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An Integration of Business Processes and Information Management for Improving the Efficiency and Reliability of Infrastructure

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Abstract: The construction industry has increasingly adopted digital construction processes and technologies, fueled in part by governmental mandates aimed at modernizing construction workflows. While these advancements promise efficiency across different phases of a project, the efficacy of the digitally generated information often remains contingent on its alignment with the specific information exchange requirements of individual organizations. Current efforts to establish interoperable data schemas have made strides, yet challenges persist, particularly when tailoring information to meet the unique needs of organizations responsible for the operation and management of built assets. This paper dissects the outcomes of standard digital construction processes applied to a linear infrastructure project, highlighting observed shortcomings such as information overload and the difficulty of adapting the information for asset management needs. Building upon these findings, this paper introduces a framework aimed at streamlining the production of essential project information. This framework was developed through a series of expert workshops and subsequently tested on a separate infrastructure project, offering insights into its potential benefits and limitations.

Keywords: digital construction; business process modelling; asset management; information requirements; interoperability; project information model

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1. Introduction

The tools and technology related to Building Information Management (BIM) have advanced rapidly over the last few years. This implementation has been mandated by the government and organisations. This drive for adoption has stemmed from the benefits of implementing digital construction processes and tools that can create efficiencies both during construction and operation for built assets [1]. There are multiple 'uses', such as scheduling, site monitoring, and safety management, that should encourage BIM adoption [2]. However, it has been observed that the implementation of information management in practice has its challenges. One of the main challenges is an overload of information, even on a project level. It has been observed that practitioners working in the operation and management of assets would get overwhelmed with the data given at handover. Therefore, research has focused on finding a solution for asset managers who are 'drowning in data', especially when managing large networks of assets such as highways and airports. The aim of this study was to create a framework that would allow those involved over the lifecycle of a project to produce their required information efficiently and effectively.

The large footprint of linear infrastructure projects poses a challenge for asset managers who must maintain and sift through large amounts of information when operating their assets. There is also a need to integrate existing processes and information requirements with new digital processes and information exchange formats. Studies have shown that a large volume of the information produced on projects is still document based [3–5]. This observation was confirmed during the initial stages of this research, in which a Project Information Model (PIM) and Asset Information Model (AIM) were developed during the construction of a viaduct. Several benefits were observed during implementation and in the data that were used and produced in areas such as cost estimation and scheduling. However, it was observed that there were challenges when handing the information over to the asset managers, as the information produced did not fully meet their information needs.

The aim at the early stages of this research was to identify the types of information produced on projects to understand why information is not stored in a manner that is easier to query and manipulate. Following the observations made during the initial implementation, a series of workshops were held with several experts involved in the project lifecycle stages of highways and airports. The workshops aimed to validate the initial observations and then develop a framework that would help organisations produce their specific exchange information requirements. Finally, a prototype system was developed to test the framework and analyse the benefits and shortcomings of using such a system by implementing it on an airport project.

This paper is broken down into four main sections: It will contain a critical review of the existing literature focusing on existing standards, existing case studies, and current shortcomings in information management. The article will then discuss the methodology followed to address the gaps observed in the review. The outcomes of the initial implementation of a linear infrastructure project are then described, along with the outcomes of the workshops following that implementation. We then discuss the implementation of the framework and prototype system on a project, before concluding with the limitations and benefits of using this framework.

2. Background

There are many standards and guides, as there is an increasing drive to incorporate related information technologies into existing asset management processes. There is a need to standardise processes and produce guidelines to implement them effectively [6]. Since then, several standards have been produced on a national level (e.g., UK government standards, National BIM Standard (NBIMS) [7] and ISO 19650 [8]), or at organizational levels (e.g., the United States Airforce [9]). They generally tend to provide guidelines within which information management processes and technologies are expected to be implemented. However, there are certain ambiguities in the standards that eventually lead to the ineffective implementation of projects. For example, due to the varying nature of projects (a building with a small footprint compared to a road network), the standards do not precisely define what an information model may require for a specific type of asset.

Studies such as those carried out by the National Building Specification (NBS) show a growing awareness, and the level of adoption has generally increased over the past few years in the UK. The National Building Specification (NBS) has carried out surveys on the adoption of and views of adopting information management in the UK since 2011. The level of adoption amongst participants grew yearly to 31% [10] (2011), 41% [11], 43% [12], and 54%, according to the results of the surveys. Following a dip in 2015, the level of adoption has grown to 73% amongst participants in the National Building Specification as of 2020 [13]. However, there is concern among experts that organizations face challenges that hinder adoption, which may slow down this growth.

It has been observed that there is resistance to adopting VDC/information management technology and processes even though the value of adoption has been recognised [14]. Other industry reports also show that experts still believe that their adoption rate given the benefits remains low [15]. These reports state that there is resistance to change and that there are human factors involved. However, they have also observed that there are minimal tangible benefits to clients, which leads to a reluctance for them to move towards adopting information management technology.

2.1. Barriers to Adoption

Five broad areas can be considered barriers to adopting digital management processes. These are technology (including interoperability), cost (training, software, and hardware), management (workflows, schedule, and safety management), personnel (training), and legal (laws, regulations, and contracts) [16]. The literature shows that among the key barriers to implementation are the challenges faced when changing workflows [17,18]. As a result, workflows with clear indicators are lacking due to the way that data are collected on site, impacting aspects such as safety management.

