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Decoding ISO 19650 Through Process Modelling for Information Management and Stakeholder Communication in BIM

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Abstract: Poor information management is predominant in construction projects and tends to have a negative effect on project outcomes. The use of technology, in particular building information modelling (BIM), has been promoted to address information management issues. However, the adoption of BIM is fraught with challenges, such as a lack of standardisation and difficulties in effectively adopting standards such as ISO 19650. This research aims to deepen knowledge and improve the management of BIM standards, particularly in using ISO 19650 to collaboratively deliver construction projects by applying process modelling techniques. By employing a mixed-methods approach that combines document analysis and qualitative interviews, this study critically examines the principles and requirements of ISO 19650 and their practical implications. It focuses on how process modelling can clarify complex concepts and improve information management. The findings indicate that process modelling significantly aids in comprehending ISO 19650, making its intricate concepts more accessible to multidisciplinary teams, enhancing stakeholder communication, improving project execution efficiency, and reducing errors and rework. Furthermore, this research emphasises the need to distinguish ISO 19650-derived elements from those adapted from other sources to ensure transparency and integrity in project management practices. The main implications of this study are two-fold. From a research perspective, it contributes to the academic discourse by addressing a critical gap in the literature, which has largely focused on BIM technology implementation rather than the processes and workflows necessary for effective standard adoption. From a practical perspective, this study promotes transparency and integrity in project management practices, enabling organisations to adopt and adhere to standardised practices more effectively in collaborative environments.

Keywords: BIM; common data environment; integrated project delivery; ISO 19650; process modelling; project collaboration

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1. Background

The construction industry is critical to global infrastructure development but is fraught with several challenges that lead to poor project delivery outcomes [1]. These include process and supply chain fragmentation, design issues, and poor coordination [2]. Poor information management is also rife and significantly impacts project costs and schedules. For instance, in 2020, poor project data and miscommunication were responsible for 48% of all reworks in the United States, with the global cost of rework estimated to represent 5%

of all construction spending, or approximately USD 625 billion [3]. An estimated 25% of construction time is lost due to rework caused by information inefficiencies [4]. Additionally, bad data have a profound financial impact on the construction industry. In 2020, bad data cost the global construction industry over USD 1.84 trillion [3]. Additionally, a McKinsey study found that 43% of organisations do not consistently make accurate decisions, and one out of every three poor decisions result from bad data [3]. This suggests that decisions made based on bad data may have had a global rework cost of USD 88.69 billion, or 14% of all reworks performed in 2020 [3].

Technology, particularly digital technology such as building information modelling (BIM), has been crucial in addressing these challenges [5–11]. BIM is a transformative process that enables the generation, storage, and management of digital representations of construction project elements' physical and functional characteristics [12]. By leveraging this capability, effective information management in construction streamlines project delivery and yields substantial financial benefits. Prior research has documented the benefits of BIM for projects, including time savings, cost savings, improved quality, and reduced reworks [8,9]. For example, a study by Li et al. [13] demonstrated that implementing BIM in a Disaster Recovery Centre project in Shanghai led to time-savings of 65.6 days when resolving mechanical, electrical, and plumbing (MEP) design clashes and shortened the construction schedule by three months. This saving is quite significant considering the monetary value of time. A KPMG [14] study highlights the potential for significant efficiency gains, where every GBP 1 invested in information management could result in GBP 5.10 to GBP 6.00 in direct labour productivity improvements and GBP 6.90 to GBP 7.40 in direct cost savings, alongside cost reductions across various asset lifecycle stages ranging from 1.6% to 18%, depending on the stage.

Despite BIM's potential and increasing uptake, the construction industry still encounters substantial challenges. It is asserted that the construction sector still has one of the lowest productivity growth rates, averaging only 1% annually over the past two decades, compared with a 2.8% global average across all industries [15]. This slow growth is often exacerbated by inadequate information management, with estimated costs of poor data miscommunication and data fragmentation costing up to USD 1.8 trillion globally in 2019 [4]. Additionally, earlier implementations of BIM to address issues of information management suffered common challenges, such as the lack of standardisation of processes and procedures and uncertainties about roles and responsibilities, among others [16]. These challenges limit the benefits achieved by adopters of BIM.

ISO 19650, which evolved from the British Standard BS 1192 and PAS 1192-2, offers a structured framework for managing information across the lifecycle of built assets. It provides standards for information creation, exchange and storage processes and enhances collaboration among team members. Although studies of the quantitative benefits of complying with ISO 19650 are rare, a recent study indicates a reduction of BIM coordination and management costs by about 70%, project management costs by about 10%, and overall data management costs during the design and construction phase by about 15% [17]. The same study reveals a time saving of up to 50% during programming and project ramp up phases, and an increase in internal productivity by up to 40% [17].

The ISO 19650 standard is, however, text-based and complex. Notably, Malla et al. [18] argued that these contribute significantly to professionals' having difficulties in interpreting and understanding it. This issue is further exacerbated by the limited training in BIM and the relevant standards guiding its implementation. For instance, a survey by the National Building Specification (NBS) in 2021 indicated that only 30% of construction professionals feel adequately trained to utilise BIM to its full potential [19]. The existing body of research predominantly addresses BIM technology implementation and associated challenges but lacks a detailed exploration of the processes and methodologies for effective information management as prescribed by ISO 19650. The ISO 19650 standards focus on the information management process, providing a comprehensive framework for managing BIM-related information throughout project lifecycles.

Understanding BIM standards, particularly ISO 19650, is crucial for effective implementation [12,18], and one way to demystify its complexity is through graphical process and knowledge representation understanding. Ref [20] demonstrated that a graph-based approach for unpacking construction processes, sequence analysis and evaluating schedules significantly improved efficiency. Another study by Kulkarni et al. [21] showed that transforming text into visual representations, such as mind maps, flowcharts, and summaries, significantly enhances information retention, overcoming the challenges of remembering and digesting information from multiple sources. Thus, there has been growing interest in using process models to represent knowledge within the construction discipline. Specifically, BPMN has gained significant popularity in this context. For instance, the integration of BIM, BPMN, and decision model and notation (DMN) has been employed to model knowledge in railway design [22]. Despite being in existence for over four years, ISO 19650 remains relatively nascent and has recently garnered attention among researchers. This growing interest has also highlighted limited but emerging research on BPMN applications in this domain. Ref [23] used BPMN to model the steps an appointing party must follow to comply with ISO 19650, culminating in the creation of a dozen technical guide templates outlining the appointing party's BIM journey. Similarly, a study by Meschini et al. [24] utilised BPMN 2.0 to propose a model-based, open-source redefinition of the process for the Italian design-build procurement approach. These studies underscore the potential of BPMN in addressing aspects of ISO 19650. However, they also reveal a scarcity of comprehensive research that thoroughly addresses the challenges and complexities involved in understanding and implementing ISO 19650.

This research investigates and demonstrates how knowledge elicitation and representation using process modelling deepens knowledge and facilitates the operationalisation of complex text-based BIM standards based on ISO 19650, offering significant contributions to both academic discourse and industry practice. Systematically representing and visualising BIM processes enables the formulation of more effective and efficient information management strategies for construction project delivery [22]. Process modelling is an aspect of design science or design research. Theories that influence design science research can be either descriptive or prescriptive, that is, kernel (contributing to problem understanding or design theories which help in developing guidance, methods or processes [25]. This study combines aspects of both. The first objective focuses on investigating the challenges and issues that are likely to be encountered when undertaking information management during the lifecycle of construction projects and understanding how ISO 19650 can be applied to address these challenges. The second objective focuses on identifying and mapping out the concepts and processes of information management using ISO 19650. The third objective identifies the interdependencies and deliverables between the main ISO 19650 standards. The last objective identifies the benefits and challenges in representing ISO 19650 workflows as process models.

The rest of the paper is structured as follows: Section 2 reviews the relevant literature, focusing on the information flows, roles and responsibilities of stakeholders in information management, as well as the concepts and requirements outlined in ISO 19650. Section 3 outlines the methodology, emphasising the iterative design and evaluation process. Section 4 presents the findings and discussion. Finally, Section 5 concludes the paper, highlighting key implications, limitations, and directions for future research.

2. Literature Review

2.1. Information Flow in Building Lifecycle

According to ISO 19650-1, information is a reinterpretable representation of structured data for easy communication, understanding, or processing. Information can be categorised as structured (such as geometric models, schedules, and databases)—which facilitates automated processing and analysis—and unstructured (such as documentation and recordings)—which lacks a predefined structure, posing systematic processing and interpretation challenges. This differentiation underscores the complexity of managing information across various contexts within the construction industry and the necessity for clear and accessible data presentation. Information management, as outlined in the UK BIM Framework [26], involves ensuring timely and accurate delivery of specific information to the intended location for a predetermined purpose. Information management is crucial in maintaining or improving construction projects' efficiency, productivity, and level of success. Effective information management practices enable better decision-making, streamline project workflows, and reduce costly errors and rework [14].

The process of information flow relates to information management. The concept of information flow within a building lifecycle encompasses the systematic generation, management, and application of data from the initial design phase to construction, operation, maintenance and eventual building decommissioning [27]. Figure 1 illustrates the data flow in each stage of the lifecycle, providing a visual representation of how information moves seamlessly and is managed across the different phases of the building lifecycle, thereby highlighting the vital role of effective information management in enhancing project outcomes.

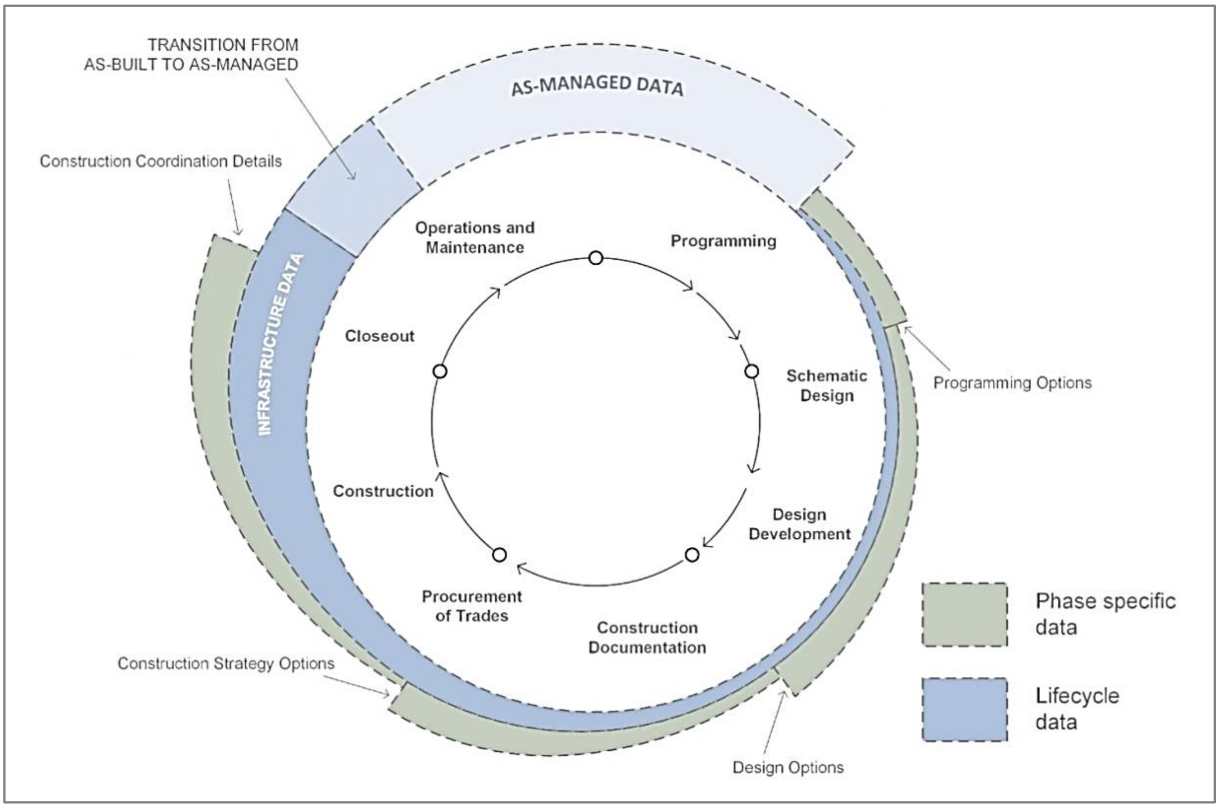

Figure 1. Information flow across building lifecycle phases (Source: [28]).

