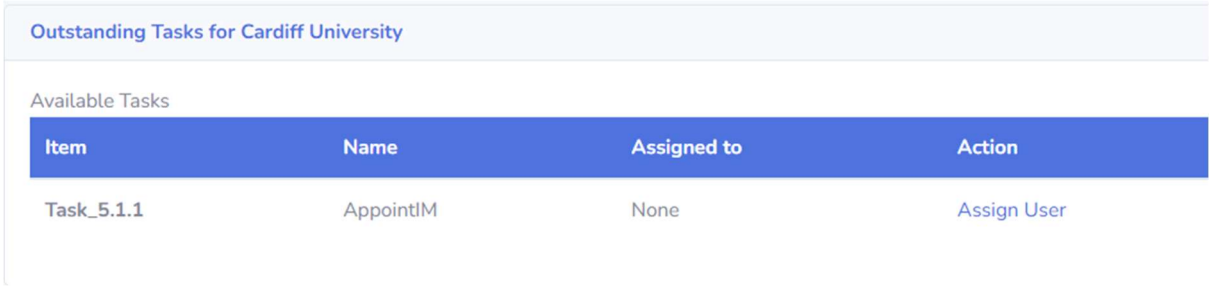


Figure 75: Outstanding tasks waiting for assignment to users

The process engine has also shown that the process has been started according to the relevant parts of ISO19650-2:2018. That is that B-Activities per project has one instance which is related to assessment and need which in turn has one outstanding task related to appointment of an information manager as shown in Figure 76 to Figure 79 respectively.

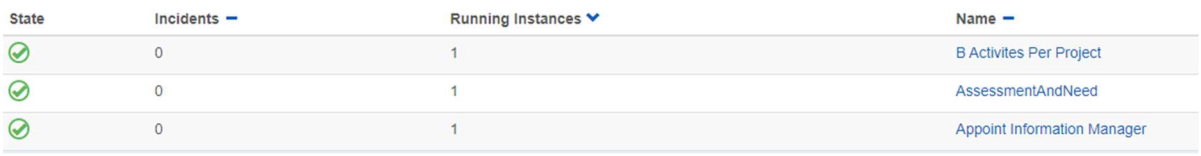


Figure 76: Camunda process engine - Total running instances at this point

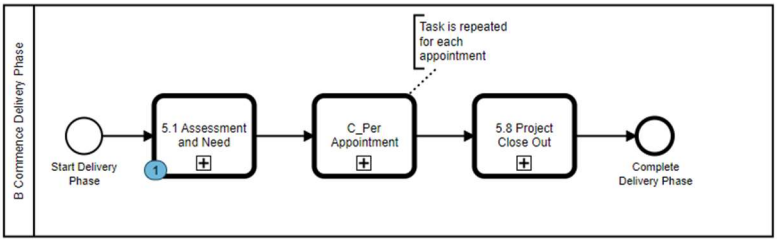
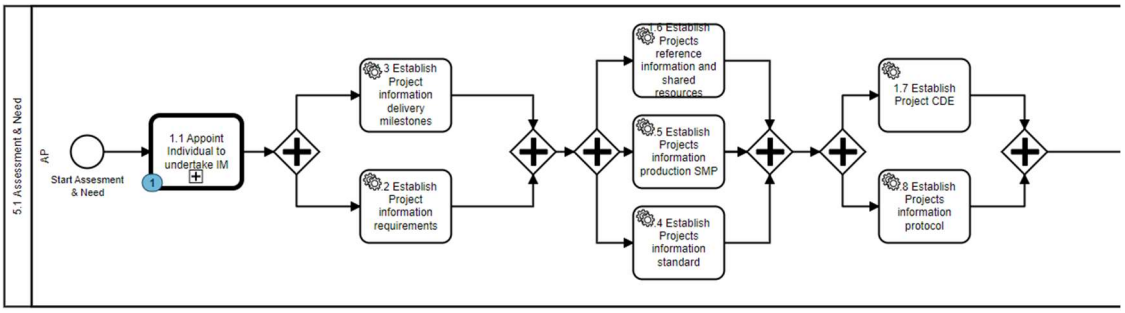


Figure 77: Camunda process engine visual representation of task at section 5.1



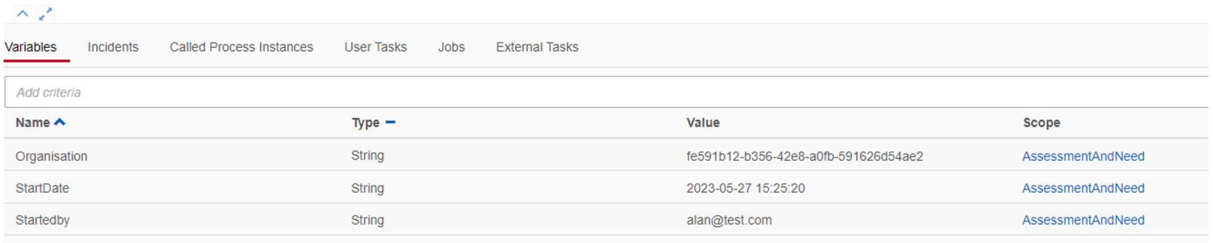


Figure 78: Camunda process engine visual representation of task initiated at next granular level 5.1.1