A review of the global standards showed that each of the analysed standards had disparate requirements, leading to confusion among those using them [19]. Looking further into countries that have mandated the use of specific standards, a review of the adoption of information management in five large UK government agencies showed that even though there was a mandate, there was no strategic guidance on managing the adoption process to achieve the desired results [20]. These conclusions were similar to those of other surveys conducted in the industry in the UK and abroad; there is a digital transformation occurring, and there has been an adoption of digital management processes. However, due to barriers such as contractual constraints, ambiguities in the standards, and the reluctance to adopt new technologies, further research needs to be carried out for a smoother transition into implementing digital transformation on projects. In recognition of this type of issue, maturity matrices have been developed to help organizations recognise their capabilities and take necessary steps to overcome some of the challenges faced.

Once information technology such as BIM has been implemented on projects, there is also a lack of good-quality data being produced [21]. In a study carried out with local authorities in the UK, there were three specific day-to-day issues faced by these organisations. These were legal issues, insufficient information quality, and a lack of resources to address the first two problems while delivering a public service [22]. The general observations were that the interviewed authorities were averse to implementing information management systems as they were mis-sold to the sector, and that there was generally a lack of good-quality data (this included inaccurate data, varying units, and various naming conventions). Other studies with public clients have also showed that, despite contract clauses requiring work using digital information management, there is a lack of adequate information on quality assurance procedures [23]. In addition, there is generally a lack of resources to enable the production of information in the desired format, as there is uncertainty in the value of adopting these new processes and tools. To encourage adoption and give recommendations, organisations such as the UK Roads Liaison Group have produced codes of practice for specific types of infrastructure, as processes and information requirements vary by asset type [24,25]. To tackle the problem of producing and receiving low-quality information, processes should be specified and monitored. Also, it is possible that, especially with repetitive tasks, human error may also be a factor in the production of low-quality information. As a result, it could potentially be beneficial to establish project-specific information requirements and potentially automate or semi-automate some of the processes.

2.2. Information Management Processes

Realigning business processes to fit in with those recommended by the information management standards and the tools that may have to be adopted to comply with them can be challenging [26]. Several studies in the infrastructure domain have shown that there is still a need to align processes, as there are still gaps related to the creation of information and the governance of the production and use of information [17]. A review of transport infrastructure further reinforced these observations and showed that there is a lack of alignment of standards with transport industry processes, hindering adoption even further [18].

The analysis of standards shows that ambiguities in industry standards and terminology can also lead to a lack of adoption or a deviation from the standards [27]. Therefore, there is a need to ensure that project participants are aware of these challenges and to ensure that their current processes are aligned in order to adopt information management. As a result, several organisations have produced more specific guidelines to help organizations follow a standard procedure on their projects [28]. The inclusion of concepts related to the standards, guidance for the transition from the previous standards, and processes for project delivery would be beneficial for producing good-quality asset information.

The studies carried out both in academia and industry have highlighted the need to realign existing processes to ensure that the standards are being adhered to while bringing value to the organisations implementing them. Further, the current guidelines have been developed to leave them open for interpretation by users. For example, ISO 19650-1 [29] describes the Project Information Model (PIM), which is expected to contain all the details of a construction project within a short paragraph. It was essential to ensure that all stakeholders interpreted the guidelines and standards in the same way. Then, their information requirements were enforced while complying with the ISO standards. Therefore, it is still necessary for clients to ensure that, on a project or organization level, information requirements are specified clearly, and the processes that are going to be used are correctly enforced.

2.3. Process Management and Establishing Exchange Information Requirements

Several techniques are available to map out processes and information flows. To record the inputs, outputs, controls (constraints), and mechanisms (tools) within a process, Integration Definition for Functional Modelling (IDEF0) [30] can be used. This method is considered to be an excellent alternative to describing a system compared to using prose [31]. This method has been used to capture processes on highway projects as it does not have chronological continuity or sequencing, which is considered an advantage due to the varied nature of procurement and contexts on such projects [4]. As a result, this method has the potential to be effective when setting out information requirements.

There has been a drive towards implementing Robotic Process Automation (RPA) to carry out routine tasks in the construction industry [32,33]. RPA can be highly beneficial when automating tasks that do not need human judgement, such as handling and processing claims that arise when operating assets. In one industry study, the initial analysis showed that automating three parts of an eight-step process using RPA saved a council an estimated 200 days per annum in total [34]. Solutions provided using RPA can automate simple, manual and repetitive tasks, which can be beneficial when complex decision-making is not needed. However, in order to streamline, analyse and optimise processes, a wider impacting technique is needed.

To bridge the gap between business process design and the implementation of those processes, the Business Process Model and Notation 2.0 (BPMN) has gained greater adoption [35]. This notation and modelling standard is regulated by the Object Management Group (OMG) [36]. They have since then also released Decision Model and Notation (DMN), which complements the BPMN and can be used alongside it. DMN aims to bridge the gap between business decision design and its implementation [37]. This standard of process modelling has been used in the construction domain and has been used alongside other forms of notation such as the Unified Modelling Language (UML) [38], which is used to visualise system designs. The combination of using BPMN has been employed in several cases to map out overall processes, activities, and data flow, while languages like UML have been used to describe expected procedures, rules, and activities [39].

Dimyadi (2016) explored the possibility of creating formalised executable workflows related to Compliant Design Procedures (CDPs) to guide the automated audit of digital models against local regulations [40]. A client/server web application was developed using Microsoft SQL Server as an underlying database to store data. In the web application that was developed, the bpmn.io JavaScript library created by Camunda was used to render the workflows graphically.