Effective information management is vital throughout the building lifecycle. Ref [29] (2021) underscores the interconnectedness of the planning, design, construction, and operation phases, emphasising the need for seamless communication among stakeholders. BIM is a digital tool that captures and represents all building data throughout its lifecycle. Unlike traditional CAD, BIM designs include more than geometrical design information. They may include design, cost, material, spatial data, and more, enabling information-driven decision-making by providing insights into real-life structures [30]. Zhang et al. [31] emphasise the adoption of BIM and digital twins as a cornerstone for this process, facilitating a cohesive and interactive data ecosystem that supports real-time analytics, predictive maintenance and collaborative stakeholder engagement. Ref [12] emphasised the importance of embracing digital tools such as BIM and implementing standardised processes to bolster construction project outcomes. This approach facilitates enhanced coordination, minimises rework, and significantly boosts project efficiency and reliability [6,32].

2.2. Roles and Responsibilities of Stakeholders in Information Management

As there have been some changes to traditional roles in implementing BIM, the importance of adequately delineating roles and responsibilities in managing information in BIM-enabled projects has been argued in the literature [33,34]. The ISO 19650 standard emphasises responsibility for collaboration across project teams, prescribing specific roles such as the appointing party (e.g., client), lead appointed parties (e.g., main contractors), and appointed parties (e.g., subcontractors), each tasked with specific responsibilities within the information management function [26]. Elaborating on this, the UK BIM Framework [26] specifies that the appointing party is accountable for assigning this information management, ensuring clear and coherent role execution. Lead-appointed parties focus on information management at an appointment level and are tasked with developing BIM execution plans and sustaining robust information delivery plans. Meanwhile, appointed parties have the responsibility for creating, reviewing, and delivering information by established requirements and standards. Therefore, it is crucial for all stakeholders involved in implementing BIM to clearly understand their roles and develop the necessary skills and capacity to fulfill these responsibilities effectively.

2.3. Managing Construction Information Using CDEs

The common data environment (CDE) is a dynamic central digital repository intended to be the single source of 'truth' about project information. This platform eases data handling throughout the project lifecycle [35] and supports collaboration by ensuring all project-related information is consistent, accessible, and accurate [36–38]. The CDE comprises components essential for effective construction project management, integrating process workflows and technical elements such as software tools. This integration allows for the collection, maintenance, sharing, and management of data in a single repository [29]. Important elements of the CDE include the information container, which can take several forms. Each container/sub-container has the necessary metadata essential for accurate data classification and access control [35]. Collaborating on a CDE significantly enhances construction project management by streamlining data transfers, reducing coordination time and costs, and minimising the need for manual rechecks [39]. Additionally, CDEs facilitate effective knowledge transfer throughout the building lifecycle, promoting a dynamic system that adapts and evolves [40].

Despite the benefits of CDEs, implementing them is challenging ([5,10,41]). Issues include limited database synchronisation, data isolation, and interoperability problems among domain-specific tools, which affect data quality and software compatibility ([38,42]). Vendor-specific BIM data access and the need for APIs further complicate open format initiatives [43]. Additionally, construction SMEs (small and medium enterprises) often lack the technical skills to effectively use cloud-based systems and BIM software [38].

Security concerns about privacy and unauthorised access, alongside the high costs linked with CDE tools, also hinder investment [38,42]. Lastly, the information structure of most CDEs does not align with ISO 19650. These challenges highlight the need for training, interoperability, and technology adoption to fully exploit the benefits of CDEs in managing construction information.

2.4. ISO 19650-2 as a Solution for Effective Information Management

The ISO 19650 is designed to support the collaboration of stakeholders in a construction process, ensuring that information is available when needed, thereby reducing waste and increasing efficiency. BS 1192, before the publication of the ISO 19650 series, provided guidelines for managing digital construction data, mainly focusing on collaboration and the CDE [44]. While now superseded, its principles continue to influence current practices, emphasising collaborative work practices and the importance of clear data structures and naming conventions [45]. Shillcock [44] and Ford [45] delve into the complexities of adopting ISO 19650, emphasising that moving from PAS 1192 to this new standard requires considerable modifications in the industry's existing processes. Integrating ISO 19650 into pre-existing systems demands a transformation of the tools and procedures used and necessitates a cultural shift within organisations. This underlines the necessity for thoroughly comprehending the standard's real-world application and adopting a deliberate strategy for its implementation [45].

To facilitate understanding, examining the principal components of the ISO 19650 series is imperative. *ISO 19650-1: Concepts and principles related to BIM* [46] establishes the concepts and principles for information management. It outlines the framework for managing information, including creating, operating, and maintaining built assets based on BIM principles [12]. *ISO 19650-2: Delivery phase of the assets* [46] focuses on the delivery phase of construction projects, detailing the management processes and production of information models. It guides the collaborative production of information, ensuring it meets quality, time, and cost requirements [12]. *ISO 19650-3: Operational phase of the assets* [46] provides guidance on using information management processes to support asset management. This phase is crucial for maintaining and utilising built asset data over their lifecycle [47]. *ISO 19650-4: Information exchange* [46] details the mechanisms for exchanging information between involved parties, promoting interoperability and efficient data exchange throughout the asset lifecycle [47]. *ISO 19650-5: Security-minded approach to information management* [46] introduces a security-minded approach to managing building information models and other related information. This part is essential for ensuring that sensitive information is appropriately protected, considering the increasing cyber threats in digital information management [47].

It is essential to highlight another cornerstone of BIM standards—data exchange standards, particularly the Industry Foundation Classes (IFC). Developed by buildingSMART, IFC is pivotal for enabling interoperable data exchange within the building and facility management industry [48]. By establishing a common language for describing the building and civil engineering project data, IFC allows diverse software applications to seamlessly communicate and exchange information across the entire lifecycle of a building, from conception through to demolition [49]. IFC data can be represented in various formats, including XML, JSON, and STEP, and can be utilised through different mediums such as web services, files and databases [49].

ISO 19650-1 & 2 primarily focus on a project's design and construction stages. They are designed for individuals and organisations involved in the procurement, design, construction, and commissioning of built assets and those engaged in asset management activities, encompassing operations and maintenance [12]. ISO 19650-2 emphasises the role of information management in the delivery phase of construction projects, focusing on the structured and systematic handling of information. It outlines the responsibilities and processes necessary to ensure efficient, accurate, and interoperable exchange of information across project teams. At its core, part 2 advocates for a methodical approach to managing project information, leveraging digital technologies to enhance communication, coordination and collaboration among stakeholders [26].

The standard introduces a framework for appointing and delegating the information management function, underlining the need for clear accountability and responsibility across the project hierarchy. This includes establishing an information assignment matrix, a tool designed to comprehensively delineate tasks and responsibilities related to information management activities. A critical aspect of ISO 19650-2 is the focus on developing and implementing project-specific information standards, including the project's information production methods and procedures. These standards are crucial for maintaining consistency and quality in information exchange, ensuring all project participants are aligned with the agreed-upon protocols and formats [26]. Furthermore, the standard addresses the generation, quality assurance, and sharing of information models, emphasising the importance of a collaborative and integrated approach to producing and managing digital representations of a project's physical and functional characteristics. This approach extends to information model review and authorisation processes, ensuring they meet the project requirements [26].

2.5. Applying BIM Standards in CDE

ISO 19650-2 requires the use of a CDE to facilitate the collaborative generation and dissemination of information among project teams and stakeholders [36]. An information container progresses through various stages, each with a defined purpose and set of permissions. These stages ensure information moves coherently and securely throughout the project lifecycle [12]. Figure 2 explains the progression of an information container through distinct phases within the CDE.

An information container's lifecycle begins in the work-in-progress (WIP) stage (Figure 2), where task teams develop information independently. When the information is deemed to be the required standard for that stage of the work, it is checked, reviewed, and approved to move to the shared stage, allowing for collaborative refinement. Information that satisfies the requirements then progresses to the published stage, marking its readiness for use in construction. Finally, the archive stage is a repository for past versions and changes, maintaining a comprehensive audit trail of the information's development [35].

ISO 19650 outlines a structured workflow within the CDE with gateways at critical points, such as transitioning from WIP to shared or published, where authorisation controls ensure information quality [36]. Metadata assignment to information containers is an important process, facilitating the transition of information through the CDE workflow and ensuring that each piece of data is appropriately classified and utilised according to the project phase it supports [35]. Incorporating ISO 19650 principles into CDE establishes a foundation for information management that promotes efficiency, minimises errors, and underpins secure collaboration throughout the project lifecycle.

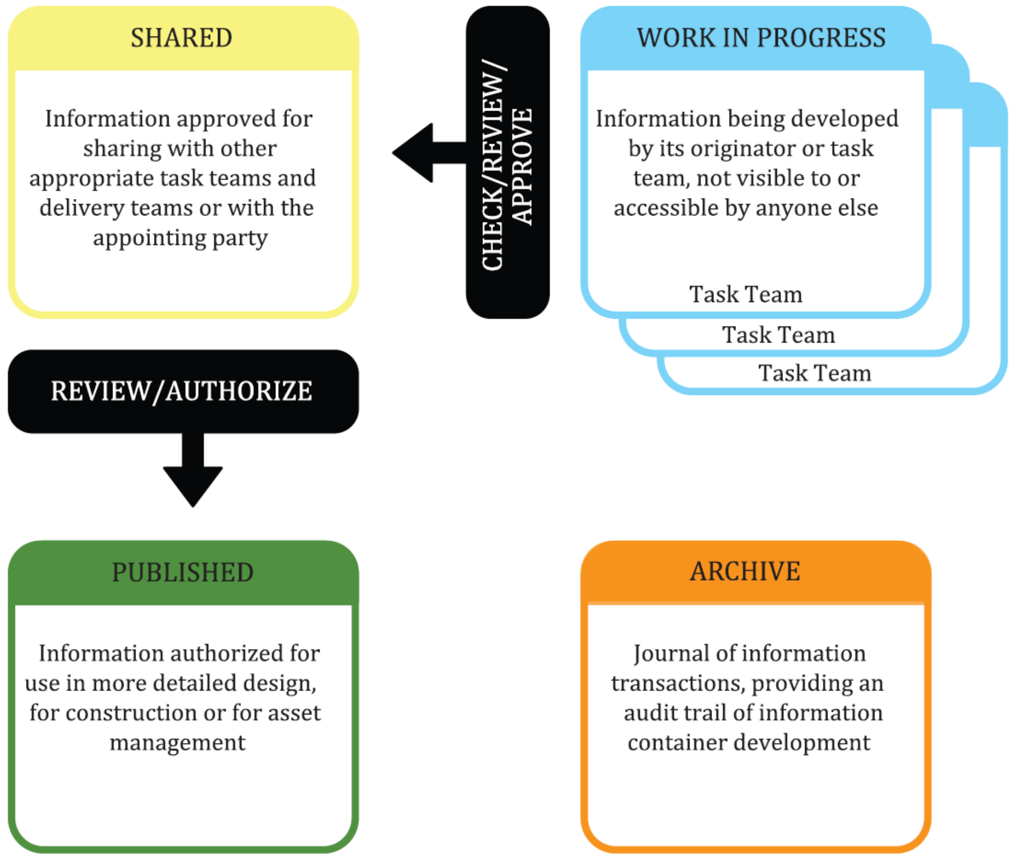

Figure 2. The framework of common data environment (CDE) (Source: [50]).