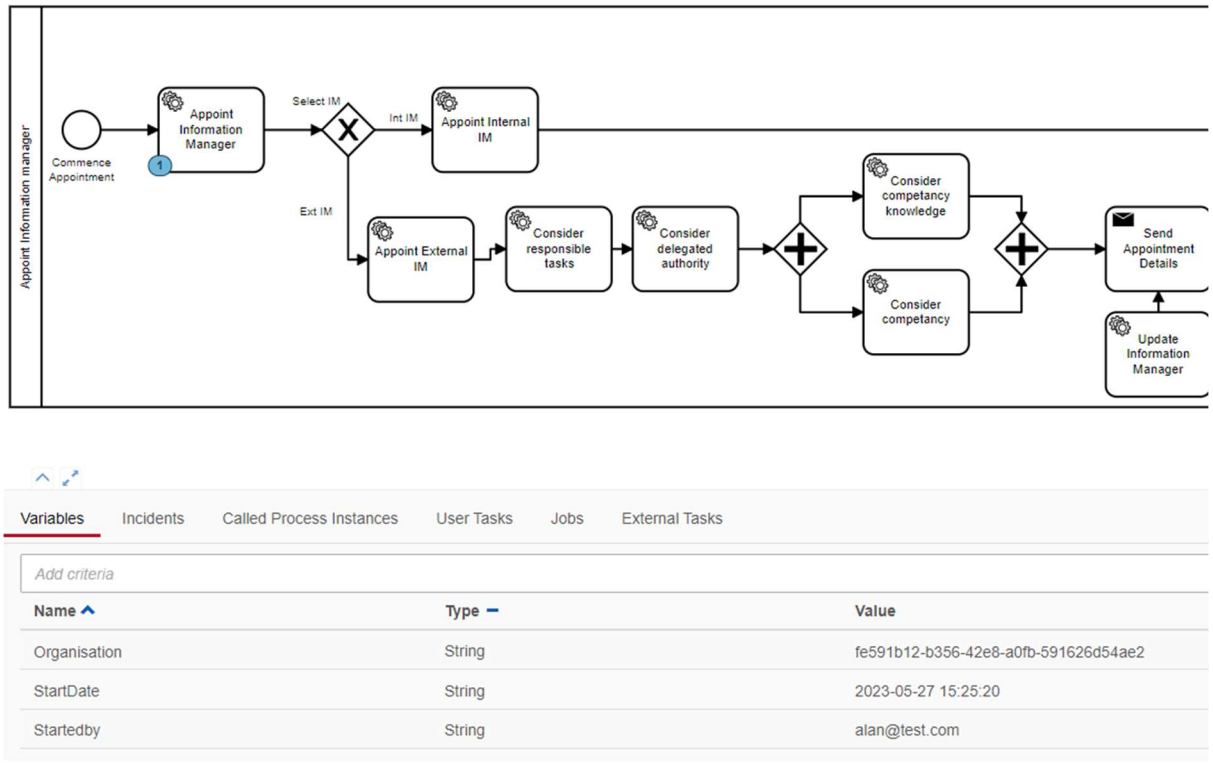


Figure 79: Camunda process engine at next granular level

The next step involves assigning a user to select an internal or external information manager. The results show that on selection of an external information manager the process engine has recognise the input and is now waiting for the task to be assigned to a user as shown in Figure 80 and Figure 81

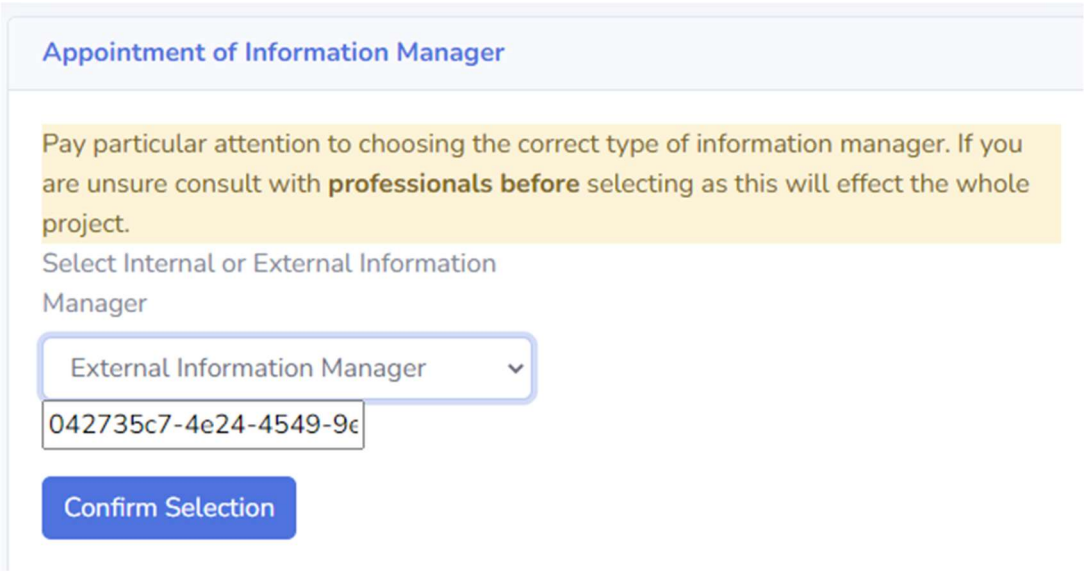


Figure 80: Selection of external information manager

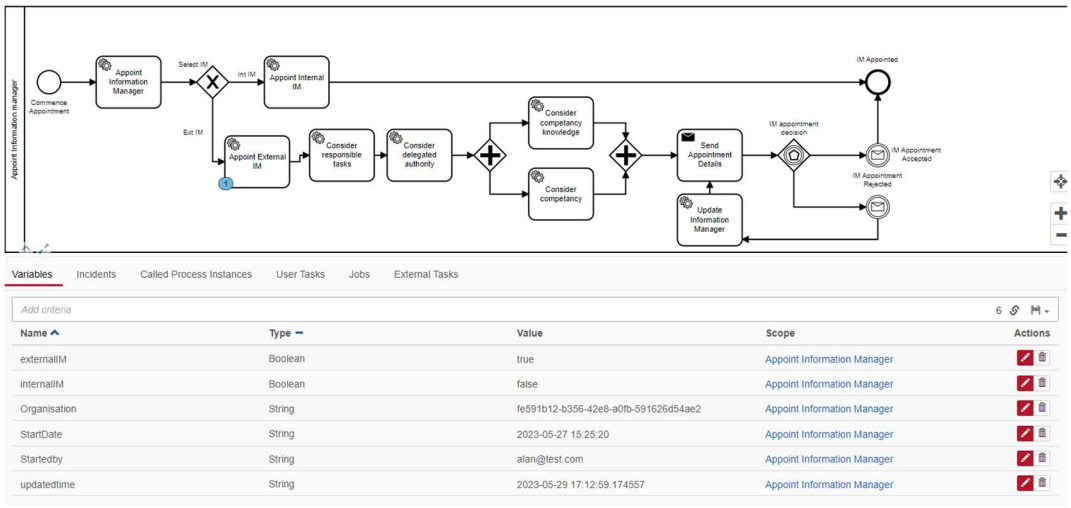


Figure 81: Process engine results for selection of external information manager

A prompt is displayed to the user correctly asking them to assign an external organisation. If there are none available, they are able to add them accordingly as shown in Figure 82