Jallow et al. (2017) proposed a framework to help manage client requirements to improve the quality of built facilities and their related services [41]. This comprised an enterprise architecture framework for electronic requirement information management. They proposed managing the content of documents rather than the conventional document-centric management of information. They also proposed a business process management (BPM) approach to managing process activities to improve control and visibility.

A review of the state of the art in the industry showed that there are several challenges faced when adopting digital information management. Specifically, there are problems with adjusting processes and enforcing information requirements in order to produce good-quality information. As a result, it was important to (1) find out what type of information is currently produced on infrastructure projects, (2) analyse the information that is produced and the processes that were followed, (3) and finally provide a solution that would help with the specific issues that are faced during implementation.

3. Proposed Approach

Several frameworks and standards have been published that focus on the implementation and establishment of information exchange requirements on construction projects. However, initial findings have showed that, even though these initiatives have driven forward implementation, there is still a need for fine-tuning. For example, making sure that information requirements are established and enforced well can then ultimately help produce an information model that can be used during the operation of an asset. Therefore, a research plan was established to develop a framework to define the specific requirements, capture them in a digital format, and then test the results on a prototype system, which can be further developed and used on linear infrastructure projects.

Figure 1 shows the overall process that was followed during the research. Following the initial implementation, processes were redefined based on the initial findings and feedback from experts. Then, a prototype system was developed and tested to compare how the proposed solution compares with the original results. This was then tested on a separate project, and the results are discussed at the end of this paper.

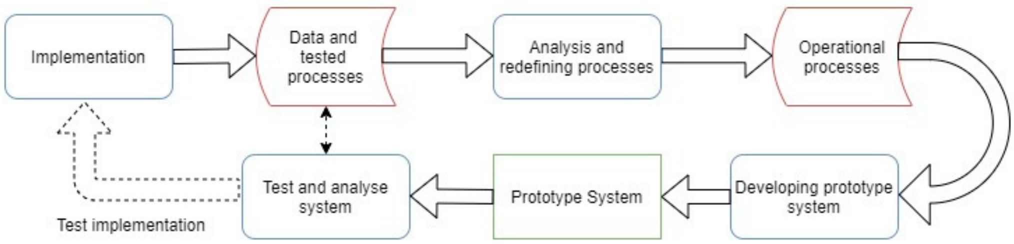

Figure 1. The overarching solution overview: the process of collecting information, refining processes, and developing the prototype.

3.1. Initial Implementation and Understanding of the Data Flow

The initial stage was to test an initial set of processes, confirm the gaps identified during the literature review, and then analyse the volume and type of information produced throughout a highway project that involved the construction of a 700 m long viaduct. Several components were fed into the project, and these are summarised in Figure 2. There was a particular focus on analysing the outcomes of implementing the BS 1192 suite of standards on the project. It has been noted that the ISO 19650 standards have superseded the BS 1192 suite of standards since the inception of this research project. However, the validity of the results from this research stage has not changed, as the transition from one standard to the other is relatively simple, with subtle variances such as those in terminology rather than overall processes [8].

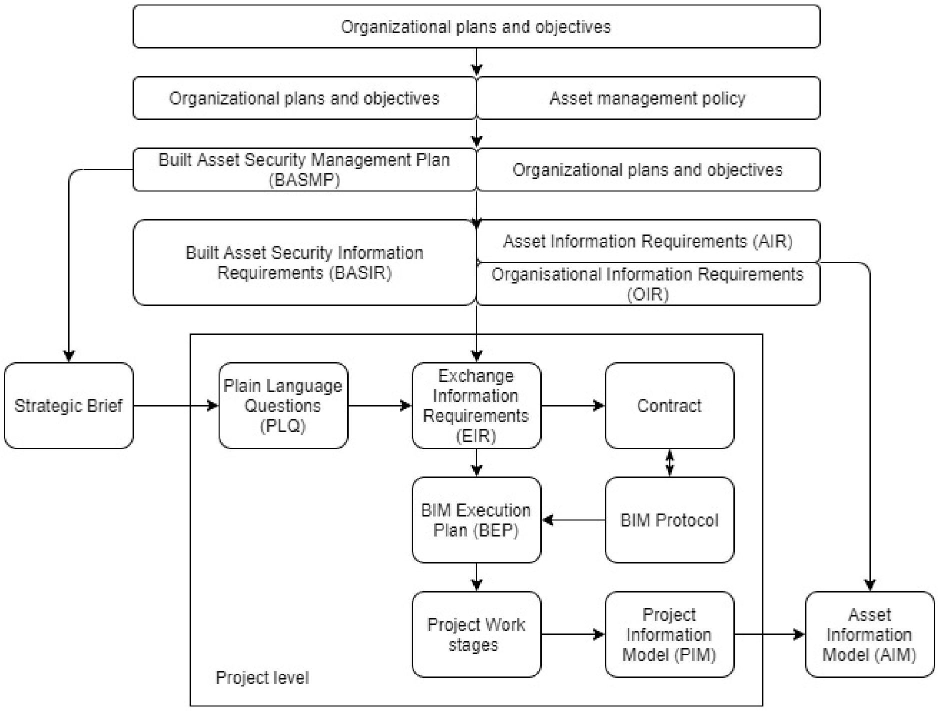

Figure 2. Interaction between policies, standards, and specific information requirements (this diagram is derived from the BS 1192 and ISO 19650 suite of standards as well as the ISO 55000).