2.6. Process Modelling

Process modelling tools, including business process modelling and notation (BPMN) and unified modelling language (UML), are quite important in the representation process of the ISO 19650 workflows. For example, BPMN provides a standard way of capturing business processes through a graphical representation for discussion among stakeholders in a bid to define workflows. Similarly, UML is used in general domains and in the BIM environments to assist in the modelling of information requirements so as to increase the interoperability of the different systems [51]. These tools are useful in understanding complicated processes because they provide visual representations that ease communication and analysis of the same [52]. Using BPMN and UML to model ISO 19650 workflows can enable formally manually operated and time-consuming processes to be automated. With the help of these tools, the organisation can define, execute, and verify processes efficiently [53]. Additionally, the incorporation of BPMN and UML as part of software engineering approaches supports the development of platform requirements and specifications for governance systems in, for example, the construction domain [54]. Furthermore, object-oriented modelling techniques such as UML augment the mapping of design models and performance simulations attached to the BIM applications [55]. This approach further improves the quality of data translation and supports the development of BIM standards [56]. Additionally, by integrating BPMN and decision model and notation (DMN), engineering knowledge is formalised with transparency during design processes [22].

BPMN 2.0 has complex and extensive features that present excellent benefits for managing complex projects in the built environment. According to the object management group (OMG), BPMN 2.0 is developed using a standard notation that is highly intuitive and can be understood by all business users, from the business analysts who create preliminary process drafts to the technical developers who implement these processes and finally, the project managers who manage these processes [57] (OMG, 2016). In view of this, standardisation is crucial in ensuring effective communication that is smooth and well-managed in the workflow of a construction project, which normally comes with great complexity and involves many stakeholders. BPMN 2.0 comes with a host of graphical elements, each with varying functionalities when incorporated in a process diagram: flow objects (events, activities, gateways), connecting objects (sequence flow, message flow, association), swim lanes, and artefacts [57].

2.7. Representing ISO 19650 1-2 Knowledge Using BPMN 2.0

Modelling ISO 19650-1 & 2 knowledge using BPMN 2.0 can effectively improve the understanding of their requirements. ISO 19650 describes the methodologies for managing digital information over the life cycle of the constructed asset. Using BPMN to document these processes can ensure that the necessary data exchange or project coordination procedures are represented graphically and simplified. Additionally, BPMN's flexibility allows it to adapt to the peculiarities of construction projects, catering to distinctive workflows and interfacing with other project management tools.

The literature underscores significant challenges in information management across construction project lifecycles, including inefficiencies in project delivery, cost management, and quality assurance. For example, 52% of global rework is attributed to poor project data and miscommunication, which resulted in a staggering USD 280 billion in costs in 2018 [4]. While BIM, particularly through ISO 19650, offers a framework to address these challenges by enhancing information flow and collaboration [58], critical research gaps persist. These gaps hinder the effective adoption and implementation of ISO 19650, thereby limiting its full potential in improving project outcomes.

One major gap lies in the inconsistent adoption of ISO 19650 among stakeholders. A lack of understanding and familiarity with its processes often leads to misinterpretation of roles and responsibilities, such as those of appointing parties, lead-appointed parties, and appointed parties [12,14]. This inconsistency not only affects project coordination but also undermines the standardisation necessary for effective information management. Furthermore, the resistance to adopting new technologies, coupled with the construction industry's slow digital transformation, exacerbates these challenges, leaving many projects reliant on outdated and inefficient methods.

Another significant challenge is the ineffective management of structured and unstructured information. While ISO 19650 provides guidance on handling structured data, such as geometric models and schedules, the systematic processing of unstructured data, like documentation, remains problematic [26]. This gap creates inconsistencies in the accuracy and accessibility of information, particularly in large-scale and complex projects. Additionally, the limited exploration of interoperability and automation in workflows further compounds these inefficiencies. Current approaches to coordination lack the integration of tools and systems that facilitate seamless data exchange and automated processing, resulting in bottlenecks and errors [52].

Existing approaches to workflow representation also exhibit weaknesses, primarily due to fragmented and inconsistent practices. While process modelling tools such as BPMN and UML are identified as valuable for representing workflows, their application in the construction sector is limited. This underutilisation hinders the standardisation and clarity needed for effective collaboration [57]. Furthermore, existing research tends to focus predominantly on technical aspects, often neglecting the critical role of stakeholder engagement and training. This oversight leaves many stakeholders—particularly those less technologically adept—ill-prepared to implement and benefit from ISO 19650 workflows.

Given these persistent gaps and weaknesses, there is a pressing need for a new approach to BIM-based information management. This approach should prioritise the standardisation of workflow representation through advanced process modelling tools like BPMN and UML, which can create clear, actionable workflows aligned with ISO 19650. Additionally, integrating automation and interoperability into information management practices is essential to reduce manual errors and improve data translation quality. Addressing the human and organisational aspects, such as stakeholder engagement and targeted training, is equally important to ensure broader and more consistent adoption of ISO 19650.

This study adopts a process-oriented perspective, emphasising the use of process modelling tools to decode ISO 19650 workflows and address existing coordination challenges. By focusing on automation, interoperability, and stakeholder engagement, the research seeks to bridge the divide between theoretical frameworks and practical applications. This perspective is essential for overcoming current limitations and paving the way for more efficient, standardised, and collaborative construction project delivery.

3. Research Methods

Figure 3 depicts the research process used for the study and the relationships between the steps for easy understanding.

The main methods used in undertaking this study are document analysis and qualitative in-depth interviews. Employing the document analysis approach, a systematic approach was used to review and/or evaluate documents—both printed and electronic versions of ISO 19650-1 & 2. The UK BIM Framework for Guidance documents (printed and electronic) were used to clarify the concepts in the standards. The printed version allowed for themes to be made bold-marked in different colours to facilitate organisation and understanding, while electronic versions allowed for the rapid search of terms. The identified concepts were examined and interpreted in order to elicit meaning, gain understanding, and develop empirical knowledge. Upon completion of the elicitation process, the modelling process was undertaken using BPMN 2.0 and MS Visio 2024.

Once the authors were satisfied with the key concepts and their interdependencies, the process models were validated through in-depth interviews with experts. A qualitative approach enables a nuanced exploration of the process models and offers an opportunity to engage the participants in in-depth discussions about their practical understanding of ISO 19650 standards application in a real-world setting and how well the process models represent the requirements, facilitating a better understanding of the concepts, requirements and procedures [59,60].

The interviewees were selected using purposive sampling, targeting respondents who had extensive experience in ISO 19650 and active involvement in BIM projects. Out of the 20 professionals approached, eight agreed to participate, providing valuable input from diverse professional roles. While there is no universally agreed-upon benchmark for the number of interviewees in a qualitative study [61,62], Guest et al. [62] observed that saturation is often achieved within the first 12 interviews, with core themes emerging as early as six interviews. In this study, the participation of eight interviewees, exceeding the minimum threshold identified for thematic emergence, is deemed sufficient and acceptable.

Each participant offered a unique perspective on the applicability and challenges of BIM and ISO 19650 standards, enriching the study with a broad range of insights. The list of the interviewees is presented in Table 1.

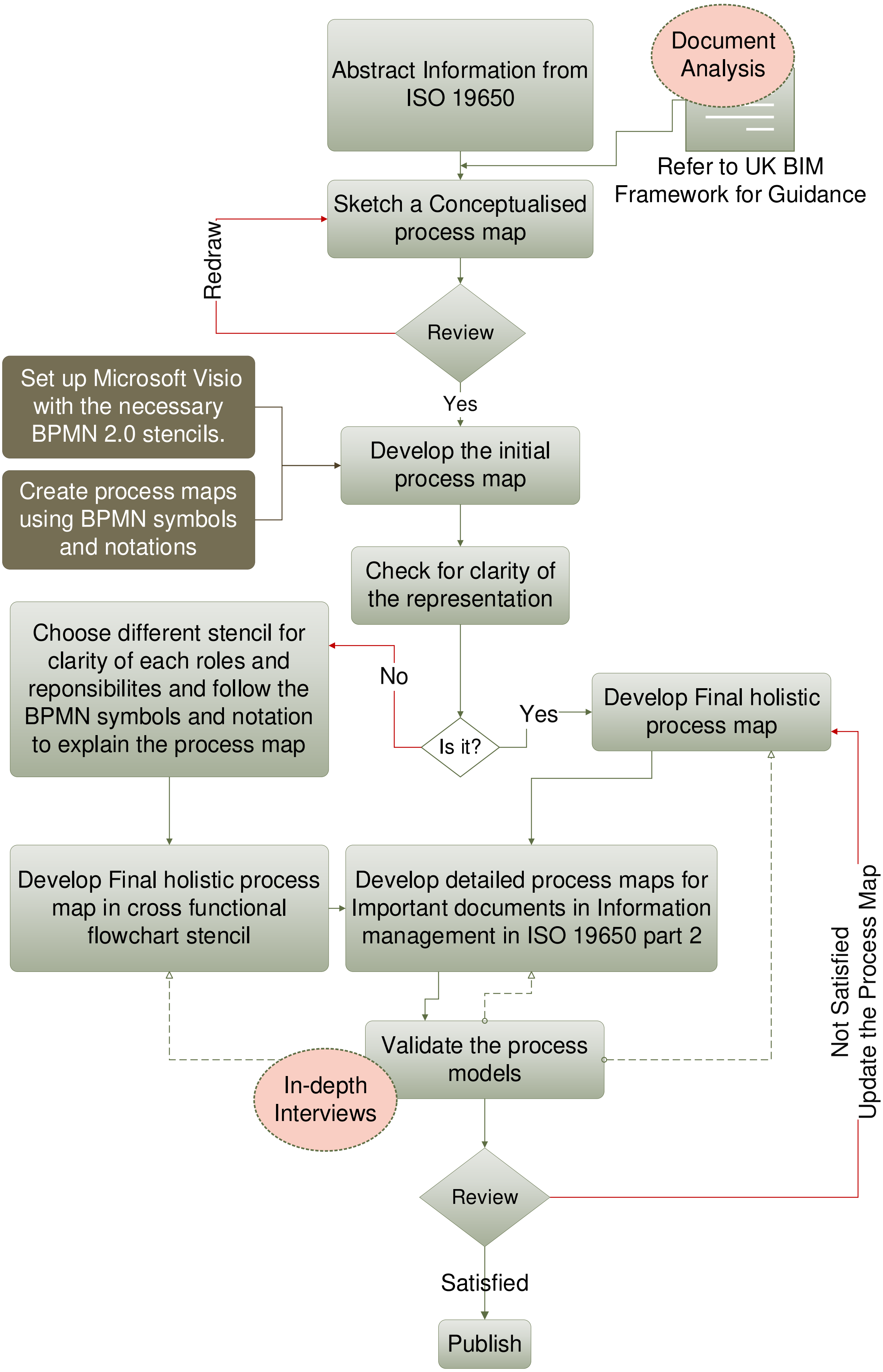

Figure 3. Research design.