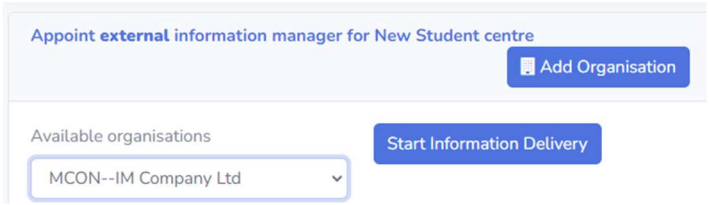
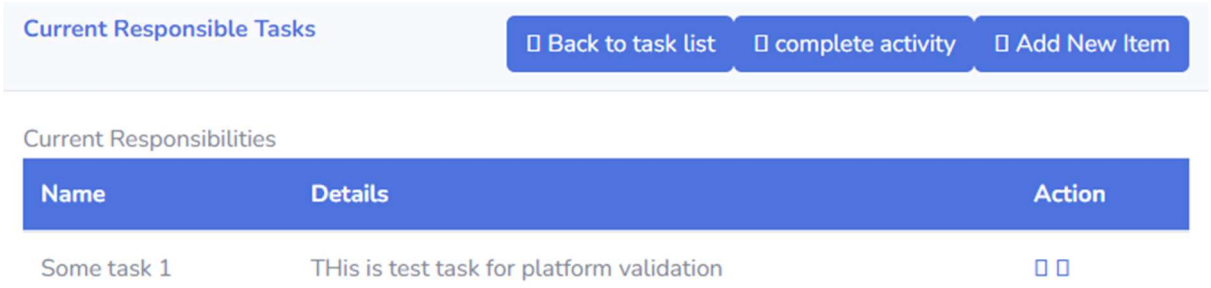
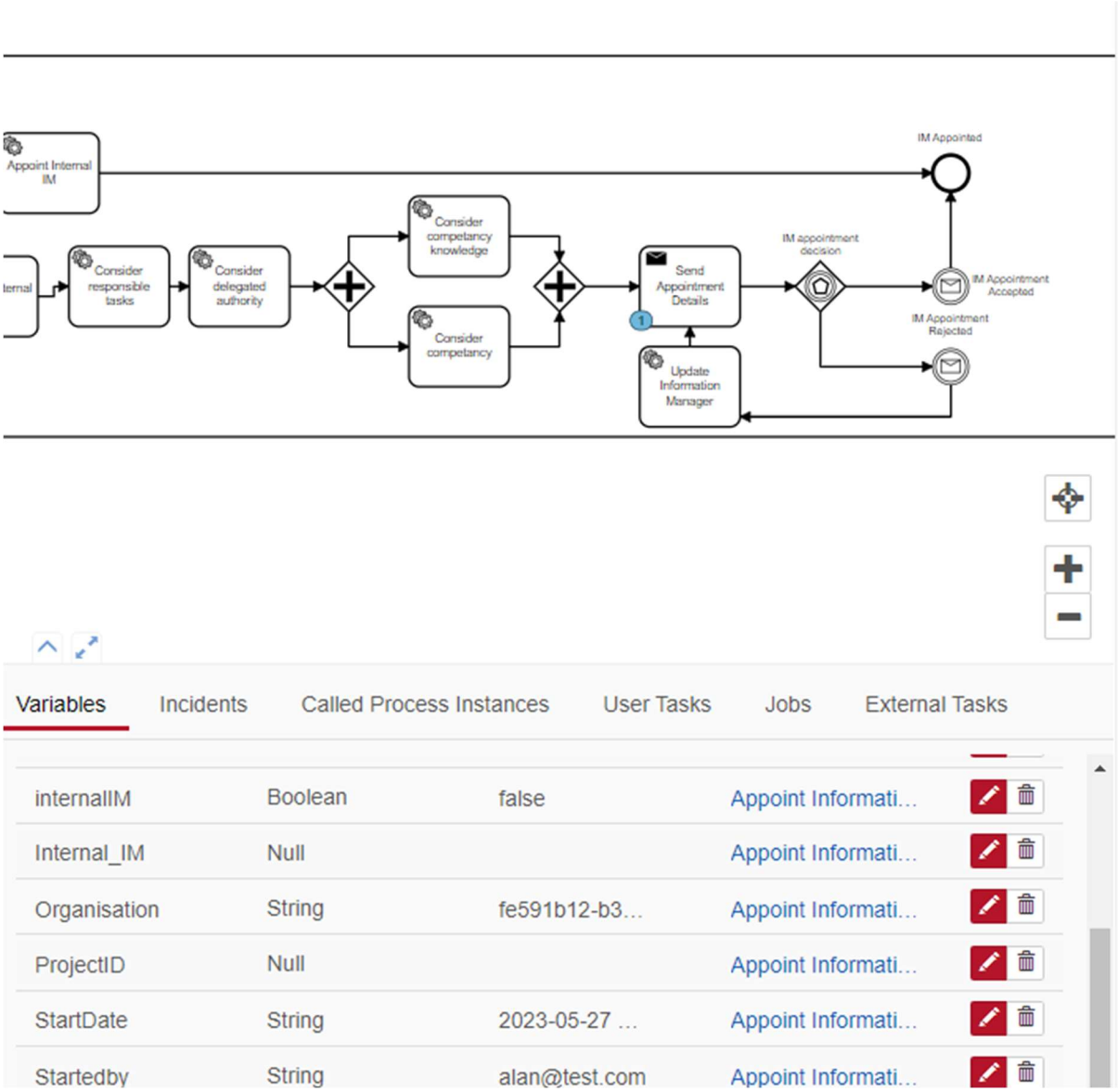


Figure 82: User prompt for selection of external organisation

According to the standard, the users should be able to select the tasks, skills and knowledge as described above. This platform correctly prompt the user to enter all of these details, whilst the process-engine also shows the correct progress.