Figure 3 shows the areas this piece of research covers. The aim was to implement the processes according to the standards, analyse the breakdown of the AIM, identify the challenges faced when creating it, and determine the potential problems that could have been faced during operation.

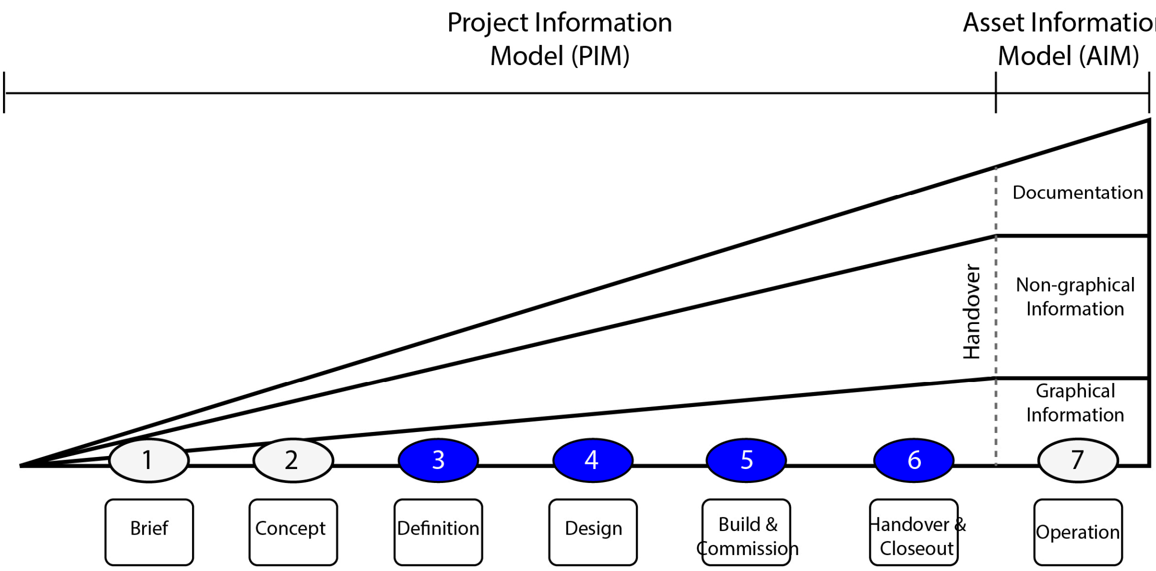

Figure 3. Stages of the construction project. The elements discussed in this paper have been highlighted in blue (this image is based on the processes defined in the PAS 1192:2 standards [42], and the stages highlighted are based on the RIBA Plan of Work stages).

3.2. Process Discovery

To record processes, both various methodologies and numerous possible methods [43] were considered, as summarised in Table 1. The three methods considered were as follows:

1. Evidence-based discovery—Studying how existing processes work by analysing existing documentation or making observations.
2. Workshop-based discovery—Putting together workshops with domain experts to obtain an understanding of processes.
3. Interview-based discovery—Interviewing experts to identify how processes are executed.

Table 1. Relative strengths and weaknesses of discovery methods [43].

Aspect	Evidence-Based	Workshops	Interviews
Objectivity	High	Medium-high	Medium-high
Richness	Medium	High	High
Time consumption	Low-medium	Medium	Medium
Immediacy of feedback	Low	High	High

A decision was made to carry out a series of workshops to provide a rich data set based on domain-specific knowledge. We also provided experts with the opportunity to discuss their specific requirements based on the stage of the project they were working on. This helped to carry out immediate iterations on processes and requirements. In comparison, the evidence-based discovery would have provided the researchers with only broad sweeping processes defined by standards such as ISO 19650. Moreover, interviews would not have provided us with the information requirements from various points of view, unlike the holistic requirements that were defined during the workshops.

To identify the information requirements and their related processes, 10 workshops were held, and these are summarised in Table 2. The workshops were carried out with project experts to define processes and analyse the outcomes of the first stage of the research.

These workshops aimed to obtain expert input when refining the processes that were implemented in the initial project. They also aimed to capture the information requirements digitally before attempting to implement them in the next phase of the research. Three asset operators, six project employers/asset owners and fourteen suppliers/contractors were involved in this workshop.

3.3. Prototype System Development

Once the processes and information requirements were established, the aim was to test the processes on a system to automate/semi-automate the flow of information based on project-specific information requirements. To undertake this system development stage of the research, a Design Science (DS) approach was used. The DS methodology focuses on creating and evaluating IT artefacts intended to solve organisational problems. The stages within the methodology used in this research project were developed based on previous methodology variations and are summarised in Figure 4. The stages within the methodology were broken down with their corresponding actions and components that were to be developed [44–46]. The core methodology that was adopted for this research considered a combination of both a theoretical and applied approach to the DS methodology. This hybrid approach was used to bridge the gap between what was proposed by the standards (that were relatively new at the time) and the application of these new standards on real-life projects.

Stage 1 focused on identifying and specifying the applied problem and was facilitated by the first two stages of this research (defined in Sections 3.1 and 3.2). This was carried out both by reviewing the existing literature and by receiving the expert feedback. The actions and components of this stage (Stage 1) were derived from the need to capture the complexity of the problem. As a result, a hybrid approach was used for this stage, where the researchers completed a comprehensive review of the state of the art while also applying the techniques to a real-life project to identify the main problems.