Table 1. Participant Profile. [Source: authors'].

Participants	Experience	Current Role	Organisation Type
Participant 1	6 Years	MSc BIM graduate student	BIM Consultancy
Participant 2	6 Years	Digital Coordinator	Multi-Disciplinary Consultancy
Participant 3	3 Years	BIM Coordinator	BIM Consultancy
Participant 4	5 Years	BIM consultant	BIM Consultancy
Participant 5	12 Years	Founder of a BIM firm	BIM/Sustainability Consultancy
Participant 6	20 Years	Senior lecturer	School of Built Environment
Participant 7	6 Years	BIM Architect	Architectural Firm
Participant 8	14 Years	BIM Manager	Architectural Firm

To ensure the interviews are fit for purpose given the technical nature of the domain, the process maps and a video about their development were sent to prospective interviewees [63]. BPMN 2.0 is used in the process maps to show all the steps outlined in ISO 19650-2 [64]. To ensure optimal visibility, the models were developed on A3-sized sheets. Reducing them to A4 size may impact their clarity. To address this, all original A3 files have been uploaded to a GitHub repository [64]. Additionally, metadata about the process models are included in the file **DTR-DTG** within the same repository [64]. Readers are therefore encouraged to consult the GitHub repository if Figures 4–10 in this manuscript appear unclear.

3.1. ISO 19650 Information Delivery Phase of the Assets Process Model

Figure 4 shows the full process model for the assets' information delivery phase. The model is structured to clearly show decision points and how information flows during key stages such as task initiation, information production, and collaborative production of information are mapped out (ISO 19650-2 [50]; clause 5.1–5.8). Figure 4 [64] depicts the whole ISO 19650-2 process model.

3.2. Process Model of Information Requirements

The steps for establishing information requirements according to ISO 19650-2 are detailed in Figure 5. It includes project information requirements (PIRs), employer's information requirements (EIRs), asset information requirements (AIRs), and organisational information requirements (OIRs). Each section shows the flow and structure of information required at different stages of a project's lifecycle. Also, each information requirement shows what information needs to be defined, as ISO 19650-2 requires, with additional guidance from the UK BIM Framework and templates provided by the Centre for Digital Built Britain. Refer to Figure 5 [64] for the information requirements process model.

3.3. Process Model of Pre and Post-Appointment BIM Execution Plan

Figure 6 states the steps involved in the pre-appointment BIM execution plan process. It starts with the delivery team's pre-appointment and going through different strategic and operational tasks like assigning roles and responsibilities, developing delivery strategy, identifying information container structure and establishing information production methods and procedures as specified in ISO 19650-2, with additional guidance from the UK BIM Framework and templates provided by the Centre for Digital Built Britain. Refer to Figure 6 [64]—pre-appointed BIM execution plan process model.

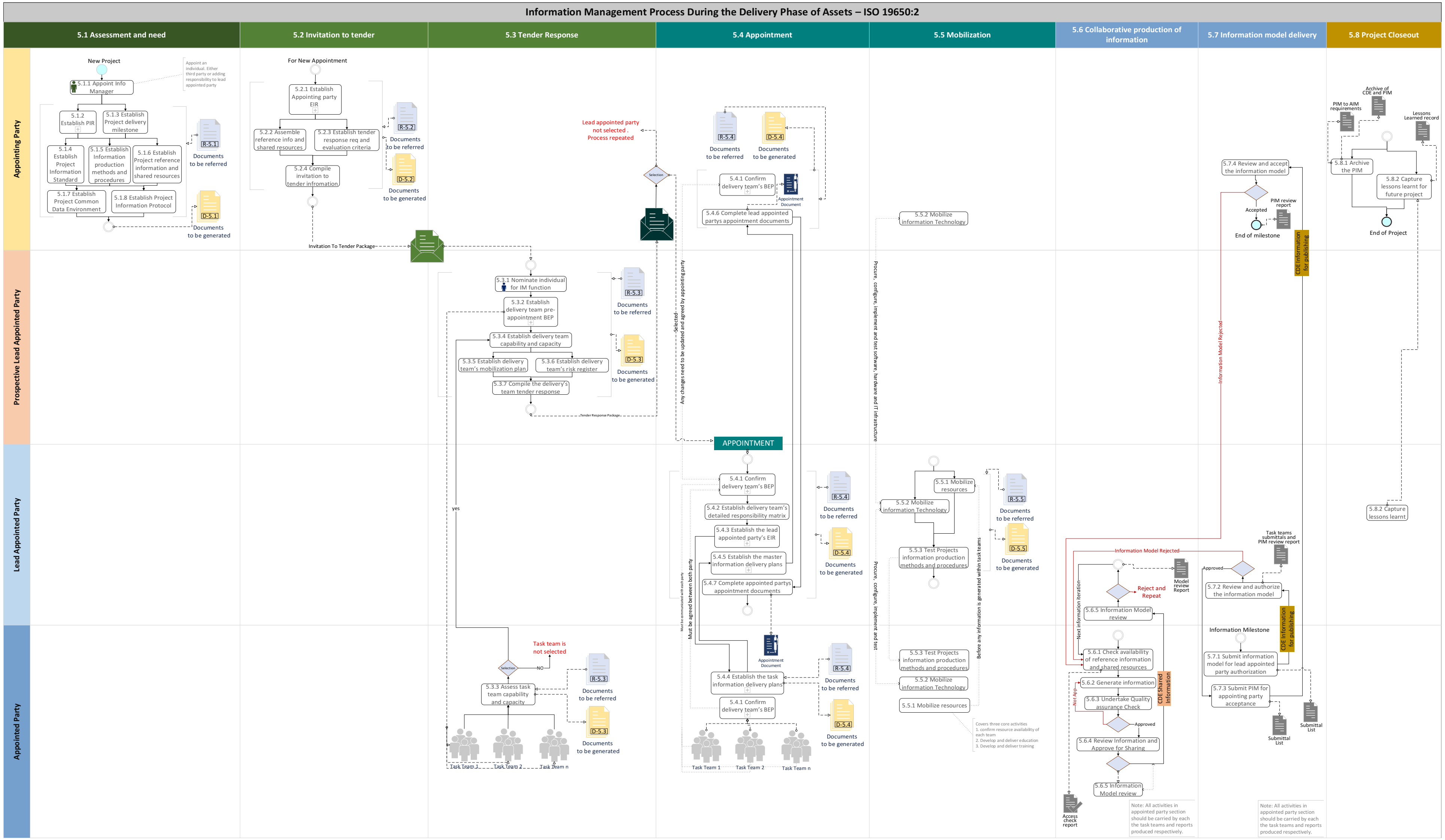

Figure 4. Holistic Process Model of ISO 19650-2—Information delivery phase of assets. [Content derived from ISO 19650-1& 2 [50,65], UK BIM framework [26,35].

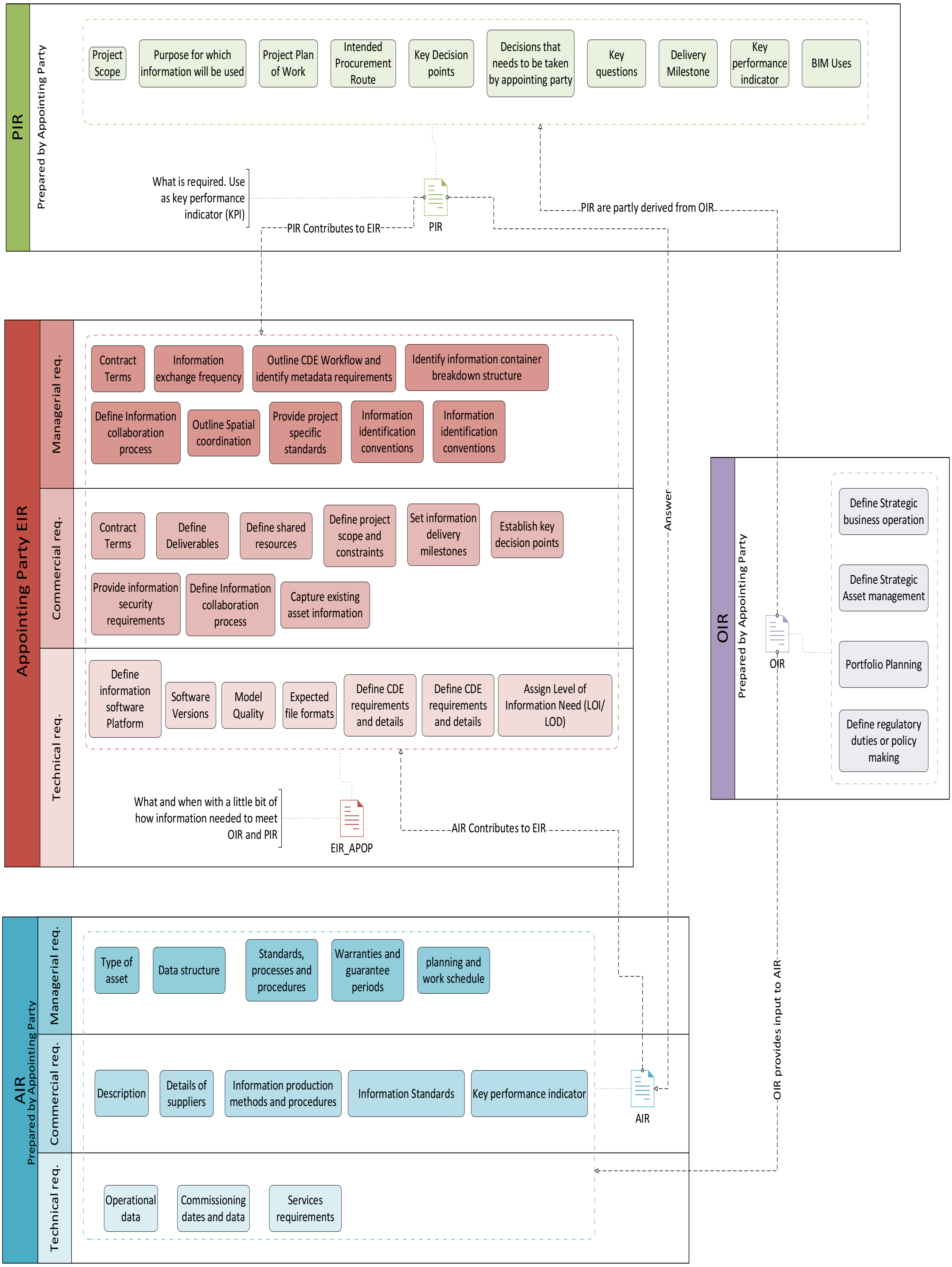

Figure 5. Information requirements process model. [Content derived from UK BIM framework ([26,31]; ISO 19650-1 & 2 [50,65], CDBB [66]).