The subsequent step in the test case involves a scenario where the ISO19650-2:2018 standard does not explicitly define the next action, highlighting the challenges faced by non-competent users in adhering to the standard's guidelines. However, within the process automation platform, the understanding of the next step is implicitly derived from the standard's terminology and context. Specifically, the platform recognises that the request for an external appointment needs to be sent to the external organisation and subsequently accepted by them. To facilitate this process, the platform offers a functionality where the user can review and verify the appointment details before initiating communication with the external organisation. This verification step is crucial to ensure the accuracy and completeness of the information being transmitted 81 and Figure 84 visually illustrates the user interface elements

and steps involved in this verification process. Once the user has reviewed and confirmed the appointment details, the platform proceeds to simulate the external organisation's perspective by logging in using their designated credentials. This simulation enables a realistic evaluation of the platform's functionality from the viewpoint of the external organisation, validating its ability to receive and respond to appointment requests in line with the ISO19650-2:2018 standard's requirements. The incorporation of these steps aims to assess the platform's adherence to the standard's implicit guidelines and its capability to facilitate smooth communication and collaboration between the user and external organisations involved in the information management process.

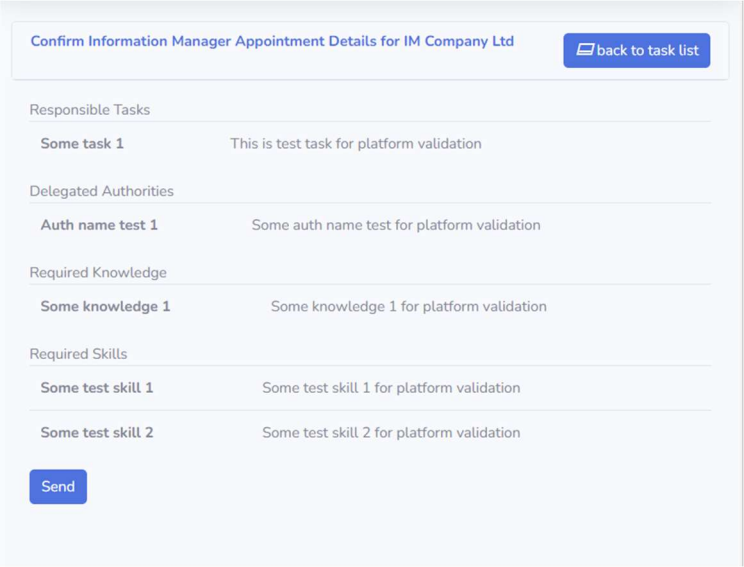


Figure 83: User interface before sending confirmation

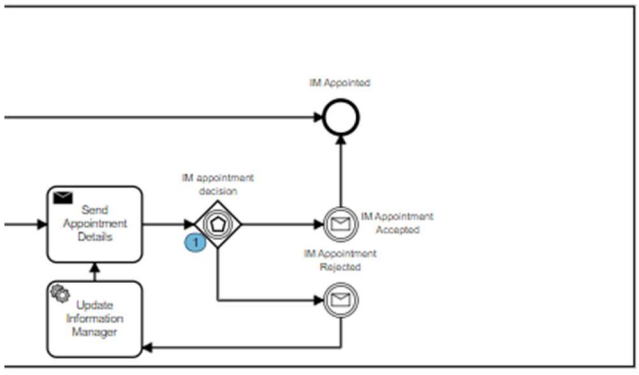


Figure 84: Corresponding view from process engine in relation to sending the request

Following the verification of the appointment details and the simulated communication with the external organisation, the next phase of testing focuses on ensuring that the external organisation receives the appointment request and has the opportunity to review the skills, knowledge, and competency requirements associated with the role. Based on this assessment, the external organisation can either reject or accept the appointment request.

In scenario 1 as shown in Figure 85, Figure 86 and Figure 87, the test case is designed to simulate a scenario where the external organisation rejects the appointment request. This rejection triggers the corresponding processes within the automation platform, updating each step and automating the subsequent actions accordingly. The expected result is that the process engine reflects the rejection progresses to handle the rejection scenario and requests the originating organisation to send the request again.

Conversely, in scenario 2 shown in Figure 88, the test case evaluates the platform's functionality when the external organisation accepts the appointment request. Upon acceptance, the process engine should seamlessly transition to the next activity outlined in sections 5.1.2 and 5.1.3 of the standard. The expected outcome is that the process automation engine updates the necessary steps, captures the acceptance response, and progresses the workflow in alignment with the standard's guidelines.

The test aim is to validate the process automation platform's ability to handle both rejection and acceptance scenarios, ensuring that it accurately reflects the outcomes as defined in the ISO19650-2:2018 standard. The automation of subsequent activities based on these outcomes contributes to streamlining the information management process and aligning it with the requirements outlined in the standard.