Table 2. Summary of workshops carried out, input and outputs.

No.	Theme	Inputs	Outputs
1	Information Gateways and Requirements	Standards; Existing processes; Assumed information requirements.	Generic gateways (points at which information is exchanged/reviewed); General information requirements.
2	Design and Build workshop (Overall)	Generic gateways; General information requirements.	Processes for the stage; Information requirements for the stage.
3	Design and Build (Bidding)	Generic gateways; Information requirements.	Processes for the stage; Information requirements for the stage.
4	Asset Information Requirements (AIR)/Common Data Hierarchies	Information from previous projects.	A review of how information is generally exchanged, stored, and then used.
5	Design and Build (Delivery and Handover)	Information from the previous workshop (AIR).	Defining common exchange formats; Processes for the stage; Information for the stage;
6	Operation and Maintenance	Information from the previous workshop (delivery and Handover information).	Reviewing and critiquing information from the previous workshop; Processes for that stage; Information requirements from that stage.
7	Operation and Maintenance	Overall processes; Information requirements.	Definition of processes from that stage; Definition of specific information requirements.
8	Operation and Maintenance	Information from previous workshops.	Agreement on whether defined processes were suitable for projects; Minor amendments to processes.
9	Design and Build	Information from workshops 2, 3, 5, and 8.	Review and amendment of processes.
10	AIR's/Common Data Hierarchies	Information from the previous workshops.	Agreement and conclusion of the established information requirements and processes.

Stage 2 of the research involved defining the objectives, which involved describing the system requirements and structuring information requirements. Then, finally, the processes that corresponded with the system and information requirements set out were defined. This stage was mainly shaped by referring to work carried out in the field of Information Systems to develop, deploy and improve artefacts within the field. Due to the need to constantly refine the process and improve the system, this stage went through multiple iterations, as defined in Figure 4.

Stage 3 involved developing the system itself and getting the various components of the proposed system to work with each other. This involved using the endpoints of the BIM server in a process management system that contained and executed the defined processes. Once the system was developed, it was given to a project team working on an airport project in the UK to test it (Stage 4). This allowed them to provide their project-specific information requirements and then evaluate the system (Stage 5). Several iterations between Stages 3, 4, and 5 were made in collaboration with the project team before finalising the prototype system.

Based on previous research carried out, the expected outcome of the first stage of the research was a graphical model along with non-graphical information and a breakdown of this information model. Based on these outcomes, a system was developed to tackle the bottleneck caused by handover (time savings) and the challenges faced by producing information that is not compatible with existing asset management systems (compatibility).

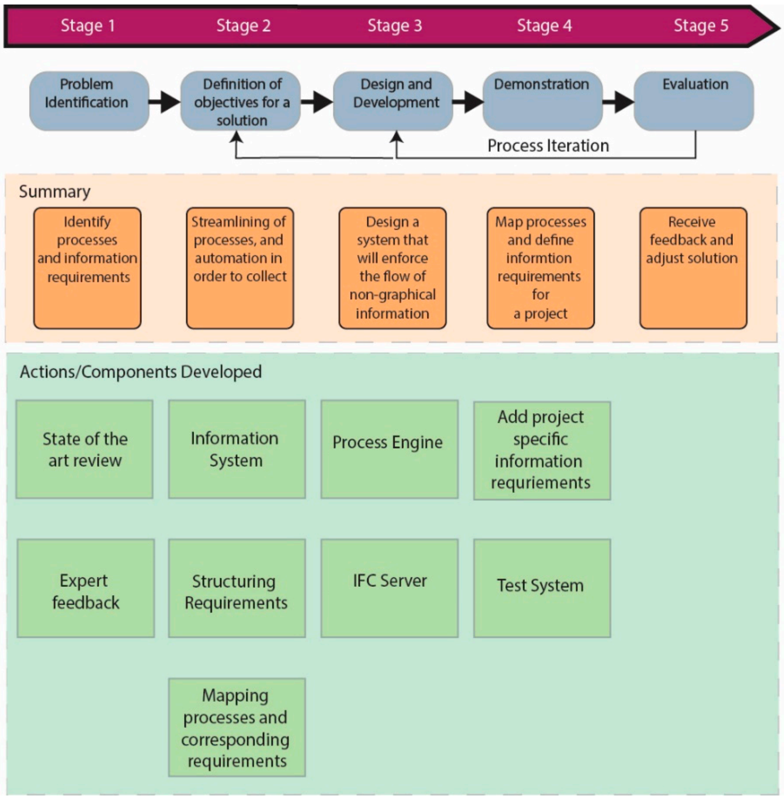

Figure 4. Alignment of research stages and components developed/used with the Design Science methodology [44–46].

4. Results

4.1. Initial Implementation and Breakdown of the Asset Information Model

The initial implementation followed the 1192 suite of standards discussed in Section 3.1. All the processes related to information exchange on the project were stipulated in the post-contract BIM Execution Plan (BEP). Overall, processes such as document control on site and the archiving of data within the project Common Data Environment (CDE) were set out (Figure 5). Also, more detailed processes such as raising and documenting Non-conformance Reports (NCRs) were established, as shown in the example process map in Figures 6 and 7.