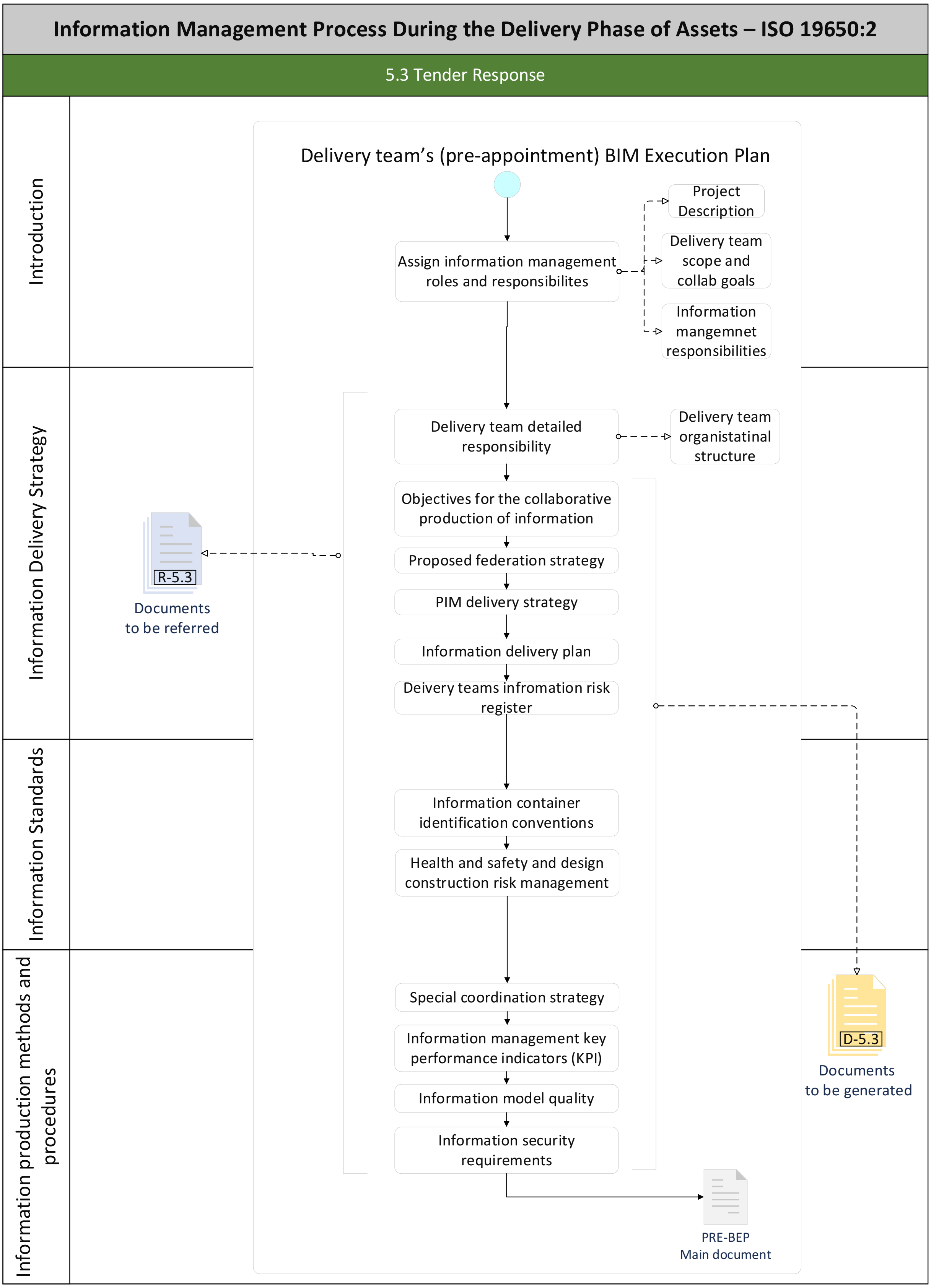

Figure 6. Pre-appointment BIM execution plan process model [content derived from UK BIM framework [26,35]; CDBB [66], ISO 19650-1 & 2 [50,65].

Figure 7 outlines the sections that need to be included after the delivery team's appointment, detailing the expanded roles and responsibilities of the delivery team under the updated EIRs. It covers a wide array of activities, from project information management and coordination standards to security requirements and data publishing protocols as specified in ISO 19650-2. This is also complemented by additional guidance from the UK BIM Framework and templates provided by the Centre for Digital Built Britain. Refer to Figure 7 [64]—post-appointment BIM execution plan process model.

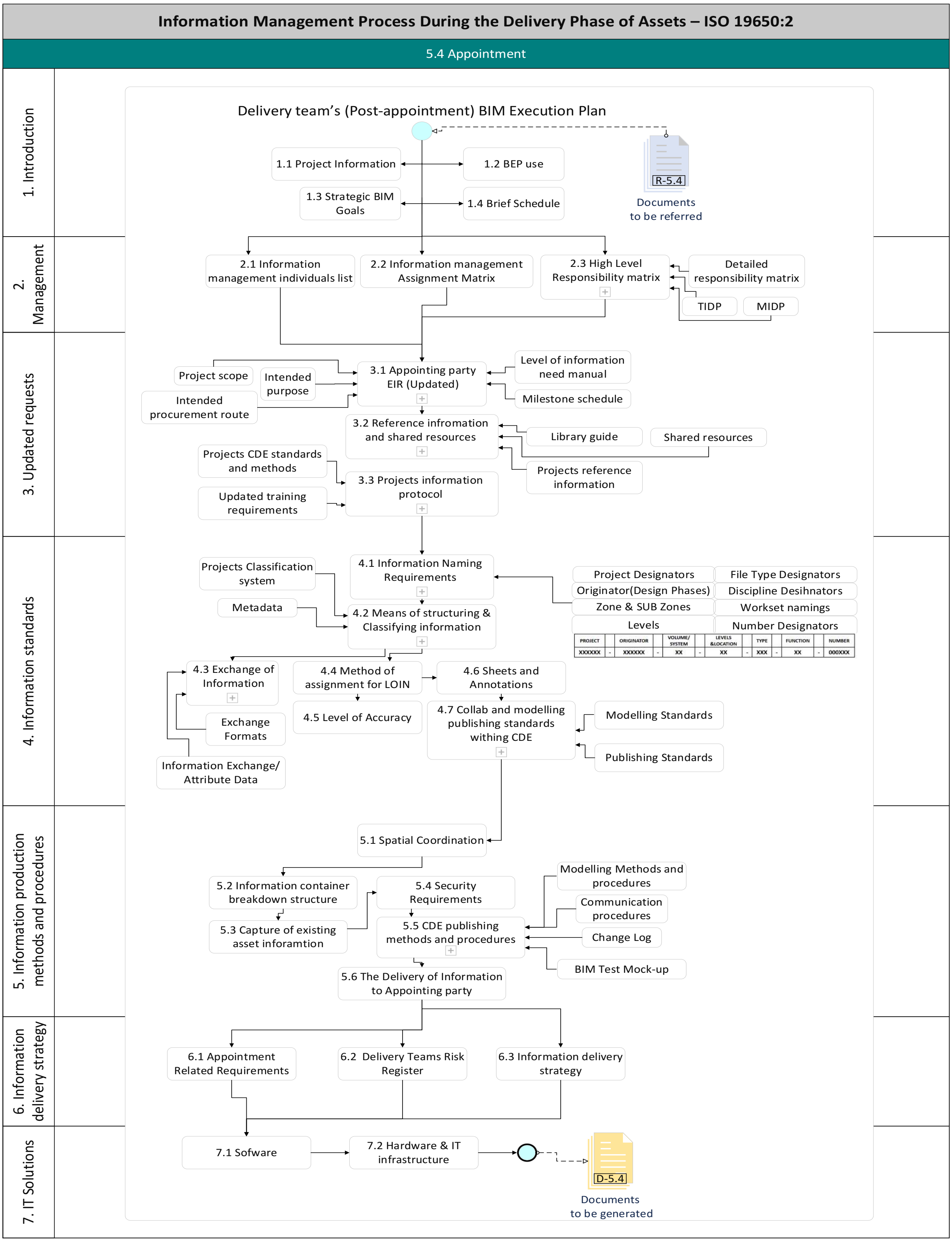

Figure 7. Post-appointment BIM execution plan [content derived from UK BIM framework ([26,35]; CDBB (2022) [66]; Archimco [67], ISO 19650-1 & 2 [50,65]).

3.4. Process Model of Lead Appointed Party Exchange Information Requirement and MIDP

Figure 8 shows what the lead-appointed party needs to do to define and manage the EIRs. This includes defining levels of information need (LOIN), levels of accuracy (LOA), and model information summary (MIS). This process map was developed using the UK BIM Framework guidance and available templates. Refer to Figure 8 [64]—Lead-appointed party EIR process model.