Figure 85: Test results for external organisation task list

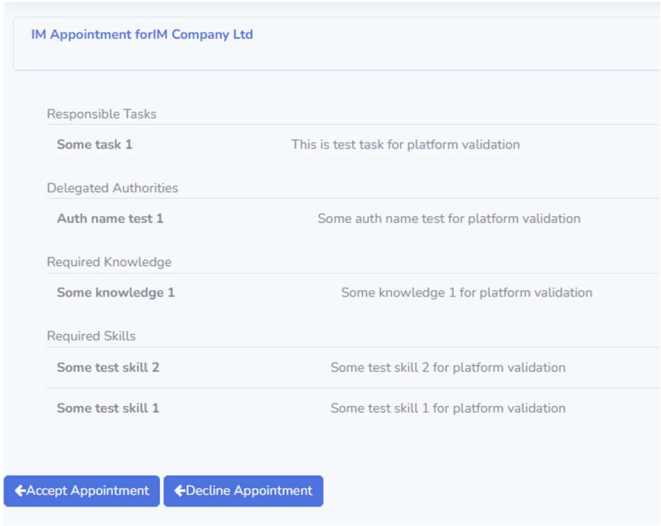


Figure 86: User interface after receiving request to appoint

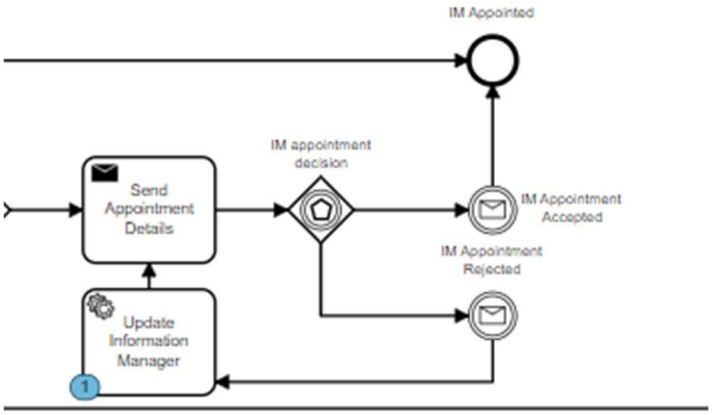


Figure 87: Process engine results after rejection

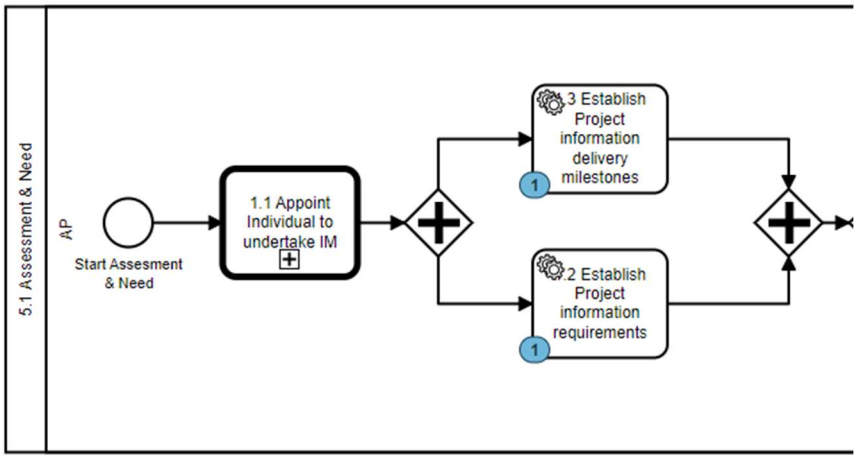


Figure 88:Process engine results after test complete

Results Discussion

The results of the validation for scenario 1 indicate that the process engine and user interface of the platform performed as expected. The process automation successfully captured the details of the rejected appointment request, including the reasons for rejection, and updated the workflow accordingly. The user interface provided the necessary fields and options for the external organisation to review the request and make the decision.

This outcome validates the effectiveness of the process automation platform in handling the selection of an external information manager and the subsequent rejection of the appointment request. The platform demonstrated its ability to accurately capture, process, and update the necessary information, ensuring compliance with the ISO19650-2:2018 standard. The successful execution of this test case contributes to the overall validation of the hypothesis by confirming the platform's capability to automate processes in accordance with published guidelines and improve project delivery within the AECOO industries.

These results provide valuable evidence supporting the need for automated information management processes and compliance checking in the industry. Showcasing the platform's functionality and alignment with the standard, organisations can consider adopting similar automation solutions to enhance their information management practices and optimise project outcomes.

Compliance document generation and checking

This section will assess the validation of the compliance document generation and check the functionality of the platform. It will involve assessing its performance and expected outcomes. The platform aimed to deliver specific results in terms of assisting users in creating compliant documentation and conducting compliance checks. The validation of these elements are:

1) The identification of the applicable elements of the standard processes and documents.

The validation of this section is based on the platform being able to select the correct documents for the correct actor according to ISO 19650. The first test case is related to the Appointing Party. The results of the test are shown below. It is important to note that the platform at this stage is only able to check documents based on text elements, this is discussed further in research limitations.

ISO 19650-2:2018 Information required	Document Shown by generation engine	Ability to add correct naming convention
Asset information requirements	Yes	Yes
Exchange information requirements	Yes	Yes
Information manager requirements	Yes	Yes
Lessons learnt	Yes	Yes
Project CDE	Yes	Yes
Project information protocol	Yes	Yes
Project information requirements	Yes	Yes
Project Milestones	Yes	Yes
Project reference information	Yes	Yes

Project reference information	Yes	Yes
Project SMP's	Yes	Yes

Table 18: Results of document generation test case 1

The second test case is related to the Lead/Appointing Party. The results of the test are shown in Table 19

ISO 19650-2:2018 Information required	Document Shown by generation engine	Ability to add correct naming convention
Detailed responsibility matrix	Yes	Yes
Task information delivery plan	Yes	Yes
Master information delivery plan	Yes	Yes
Resource mobilisation	Yes	Yes
Information technology mobilisation	Yes	Yes
SMP mobilisation	Yes	Yes
Post-Appointment BIM execution plan	Yes	Yes
Detailed responsibility matrix	Yes	Yes
Task information delivery plan	Yes	Yes
Master information delivery plan	Yes	Yes

Table 19: Results of document generation for test case 2

2) The platform should provide a structured format for document creation, ensuring that all necessary sections are included.