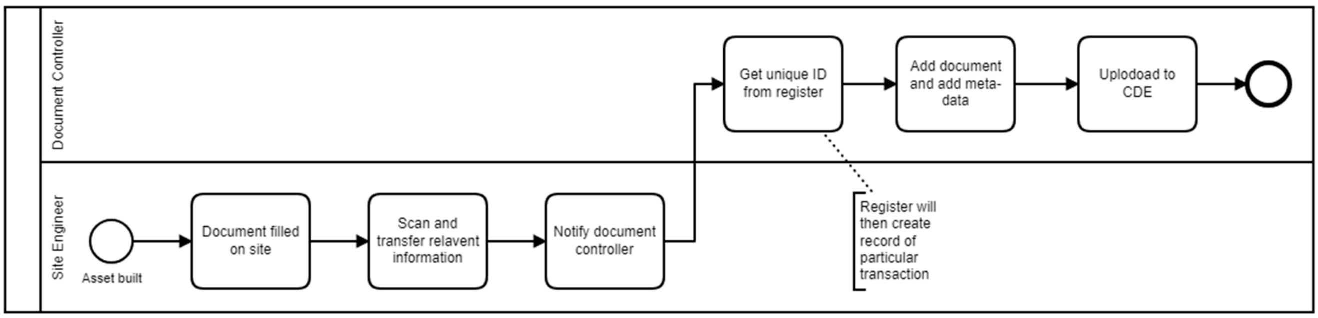

Figure 5. Document control on site.

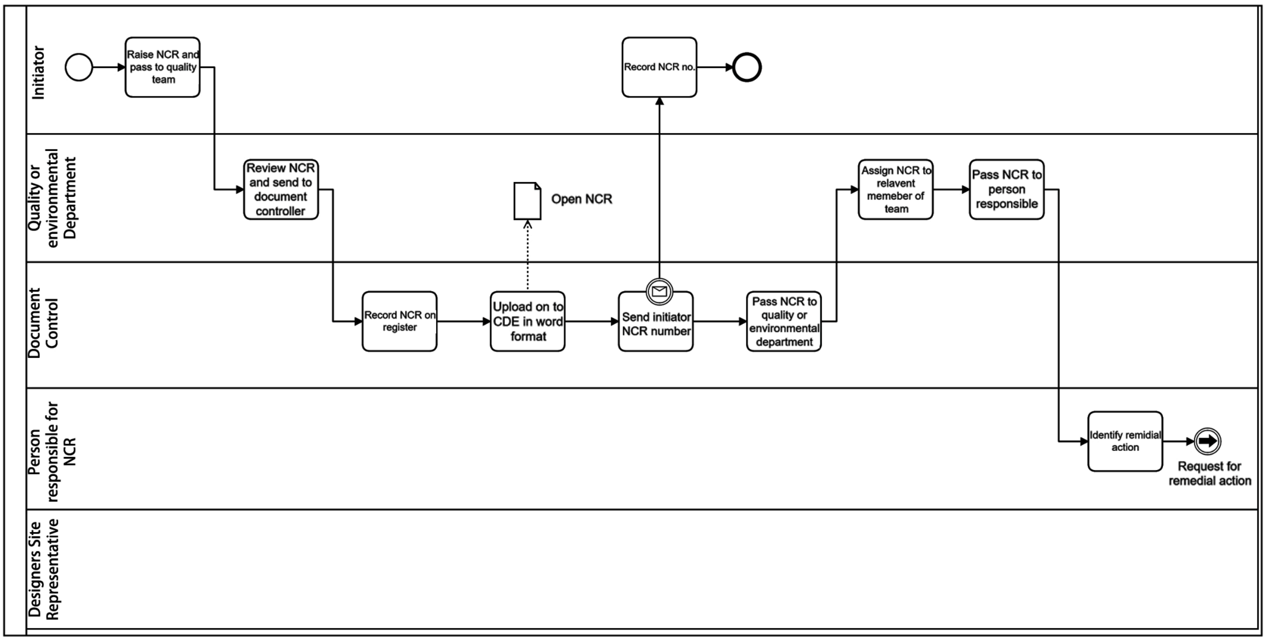

Figure 6. Process for communicating and closing the Non-Conformance Report (NCR)—Part 1.