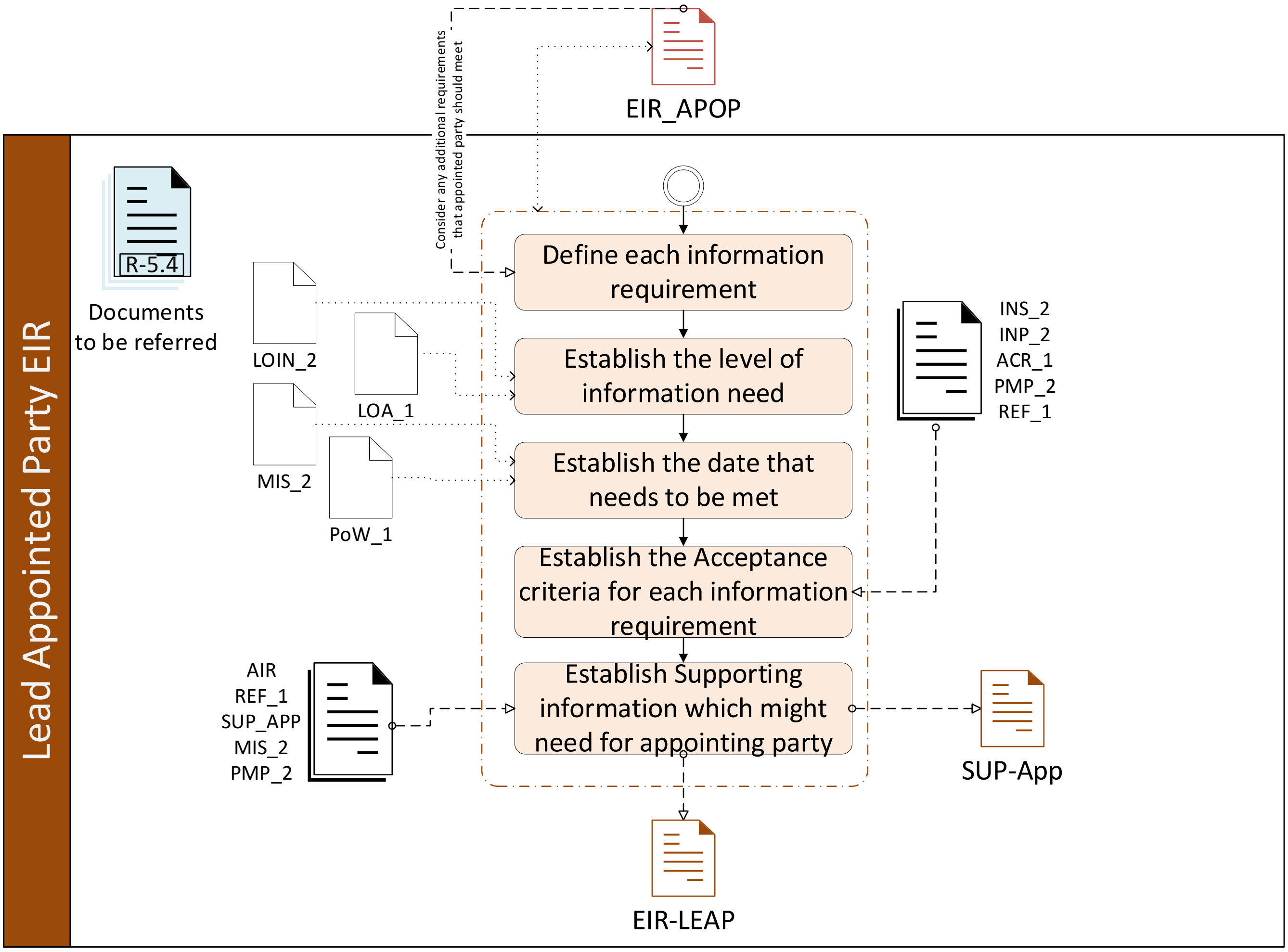

Figure 8. Lead appointed party EIR process model [content driven from UK BIM framework [26,35]; CDBB [66], ISO 19650-1 & 2 [50,65].

Figure 9 displays the workflow between task teams, creating task information delivery plans and combining them into an MIDP. The TIDP determines information requirements, scope, formats, and tools. The MIDP aggregates all TIDPs to identify gaps and misalignments and determine the final deliverables, which comprise models, drawings, specifications, and timelines as per ISO 19650-2. Refer to Figure 9 [64]—MIDP and TIDP process model.

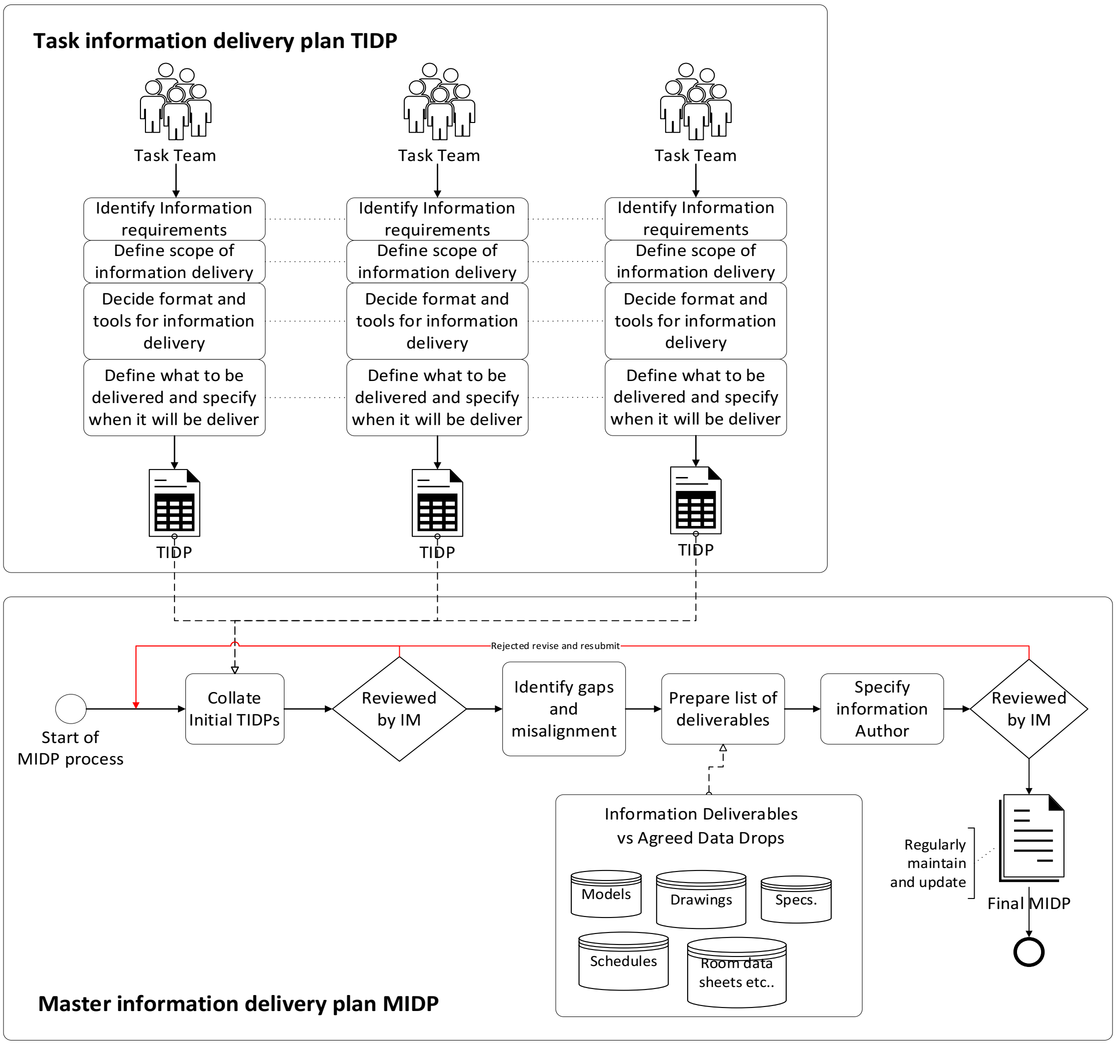

Figure 9. Process model of MIDP and TIDP [content derived from UK BIM framework [26,35]; CDBB [66], ISO 19650-1 & 2 [50,65].

3.5. Process Model of Workflow in Common Data Environment

Figure 10 shows the ISO 19650 collaboration workflow for project information modelling (PIM) production using the CDE. This method streamlines BIM data sharing and approval during a construction project. The start of PIM Production: Each model is appraised for its LOIN and submitted for verification. Based on comments, models may be updated, resubmitted, or progressed for approval. Shared Section: An interface manager spatially coordinates models to resolve disputes in the shared section. To ensure integrated models, proposed solutions must be authorised by the lead designer or contractor. The CDE publishes models if the information manager approves them. The delivery manager either certifies models as complete or requests adjustments. CDE's published part receives certified models for wider availability. Project information models are sent to the CDE repository to complete the procedure. The common data environment's information management cycle is completed by storing all documents for future reference. BS EN ISO 19650-2 does not encompass information management roles. Instead, the entire range of operations involved in the information management process will be carried out by a single "information management function." Different real-world roles like interface manager and information manager have been used to better understand the workflow. Refer to Figure 10 [64]—workflow in common data environment.

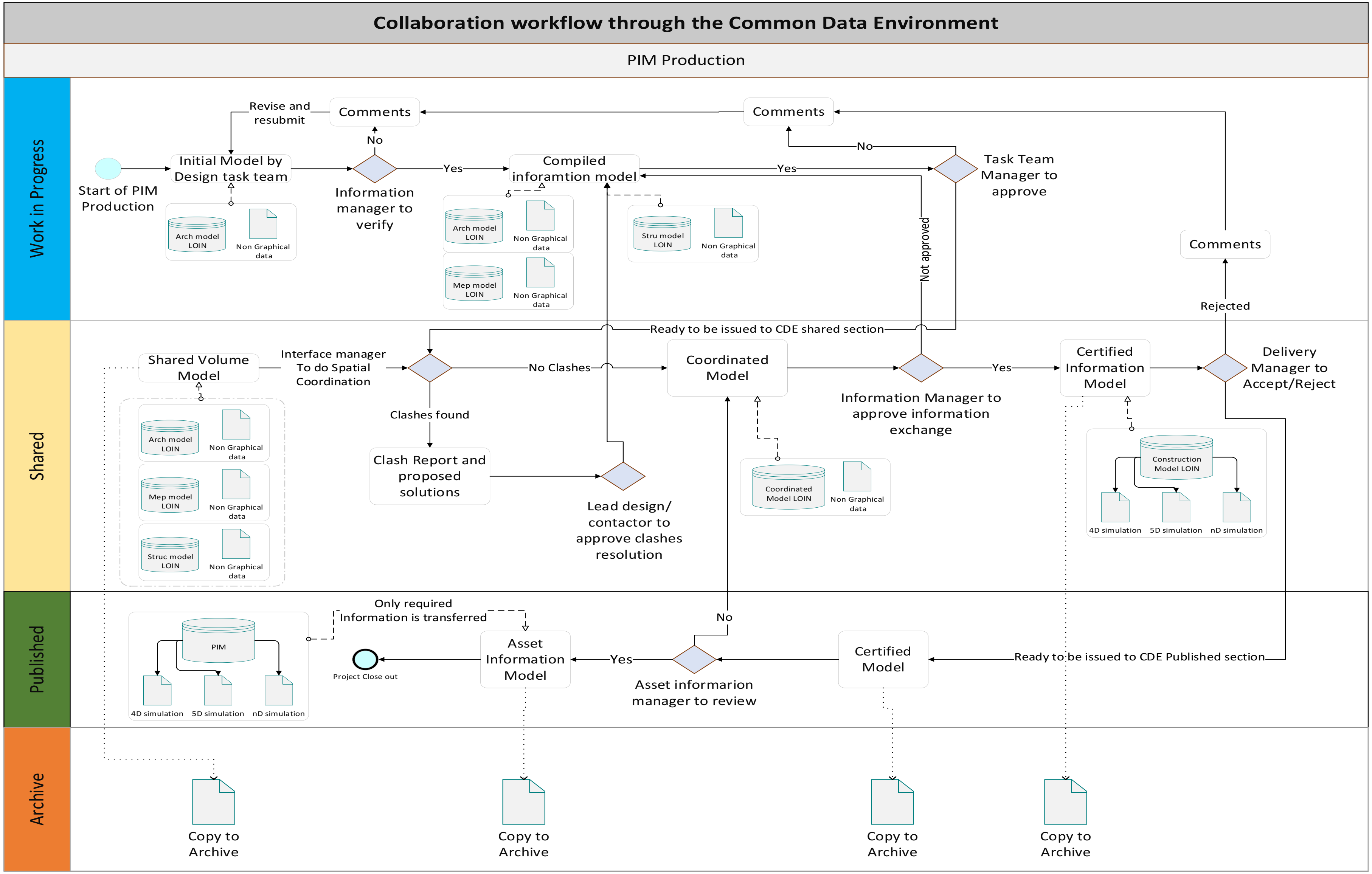

Figure 10. Workflow in common data environment [content driven from UK BIM framework [26,35]; CDBB [66], ISO 19650-1 & 2 [50,65].

3.6. Data Analysis

The data analysis process involved a detailed examination of the data collected through multiple stages. First, the documents were carefully reviewed to identify and extract relevant concepts. These concepts were structured and organised using BPMN to create process models. The BPMN models were then refined and validated through in-depth interviews with stakeholders, ensuring that they accurately reflected the processes and interactions within the study's focus area.