   The validation of this section is based on the platform being able to present valid section headers and content where applicable and allow users to add metadata to each section The results of the test are shown below in

Test for Document PIR		
ISO 19650-2:2018 Reference section (5.1.2)	Document generation Section Visible	Ability to add classification
The project scope	Yes	Yes
Intended purpose	Yes	Yes
Plan of work	Yes	Yes
Procurement route	Yes	Yes
No of Key Decisions	Yes	Yes

Decisions	Yes	Yes
Questions	Yes	Yes

3) The platform's compliance checking functionality should accurately assess the generated documents for compliance with the specified standards and requirements. It should identify any potential gaps, errors, or inconsistencies within the documents.

   For the purpose of this test, a test case was developed from which several documents from one of the research participants were tested in the compliance engine. These documents had already been classed as suitable by an external auditor from a reputable auditing organisation. The test should identify if the document has passed or failed along with an indication of the reason for failure. In addition to this, another document made up of completely random generated text was also tested in the compliance engine. The results are shown below

Test CASE 1 for Actual compliant Document		
ISO 19650-2:2018 Reference section (5.4.3)	Platform compliance checking result	Similarity Result
BEP	PASS	0.78
EIR	PASS	0.68
Information Protocol (UK BIM Framework)	PASS	0.88

Test CASE 1 for Non-compliant Document		
ISO 19650-2:2018 Reference section (5.4.3)	Platform compliance checking result	Similarity Result
BEP	Fail	0.01
EIR	Fail	0.01
Information Protocol	Fail	0.01

Summary of validation

The results obtained from the document generation component of this research demonstrate its effectiveness in producing the required documents, sections and implementing document naming conventions within a project. The document generation platform successfully generates the necessary documentation in alignment with the ISO 19650 standards, providing a structured format and content organisation.

The automation of the document generation process enables organisations to save time and effort in manually creating and fatting documents. The platform ensures consistency in document structure and content, reducing the risk of errors or omissions. The successful implementation of document naming conventions further enhances the organisation and retrieval of project documents, facilitating efficient information management throughout the project lifecycle. However, it is important to note that the content generation for the documents was limited due to time constraints. The scope of this research focused on validating the document generation process and its alignment with the ISO 19650 standards. While the method is considered valid for generating the remaining documents, further research and refinement are necessary to encompass a broader range of document types and contents. Nonetheless, the results of the document generation component provide a foundation for future developments and improvements in the automation of compliant document production. It highlights the potential of automation in enhancing document management processes, improving accuracy, and promoting compliance with industry standards.

Further research can explore the integration of advanced technologies such as natural language processing and machine learning to enhance the content generation capabilities of the platform. Additionally, collaboration with industry practitioners and regulatory bodies can provide valuable insights and feedback to refine and validate the document generation processes in real-world scenarios.

The second test case focused on compliance checking within the document generation platform. It aimed to evaluate the platform's ability to distinguish between compliant and

non-compliant documents, as well as identify instances of non-compliance. The results of the compliance checking test case indicate that the platform effectively recognises and distinguishes between compliant and non-compliant documents. It successfully detects non-compliant documents based on predefined criteria and compliance requirements specified by the ISO 19650 standards. This capability enables users to easily identify areas of non-compliance and take appropriate corrective actions.

Automation of the compliance checking process enable the platform to provide a valuable tool for ensuring adherence to industry standards and regulations. It assists users in maintaining compliance throughout the project lifecycle and mitigating potential risks associated with non-compliant practices. The ability to recognise non-compliant documents not only promotes compliance but also helps in improving the overall quality and reliability of project documentation. However, it is important to note that the compliance checking component of the platform has its limitations. The scope of this research was focused on evaluating its basic functionality and the ability to identify non-compliant documents and give an indication of compliance against others. Further research and development are necessary to enhance its capabilities, such as providing more detailed compliance analysis and offering suggestions for achieving compliance.

The compliance checking test case demonstrates the platform's ability to distinguish between compliant and non-compliant documents, highlighting its potential in promoting adherence to industry standards. While further improvements and validations are required, the results obtained thus far contribute to the ongoing efforts in automating compliance checking processes within the AECOO industries.

Research Limitations

Despite the rigorous approach taken in this research, there are several limitations that should be acknowledged. These limitations highlight areas where further investigation or refinement may be needed to enhance the validity and generalisability of the findings.

Firstly, the scope of the automated process engine was limited to section 5.1 of the ISO19650-2:2018 standard. This limitation was imposed due to time constraints and resource limitations. Consequently, the evaluation of other sections or additional complexities within the standard was not possible. Future research could expand the scope to cover a broader range of standard requirements and assess the platform's effectiveness in handling more complex scenarios.

Secondly, the BPMN process maps developed for the automation were not verified or validated by industry or regulatory bodies. While the process maps were designed based on the standard's guidelines and best practices, their effectiveness in practical implementation has not been externally assessed. Collaborating with industry experts or regulatory bodies to validate the process maps would enhance their credibility and reliability.

Another limitation relates to the development of separate platforms for process automation and document generation. This was due to time constraints and resource availability. Integrating these functionalities into a unified platform would provide a more seamless and efficient user experience. Future research could focus on developing an integrated solution that combines process automation and document generation within a single platform.

Furthermore, the framework for compliant governance presented in this research would benefit from further validation through methods such as a Delphi study or expert panel review. This would involve soliciting input from industry professionals, regulators, and other stakeholders to assess the framework's comprehensiveness, relevance, and practical applicability. Incorporating diverse perspectives would enhance the robustness and acceptance of the framework within the AECOO industries.

Lastly, due to time constraints, not all content for the documentation was generated and evaluated within the research timeframe. The compliance checking functionality within the platform is designed to assess the textual content of documents against the requirements specified in ISO 19650-2:2018. It is important to note that the current implementation focuses on analysing the text itself rather than extracting structured data from the documents. This

approach, while effective in identifying inconsistencies and deviations from the standard, has limitations in capturing and evaluating structured information such as metadata, classifications, or specific data fields.