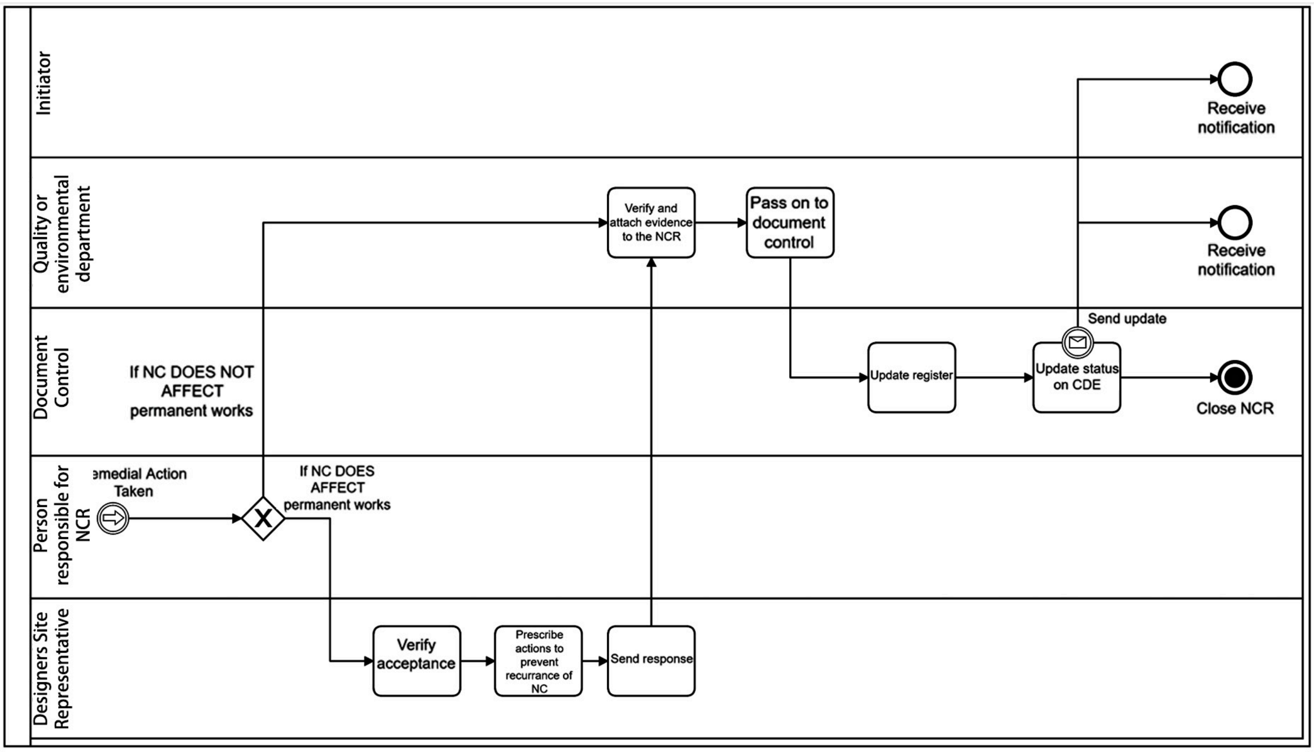

Figure 7. Process for communicating and closing the Non-Conformance Report (NCR)—Part 2.

Following the procedure that was agreed upon and executed led to the development of the Project Information Model (PIM), which contained 26,401 individual files (these included 3D models, documentation, drawings, and images). Based on the Exchange Information Requirements (EIRs) set by the asset operators, an Asset Information Model (AIM) was produced, which contained 5549 files. A breakdown of the AIM can be seen in Figure 8.

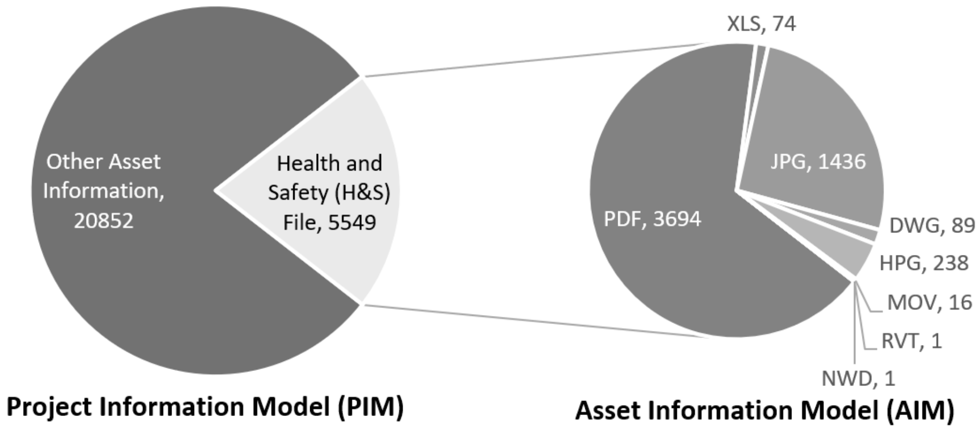

Figure 8. Breakdown of the data produced after the first stage.

The results confirmed the observations made in previous studies as, more than 90% of the AIM was document based [3,4]. Furthermore, given the asset management systems that were being used, this was the most suitable form of information exchange as the documentation contained certificates, drawings, and maintenance manuals, which are an integral part of the information to be handed over.

As a part of the EIR, a federated 3D model was produced, along with linked non-graphical information. To produce the 3D model, manufacturers were given Product Data Templates (PDTs), which contained the required attributes to be attached to the 3D objects. This was a relatively manual process that involved manufacturers filling in spreadsheets and then the modellers attaching this information to the relevant objects. This was time consuming and prone to human error given the scale of the project and the volume of information being produced.

4.2. Defining Operation Processes and Information Requirements

The information produced during the initial implementation revealed that a large portion of the information is document based and is exchanged as flat files with some metadata linked to it. This stage of the research aimed to understand how some of that information might be represented at an object level (within a larger 3D model) and how those data can be captured automatically or semi-automatically.

The workshops were carried out with a group of domain experts who helped the following objective to be met: to capture how information requirements could be digitised. This process involved showing the processes that were implemented in the initial project, then altering the processes to identify which processes could be automated and how these information requirements could be digitised.

Based on the given feedback, several strategic process maps were produced to give an overview of the processes and the interaction between various parties. Then, more specific operational process maps were derived from those maps as iterations were made throughout the workshops. First, an overall map was created, as shown in Figure 9, to understand the flow of information from different points of view. Then, more specific sub-tasks were mapped out based on the overall process. For example, Figure 10 is a breakdown of the items identified in Figure 9.

The operational process models could then be utilised to set specific information requirements against each task and help to automate or semi-automate each of those tasks. This method of breaking tasks down and identifying specific information requirements could then aid in identifying human tasks and technical tasks (tasks that can be automated). To be able to define these on a project level, a general framework was suggested, as shown in Figure 11, where specific processes are identified for a project and then integrated within an Execution Plan (BEP).