During the interviews, rich qualitative insights were gathered from the participants, capturing their perspectives, experiences, and feedback on the proposed models. These insights were systematically compared and contrasted to identify commonalities and divergences across the responses. The alignment and disparities among the interviewees' inputs were critically analyzed to refine the models further and ensure their relevance and comprehensiveness. Additionally, the findings were evaluated against existing literature to situate the study's outcomes within the broader academic and professional context. This comparison with prior research helped validate the findings, highlight innovative aspects, and identify areas of alignment or departure from established knowledge. This multi-step analytical approach ensured a thorough and robust interpretation of the data, combining empirical insights with theoretical grounding.

4. Results and Discussion

4.1. Challenges to the Application of ISO 19650-1 & 2 in Construction Project Information Management

An objective of this study was to evaluate the practical challenges and issues encountered in managing information during the lifecycle of construction projects and how ISO 19650 can be utilised to mitigate these challenges. Analysis of interview data combined with insights from the literature offers insight into how effectively ISO 19650 standards are perceived and implemented in real-world settings to mitigate these challenges.

Data from the interviews suggest that participants recognise the value of ISO 19650 in structuring and clarifying information management processes. However, they also acknowledged the difficulty in understanding its usage. One reason for this is its textual format. All the interviewees agreed that the textual format of ISO 19650 can lead to difficulties in interpreting complex concepts, especially for individuals without a deep technical background in BIM or standards management. The dense and detailed nature of the document often results in varying and inconsistent interpretations of the requirements.

Additionally, all the participants stated that the linear and static nature of the ISO 19650 standard was a challenge. Participant 7 stated that: "*the linear and static presentation of information within a text-based document does not easily convey the dynamic interrelationships between various elements of the standard.*" The participant further stated: "*This makes it challenging for stakeholders to grasp the full scope of interdependencies, which is crucial for effective project management and decision-making.*" The lack of visual aids or interactive components within the document further complicates the process of understanding how different parts of the standard relate to each other in practice. This view corroborates a recent study by Di Martino et al. [68], who stated that using standard process models—in other words, text-based documents—can lead to ambiguities in task definitions, and communications can lead to misinterpretations

Lastly, seven of the eight interviewees stated that the extensive and detailed nature of ISO 19650 can be overwhelming, leading to challenges in efficiently locating and extracting relevant information. This often necessitates a significant time investment to thoroughly understand and apply the standards correctly, which can be a barrier to effective use, particularly in fast-paced project environments.

Participant 8, for instance, remarked on the accuracy and clarity of the process models based on ISO 19650:

> *"The process map for ISO 19650 is quite accurately represented. It clearly defines scope and actions to be taken by various parties involved... It summarises the ISO 19650-2 in a flowchart diagram, which is easy to follow."*

Similarly, Participant 5 commented on the utility of the process models:

> *"Your process maps for the ISO 19650 framework are really impressive in showing how everything in our construction project is connected right from data sharing and role assignments to how tasks flow from one to the next...and they give a clear picture of the entire project lifecycle which is very helpful."*

Furthermore, Participant 7 underscored the advantage of graphical representation:

> *"It's a great idea really to represent it graphically... It's really hard to understand [ISO 19650] when it's a lot of pages written. But when you see it graphically represented as you put it in a table, I find it really helpful."*

Overall, feedback from the respondents recognised that the ISO 19650 framework does enhance information management on construction projects. The respondents acknowledged the clarity of the ISO 19650 framework. It makes the complex standards understandable and operational through graphical process models. This becomes useful in improving communication across the project teams and then, in turn, improving coordination. This finding affirms that ISO 19650 provides a road map in a structured and transparent way to manage project information to ensure successful construction project delivery. This has brought out the practical benefits that the implementation of ISO 19650 assures, hence its capacity to bridge the gap between theoretical standards and their practical implementation in the field.

Participant 8's remark on the clarity of ISO 19650 process maps aligns with the prior literature's assertion that ISO 19650 provides a standardised approach for information management, ensuring clarity and operational efficiency [12]. Participant 5's comments on the utility of process maps resonate with [12], emphasising the importance of structured information management processes to enhance project outcomes. Participant 7's appreciation for graphical representation reflects OMG [57], which discusses the benefits of graphical notations like BPMN in improving the comprehension of complex standards such as ISO 19650. The respondents' recognition of ISO 19650's role in enhancing communication and coordination supports [22], underscoring the value of effective information management in reducing errors and rework. The acknowledgement of ISO 19650's role in minimising data silos and miscommunication is supported by Autodesk [4] and KPMG [14], both highlighting the impact of poor data management on project inefficiencies and costs. The enhanced collaboration and data management facilitated by ISO 19650, as noted by the participants, is consistent with the UK BIM Framework [26] and Mahmood et al. [58], which stress the benefits of BIM and ISO 19650 in improving productivity and project delivery. ISO 19650 is felt to underpin the need for effective, interoperable, and structured information exchange associated with the project at all stages of its lifecycle. Indeed, the UK BIM Framework [26] and Ref [12] confirm that ISO 19650 furnishes a standardised way of managing the information concerning projects during the stages of the projects; that is, it deals with the creation, operation, and maintenance of built assets so that the deliverables are of specified quality and are delivered on time and within cost [12]. Additionally, the efficiency with which ISO 19650 reduces information fragmentation in itself—a nightmare for the entire construction sector—is stressed. It helps to minimise common data management problems, such as miscommunication and data silos, which are key drivers of project delays and overruns [14].

4.2. Identification and Mapping of Key ISO 19650 1 & 2 Concepts

The concepts identified through document analysis were categorised into seven main categories. The first category was a high-level process portraying all the high-level concepts in the information delivery phase of assets (see Figure 4). The second was a process model about the information requirement required in a BIM-compliant project (Figure 5). The third and fourth process models were pre-appointment (Figure 6) and post-appointment (Figure 7) BIM execution plans. The lead-appointed party EIR process model was the fifth process model (Figure 8). The MIDP and TIDP were combined into one process model (Figure 9). The sixth process model consisted of the workflow in the common data environment (Figure 10). These concepts were then validated using in-depth interviews.

4.3. Identification and Mapping of Interdependencies in ISO 19650

The participants emphasised several critical aspects for accurately capturing interdependencies. All participants agreed on the importance of standardised terminology, efficient documentation management, and transparency in process models. Notably, two participants recommended specific strategies to enhance clarity and effectiveness. The following interview themes which emerged provide a cohesive understanding of how key concepts, including their interdependencies, are recognised and managed in the developed process models.

4.3.1. Standardised Terminology

All interview participants recognised the importance of standardised terminology in improving the clarity and utility of process models. Five participants specifically mentioned the shift from “level of detail (LOD)” to “level of information need (LOIN)” as a critical change that aligns with ISO 19650 standards and enhances the focus on information requirements. Participant 1 was very unequivocal about the use of standard terminologies:

> “*Moving from LOD to LOIN helps align our process models with ISO 19650’s focus on information requirements rather than just detail, enhancing both clarity and utility in our project management practices*.”

This insight aligns with the UK BIM Framework, which stresses the importance of using standardised terms for consistency and clarity [26]. The literature also supports this shift, highlighting that ISO 19650 provides a comprehensive framework for information management, emphasising the use of standardised terms to ensure clarity and consistency [44].

4.3.2. Documentation in Common Data Environment (CDE)

Six participants highlighted the importance of efficient documentation management within the CDE. Participants stressed the need for a container naming strategy in the BIM execution plan, crucial for the efficient handling and retrieval of information:

> “*Incorporating a container naming strategy ensures that our documentation is organised and traceable, significantly boosting our operational efficiency within the CDE*.”

The literature supports this view, emphasising the role of BIM standards, including CDE, in enhancing the structured and efficient sharing of project information, which is crucial for managing interdependencies effectively [36]. The implementation of a CDE, as discussed in the literature, facilitates the centralisation and accessibility of project data, ensuring that all stakeholders have access to the most current information, thereby reducing errors and inefficiencies [37].

4.3.3. Transparency and Integrity in Process Models

All the participants underscored the need to clearly delineate the origins of elements in the process models, distinguishing those directly derived from ISO 19650 from those adapted from other templates. This approach is crucial for maintaining the integrity and transparency of the process models as reliable resources for project stakeholders. In fact, Participant 6 was very unequivocal in their view and stated:

> "*It is important to delineate which aspects of our process maps are directly taken from ISO 19650 and which are adapted to ensure users understand the framework thoroughly and the basis of our methodologies*."

This necessity for clear and transparent processes when integrating ISO 19650 standards into existing frameworks is echoed in literature, emphasising the importance of maintaining integrity and stakeholder trust ([44,45]). The literature stresses the importance of distinguishing between standardised practices and project-specific adaptations to maintain clarity and trust among project stakeholders [45].

4.4. Benefits of and Barriers Representing ISO 19650 as Process Models

The fourth objective was to identify the benefits and barriers to representing ISO 19650-1 & 2 using process models. The interviews captured stakeholders' opinions regarding the benefits of using process models to represent the concepts defined in ISO 19650. Multiple recurring themes show areas of consensus among participants on the usefulness of process models for better project planning. Despite variations in responses, several key themes emerged, indicating widespread agreement on the advantages of process models in project planning according to ISO 19650. In total, five main themes were uncovered.

4.4.1. Enhanced Understanding and Clarity

All eight participants recognised that process models make the complex and often abstract concepts of ISO 19650 more tangible and understandable. Six participants strongly agreed that this clarity is particularly beneficial in multidisciplinary project teams where not everyone may be familiar with ISO standards. This is exemplified by Participant 4, who said:

> "*The visual representation of ISO 19650 through process models simplifies understanding complex standards, making it easier for all stakeholders to grasp essential concepts and their applications in real projects.*"

This insight aligns with Rosser et al. (2018) [52], who emphasise the importance of visual process models in breaking down complex standards into manageable parts for effective implementation.

4.4.2. Better Communication Across Teams

Seven of the eight interviewees noted that visual representations facilitate clear communication among teams, bridging understanding gaps and ensuring all members are aligned regarding workflows and responsibilities. Amongst the seven, five participants stated that process models support practice standardisation across projects, ensuring consistent application of ISO 19650 standards and maintaining quality and conformance at all project stages. This, in a way, contributes to enhancing communication amongst project stakeholders. Participant 7 stated:

"Using process models to depict ISO 19650 helps in delineating roles and responsibilities clearly, which streamlines project coordination and reduces conflicts."

Nordemann et al. [53] highlight the role of visual process models in enhancing communication and standardising project task execution, which is crucial for maintaining consistency and ensuring quality. Another recent study by Polančič and Orban [69] revealed BPMN enhances communication.

4.4.3. Efficiency in Project Execution

All the participants agreed that process models may facilitate project implementation, reduce errors, and minimise rework by providing a clear map of processes and expected outcomes. Among eight participants, five strongly highlighted the impact of process models on improving project efficiency. In fact, in very strong terms, Participant 3 noted:

> "*Process models make everyone aware of the standards or the basic requirements needed to ensure the project is done at a high level. This clarity helps reduce errors and minimise rework*."

The UK BIM Framework [26] and Mahmood et al. [58] corroborate this, highlighting that structured information management practices facilitated by visual process models enhance productivity and quality, reduce errors, and minimise rework.