This limitation arises from the nature of the compliance-checking process, which primarily relies on NLP techniques to analyse the textual content. While NLP can identify keywords, phrases, and patterns within the text, it may not be able to extract and interpret structured data elements accurately. For instance, the platform may not be able to automatically identify and validate specific data fields such as tables or verify the correct application of classification systems within the documents.

Therefore, the compliance checking functionality, in its current state, is more suitable for assessing the overall compliance of the document's textual content with the ISO 19650-2:2018 standard. It can identify missing sections, inconsistencies in terminology, or deviations from the recommended practices outlined in the standard. However, it may not be able to provide a comprehensive assessment of structured data elements or specific data fields within the documents.

To address this limitation, future research could explore the integration of more advanced data extraction and analysis techniques. This could involve utilising machine learning algorithms or developing specialised parsers to extract structured data from documents and validate them against the ISO 19650-2:2018 requirements. By incorporating these enhancements, the compliance checking functionality could provide a more comprehensive and accurate assessment of both textual content and structured data, further improving the quality assurance process in BIM projects.

While the current research focuses on document content and structure compliance, future iterations of the platform could incorporate unique ID guidance and implementation as outlined in BS EN ISO 19650-2. This would enhance the platform's ability to track and manage information containers throughout their lifecycle, ensuring traceability, version control, and

compliance. By addressing this aspect, the platform could provide a more comprehensive solution for information management and compliance in the AECOO industries.

Despite these limitations, the findings of this research provide valuable insights into the potential benefits of process automation and compliance checking in the context of information management within the AECOO industries. The identified limitations serve as opportunities for future research and refinement, ultimately contributing to the continuous improvement and advancement of information management practices in the industry.

Research Contribution

The research conducted in this thesis has made several contributions to the field of automation in information management and compliance checking within the AECOO industries:

Practical Implementation: The development of a process automation platform specifically designed to align with ISO 19650 standards provides a practical solution for organisations seeking to improve their information management practices and compliance checking. The platform serves as a tangible demonstration of how automation can be applied to streamline processes and enhance efficiency in the AECOO industries.

Validation of Automation: Through the validation tests conducted on the process automation platform, this research has demonstrated the effectiveness of automation in capturing and processing information, facilitating compliance checking, and generating compliant documentation. The results validate the potential of automation to improve the accuracy, speed, and reliability of information management processes.

Insights into Challenges: By investigating the challenges faced by organisations in implementing information management standards, this research sheds light on the complexities and gaps that automation can help address. It provides valuable insights into the areas where organisations struggle the most, such as understanding the standard requirements, generating compliant documentation, and ensuring compliance throughout the project lifecycle.

Contribution to Knowledge: This thesis contributes to the existing body of knowledge by providing a comprehensive exploration of automation in information management and compliance checking. It synthesises relevant literature, identifies gaps in current practices, and proposes practical solutions. The research findings contribute to the understanding of how automation can improve project delivery and enhance information management practices in the AECOO industries.

Future Research Directions: The research presented in this thesis sets the stage for future investigations and advancements in the field. It highlights the need for further validation, collaboration with industry and regulatory bodies, and the development of comprehensive automation frameworks that encompass a wider range of standards and processes. The research also encourages the exploration of additional smart technologies, such as artificial intelligence and machine learning, to further enhance automation capabilities.

Chapter 8 – Conclusion

This thesis has presented a comprehensive exploration of the automation of compliance management within the AECOO industries. The research has delved into the intricacies of information management, process automation, document generation, and compliance checking, with a specific focus on the implementation of the ISO 19650 standard. Through a multifaceted approach combining literature review, system development, and validation, this study has yielded valuable insights and contributions to the field. A significant aspect of this research has been the investigation of the challenges faced by organisations in adopting and adhering to information management standards. The findings from industry workshops, interviews, and questionnaires have revealed a lack of awareness, understanding, and consistent implementation of standards like ISO 19650. These challenges have underscored the need for a more streamlined and automated approach to compliance management, prompting the development of the AutoBIM and BIMComply platforms.

The AutoBIM platform, designed to automate information management processes, has demonstrated its effectiveness in capturing and processing information, facilitating compliance checking, and generating compliant documentation. The platform's ability to monitor project progress, assign tasks, and integrate with external information management roles has showcased the potential of automation to enhance efficiency, accuracy, and collaboration within the AECOO industries. Furthermore, the BIMComply platform, focused on document generation and compliance checking, has proven to be a valuable tool in ensuring adherence to ISO 19650 standards. By automating the generation of compliant documents and employing natural language processing techniques for compliance checking, the platform has streamlined the documentation process and improved the quality and reliability of project information.

The validation tests conducted on both platforms have yielded promising results, confirming their effectiveness in automating information management processes, generating compliant documentation, and conducting accurate compliance checks. The platforms' ability to identify and rectify non-compliance issues has highlighted their potential to mitigate risks, reduce errors, and enhance overall project delivery.

However, this research acknowledges certain limitations that provide avenues for future exploration. The scope of the automated process engine was limited to a specific section of the ISO 19650 standard due to time and resource constraints. Future research could expand the scope to encompass a wider range of standard requirements and assess the platform's effectiveness in handling more complex scenarios. Additionally, the BPMN process maps and compliance framework developed in this study would benefit from further validation by industry and regulatory bodies. Their expertise and feedback would enhance the credibility and applicability of these tools in real-world settings.

The research also highlights the need for integrating process automation and document generation platforms into a unified solution. This integration would streamline the user experience and provide a more comprehensive and efficient tool for information management and compliance checking. Despite these limitations, this thesis has made significant contributions to the field. It has provided a practical implementation of automation in information management and compliance checking, validating its effectiveness through rigorous testing. The research has also shed light on the challenges faced by organisations in adopting information management standards, offering insights that can inform future research and development efforts.