4.4.4. Training and Adoption

Six of the eight participants noted the benefits of using process models as training aids, with four of these participants emphasising that visual representations help new team members quickly grasp essential concepts and practices associated with ISO 19650. This accelerates their learning curve and ensures they can contribute effectively to the project. This is exemplified unequivocally by Participant 7, who stated:

"Representing something in a graphical mode is so much more helpful, especially in our industry where we are used to working with graphic representations of buildings and maps."

The literature corroborates this, emphasising that visual tools enhance learning and retention, making complex standards more accessible to diverse teams and promoting smoother adoption of new practices [37].

4.4.5. Identifying Gaps and Improvements

Five of the eight participants mentioned that process models allow organisations to identify gaps and inefficiencies in their information management processes. Four of these participants emphasised that visualising these processes makes it easier to spot areas that need improvement, enabling organisations to optimise workflows and enhance overall performance. In the words of Participant 4:

"Process models allow organisations to identify gaps and inefficiencies in their information management processes, making it easier to spot areas that need improvement and optimise workflows."

This finding is corroborated by the literature, which has found that continuous improvement and the iterative refinement of processes for identifying and bridging gaps can lead to better project outcomes [26].

In summary, visualising ISO 19650 standards through process models has many benefits. These benefits include enhanced understanding and clarity, better communication across teams, increased efficiency in project execution, practical training and adoption, and identifying gaps and improvements. This alignment underscores the value of process models in making complex standards more accessible and operational, leading to more effective project management and successful outcomes.

Additionally, participants' opinions about the challenges of representing ISO 19650-1 & 2 standards through process models are identified and discussed. The findings from identifying the challenges of representing ISO 19650-1 & 2 standards through process models can be grouped into four main themes.

4.4.6. High Standards Complexity

All eight participants believe that ISO 19650-1 & 2 contains numerous complexities that are difficult to express comprehensively and accurately through process models. Six participants highlighted the challenge of capturing the full complexity of ISO 19650 in process models, which can lead to information loss and potential issues. Participant 3 was very unequivocal about this and noted:

> "*Sometimes, the models oversimplify things. You miss out on important details, which can lead to problems down the line.*"

This aligns with Ashworth et al. [56], who highlight the challenges of representing deep technical content in process models, emphasising the risk of oversimplification. Succar and Poirier [70] also discuss the inherent complexity of BIM standards like ISO 19650, emphasising the difficulty of representing these standards in a simplified yet comprehensive manner.

4.4.7. Human Error and Miscommunication

While process models aim to improve communication and understanding, three participants noted that these models still risk misinterpretation if they oversimplify and misrepresent the refined details of the standards. Participant 6 highlighted this issue:

> "*Even though models help in understanding, there's always a risk of misinterpretation if the details are oversimplified.*"

Sacks et al. [71] discuss the potential for human error in creating and interpreting process models, emphasising the need for accuracy to avoid miscommunication. Succar and Poirier [70] note that while process models can improve communication, they also risk misinterpretation if not accurately detailed.

4.4.8. Levels of Education and Training

Among eight participants, four identified the variation in expertise among team members as a major challenge, leading to inconsistencies in the understanding and usage of process models. Five participants emphasised the need for adequate training to ensure consistent understanding and usage of process models across project teams. Participant 5 commented:

> "*Not everyone is on the same page about how to use these models, especially when they're new to the ISO standards or to modelling tools.*"

Jeong and Kim [55] emphasise the importance of training in addressing variations in expertise among team members.

4.4.9. Integration with Existing Systems

Out of the eight interviewees, six participants indicated the difficulty of integrating process models with existing project management tools and systems, which reduces the usefulness of the models. The six participants specifically mentioned that integration issues significantly impact the adoption and effectiveness of process models. In fact, Participant 5 noted:

> "Integrating these models with our current project management systems is quite challenging, which limits their use."

Ashworth et al. [56] and Jeong and Kim (2016) [55] discuss the barriers to the effective adoption of process models due to integration issues, highlighting the impact on usability and effectiveness.

Summarily, from the aforementioned paragraphs, there are many challenges in representing/visualising ISO 19650 standards through process models. These challenges include high standards of complexity, risks of human error and miscommunication, varying levels of education and training, and difficulties in integration with existing systems. Addressing these challenges is crucial for improving the usability and effectiveness of process models in representing ISO 19650-1 & 2 standards, leading to more efficient project management and better outcomes.

In addition to the findings discussed in the preceding section, it is imperative to examine some main contributions to knowledge. The originality and novelty of this work are rooted in its systematic approach to addressing the challenges of understanding and implementing ISO 19650 standards through process modelling. This is demonstrated through the following key contributions:

Simplification of Complex Concepts: This study tackles the inherent complexity and static nature of ISO 19650 by utilising process modelling tools such as BPMN. Through graphical representations, the research demystifies the standard, making workflows more accessible and easier for stakeholders to understand and apply in construction projects.

The Value of Graphical Representations: This research underscores the significance of graphical process models in enhancing both the comprehension and practical application of BIM standards. By translating text-based standards into visual workflows, the study improves clarity, fosters better communication, and enhances collaboration across multidisciplinary project teams.

*Revealing Interdependencies Within ISO 19650***:** Using BPMN models, the research exposes the interdependencies between various concepts within ISO 19650, providing a level of insight that is not readily apparent in the standard's traditional text-based format. This visualisation aids stakeholders in understanding how different components of the standard interact, ultimately improving its usability.

Practical Utility of Process Models: The work demonstrates how BPMN-based process models streamline information flow, improve project execution efficiency, and ensure compliance with ISO 19650. This practical application bridges the gap between theoretical standards and their real-world implementation, showing the models' effectiveness in achieving project goals.

5. Conclusions

This research aims to analyse the impact of process modelling on the comprehension of BIM standards, particularly ISO 19650. The study employs a qualitative multi-method approach to comprehensively capture theoretical frameworks and practical applications of BIM processes and standards. The research integrates qualitative and simulation methods. In the qualitative phase, in-depth interviews with professionals experienced in BIM and ISO 19650 provided rich contextual insights into their experiences and the practical challenges encountered. These interviews yielded valuable qualitative data, shedding light on the subjective experiences of professionals involved in BIM projects. In the simulation phase, process models were developed to simulate the workflows prescribed by ISO 19650 standards, allowing for an examination of their practical applications and implications in real-world settings. Through these visual models, the research demonstrated that process modelling can enhance the understanding and management of BIM standards.

The first objective focused on understanding the challenges in information management. Through qualitative data from interviews and an extensive literature review, key issues such as interoperability and data integration were identified. The second objective investigated how ISO 19650 could address these challenges by creating a process map for information management using BPMN, which visually represents the flow of information as prescribed by ISO 19650, making it easier to comprehend and implement. The interdependencies within ISO 19650 were effectively represented through process modelling, refined based on expert feedback. The final objective identified the benefits and challenges of process modelling, highlighting improvements in information flow clarity, stakeholder collaboration, and project execution efficiency while also noting issues like oversimplification and varying levels of team understanding. This study significantly contributes to the field of BIM by demonstrating how process modelling can facilitate the comprehension and implementation of ISO 19650 standards, providing a valuable tool for connecting theoretical frameworks with real-world construction management applications and serving as a foundation for further development in both academia and industry.

This article predominantly focuses on ISO 19650-2, providing deep insights into specific standards; however, this narrow scope does not encompass all the complexities or potential of BIM across different standards and contexts. By limiting the exploration to ISO 19650-2, the article may present an incomplete picture of the broader applications and challenges associated with BIM, potentially overlooking significant aspects covered by other related standards. Such a focused approach might restrict the audience's understanding, leading to an incomplete grasp of BIM's multifaceted nature and its various implementation scenarios in diverse projects.

In addition, the article acknowledges that the models used to represent ISO 19650 standards sometimes oversimplify the processes, missing out on important details. This oversimplification can lead to problems down the line, as critical nuances might be lost in translation. This challenge aligns with Ashworth et al. [56], who emphasise the difficulties of representing deep technical content through process models, underscoring the risk of undermining the effectiveness and accuracy of these models. Consequently, while process models are useful for simplifying complex standards, they must be designed carefully to avoid significant omissions that could impact the practical application of BIM standards.

Future research should broaden its scope beyond ISO 19650-1 & 2 to encompass other relevant BIM standards. By investigating a wider range of standards, a more comprehensive understanding of the complexities and potential of BIM across diverse contexts and applications can be gained. This holistic approach would mitigate the limitations associated with focusing on just two standards, providing a more inclusive perspective of BIM implementation and its various challenges. Considering the scope of this article, the proposed process models were not applied within detailed case studies that could illustrate their practical benefits in real-world construction projects. Future research should prioritise the integration of these process models into comprehensive case studies, enabling a thorough evaluation of their real-world applicability. Such studies would provide concrete evidence of the model's effectiveness in enhancing project workflows and ensuring adherence to BIM standards, particularly ISO 19650. By validating both the strengths and limitations of the process models, this research direction would bridge the gap between theoretical development and practical implementation in the construction industry.

Additionally, there is a pressing need to develop advanced modelling techniques that can accurately capture the intricate and complex nature of BIM standards. Future studies should focus on creating sophisticated process models that minimise oversimplification and retain critical details. Although the oversimplification of process models can be beneficial, it can lead to several significant risks, particularly when dealing with complex systems. One major risk is the loss of critical details, where important nuances and factors that influence the system are omitted. This omission can result in overlooking key dependencies and constraints, leading to ineffective or incomplete solutions. Furthermore, oversimplified models often fail to adequately represent the complexities and interdependencies inherent in real-world systems. As a result, they may produce unrealistic predictions, misguide decision-making, and fail to address the intricacies of dynamic environments.

Another critical risk is the potential for misleading assumptions embedded in oversimplified models. These assumptions, which may not hold true in all scenarios, can skew the interpretation of results and undermine the credibility of the model. Additionally, stakeholders might view oversimplified models as lacking depth or relevance, resulting in resistance to adoption and limiting the model's practical utility.

To mitigate these risks, an iterative refinement approach can be employed. Starting with a basic model and gradually enhancing it based on stakeholder feedback and additional data ensures a balance between simplicity and comprehensiveness. Another effective strategy is modular modelling, where complex systems are divided into smaller, manageable components. Each module can be simplified individually while maintaining the ability to integrate them for a holistic analysis.

Stakeholder involvement is also crucial in overcoming oversimplification. By collaborating with key participants, it becomes easier to identify critical aspects that must be retained in the model to ensure its relevance and practicality. This collaboration helps to avoid the omission of vital components and ensures that the model aligns with real-world applications.

Additionally, advanced tools such as simulation software or machine learning algorithms can help manage complexity without sacrificing critical details. Incorporating technologies such as artificial intelligence and machine learning can enhance the precision and effectiveness of these models, making them more robust and reliable for practical applications. Such advancements would ensure that the models are not only theoretically sound but also practically viable, supporting more effective BIM implementation in real-world scenarios.

Author Contributions: F.H.A.: Led the overall research design and execution, contributing to the conceptual framework and analysis of findings. B.B.: Assisted in data collection, particularly in conducting qualitative interviews, and contributed to the development of the process models. S.E.A.: Focused on the technical aspects of process modelling, particularly in the application of BPMN and UML to ISO 19650 workflows. A.A.: Contributed to the interpretation of results and supported the validation of process models through expert interviews. All authors have read and agreed to the published version of the manuscript.

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