The findings of this research have implications for both industry practitioners and policymakers. For practitioners, the developed platforms offer a tangible solution to streamline information management processes, improve compliance, and enhance project delivery. The insights gained from this research can guide organisations in adopting and implementing automation solutions to optimise their information management practices.

For policymakers, this research underscores the importance of clear and comprehensive standards, as well as the need for accessible guidance and support for organisations in implementing these standards. The findings can inform the development of policies and regulations that promote the adoption of automation in information management and

compliance checking, ultimately leading to improved efficiency, quality, and sustainability in the AECOO industries.

This thesis has explored the automation of compliance management in the AECOO industries, focusing on the implementation of ISO 19650 standards. The research has demonstrated the potential of process automation and document generation to streamline compliance processes, improve information management practices, and enhance project delivery. While acknowledging the limitations, this study has made significant contributions to the field and paved the way for future research and advancements in automation within the AECOO industries.

The research findings presented in this thesis have far-reaching implications for the future of information management and compliance checking in the AECOO industries. The successful development and validation of the AutoBIM and BIMComply platforms demonstrate the feasibility and effectiveness of automation in streamlining complex processes and ensuring adherence to industry standards.

One of the key implications of this research is the potential for widespread adoption of automation in information management across the AECOO industries. The demonstrated benefits of improved efficiency, accuracy, and collaboration can incentivise organisations to embrace automation solutions, leading to a transformative shift in how information is managed, and compliance is ensured. Furthermore, the research findings highlight the importance of continuous improvement and refinement of automation tools and frameworks. The limitations identified in this study, such as the limited scope of the automated process engine and the need for further validation, underscore the importance of ongoing research and development efforts. By addressing these limitations, future iterations of the platforms can be even more comprehensive, robust, and adaptable to the evolving needs of the industry.

The integration of emerging technologies, such as artificial intelligence and machine learning, presents exciting possibilities for the future of automation in information management. These technologies can be leveraged to enhance the capabilities of the platforms, enabling more sophisticated data analysis, predictive modelling, and decision support. By incorporating AI

and ML algorithms, the platforms can become even more intelligent and adaptive, providing valuable insights and recommendations to users. Collaboration between academia, industry, and regulatory bodies will be crucial in driving the future of automation in information management. By working together, these stakeholders can ensure that automation solutions are aligned with industry standards, regulatory requirements, and best practices. Collaborative efforts can also facilitate the development of comprehensive frameworks that address the diverse needs of different sectors within the AECOO industries.

The future of automation in information management also lies in the development of user-friendly interfaces and intuitive tools that enable seamless adoption and utilisation by a wide range of stakeholders. The platforms developed in this research have already demonstrated the importance of user-centred design, but further enhancements can be made to make automation more accessible and user-friendly for both technical and non-technical users.

In conclusion, the research presented in this thesis has laid a solid foundation for the future of automation in information management and compliance checking within the AECOO industries. The developed platforms, AutoBIM and BIMComply, have showcased the potential of automation to streamline processes, improve compliance, and enhance project delivery. By addressing the limitations identified in this study and embracing emerging technologies, future research and development efforts can further advance the field and unlock the full potential of automation in transforming information management practices in the AECOO industries.

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Appendix A – CSV Files used for processes (as separate files)

Appendix B – Copy of Survey Questions

Questionnaire on BIM Implementation and ISO 19650 Adoption

Section 1: Responder Qualifications

1. Please indicate your professional membership (if applicable):
    - RICS
    - CIOB
    - ICE
    - RIBA
    - Other (please specify):
2. How many years of experience do you have in the construction industry?
    - Less than 5 years
    - 5-10 years
    - 11-20 years
    - More than 20 years

Section 2: Implementation of BIM Standards

3. Have you implemented BIM standards within your organisation?
    - Yes (Proceed to Section 3)
    - No (Proceed to Section 4)

Section 3: Implementation Experience (For Participants Who Have Implemented BIM Standards)

4. How well do you perceive the standard aligns with your organisation's information management practices? (1 = Very Unwell, 5 = Very Well)
    - 1
    - 2
    - 3
    - 4
    - 5

5. How satisfied are you with the level of support and guidance provided by the standard documentation? (1 = Very Unsatisfied, 5 = Very Satisfied)
    - 1
    - 2
    - 3
    - 4
    - 5
6. The implementation of the BIM standard improved the efficiency of your organisation's information management processes. (1 = Strongly Disagree, 5 = Strongly Agree)
    - 1
    - 2
    - 3
    - 4
    - 5
7. How confident are you in the accuracy and reliability of the information produced and managed using the standard? (1 = Not Confident, 5 = Very Confident)
    - 1
    - 2
    - 3
    - 4
    - 5
8. How confident are you that the processes are easy to follow and can be tracked? (1 = Not Confident, 5 = Very Confident)
    - 1
    - 2
    - 3
    - 4
    - 5

9. How easy is it to produce the required documentation? (1 = Very Difficult, 5 = Very Easy)
    - 1
    - 2
    - 3
    - 4
    - 5

Section 4: Reasons for Non-Implementation (For Participants Who Have Not Implemented BIM Standards)

10. The complexity of the standard hinders our organisation's understanding of the required processes. (1 = Strongly Disagree, 5 = Strongly Agree)
    - 1
    - 2
    - 3
    - 4
    - 5
11. Please rate the extent to which the lack of clear guidelines for document writing according to the standard has impeded implementation in your organisation. (1 = Not Impeding, 5 = Very Impeding)
    - 1
    - 2
    - 3
    - 4
    - 5

12. Having a system that enables automation of processes and provides guidance would significantly help in implementing the standard in your organisation. (1 = Strongly Disagree, 5 = Strongly Agree)
    - 1
    - 2
    - 3
    - 4
    - 5

Please provide any additional comments or feedback you may have regarding the implementation of BIM standards or the ISO 19650 standard