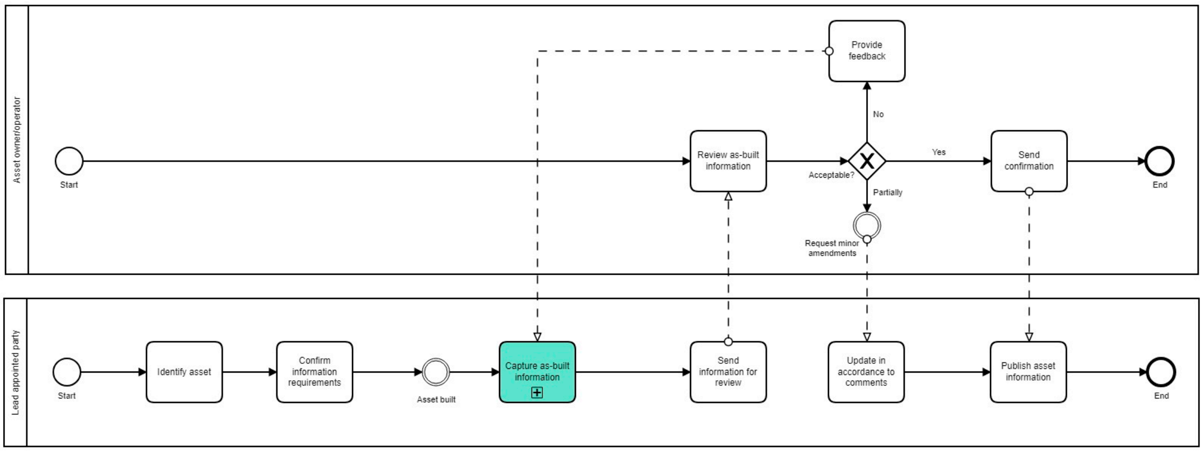

Figure 9. Process map describing the process of capturing the as-built information.

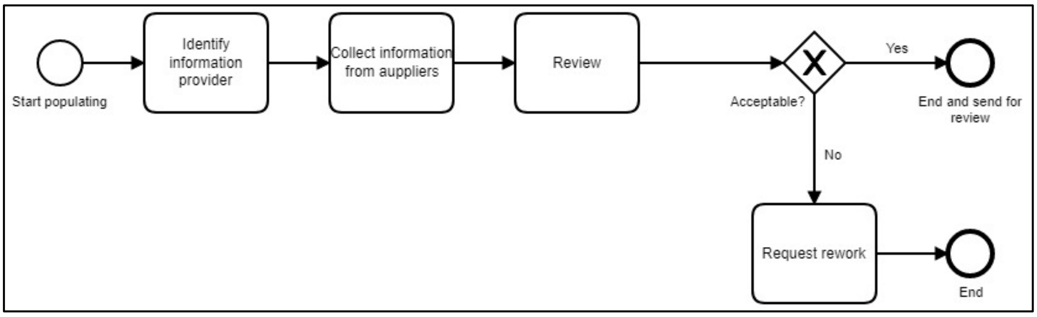

Figure 10. Capture of as-built information—operational process model.

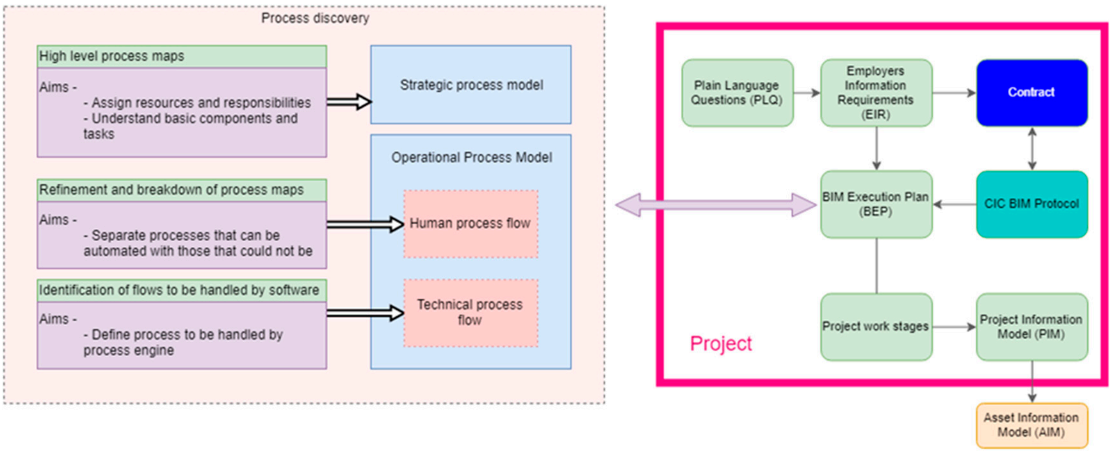

Figure 11. Process discovery on a project level.

The data gathered during the workshops helped establish a series of strategic processes and more detailed operational processes. The operational processes were then broken down even further to identify 'technical process flows', which can be automated or semi-automated. The next stage of the research involved exploring how these processes can be implemented on a project and be governed.

4.3. Developing and Testing the Prototype

The focus of this section was on how processes could be executed to produce an Asset Information Model that can be integrated into an asset management system. Figure 12 shows the inputs (information from stage 2) and outputs of the system once developed.

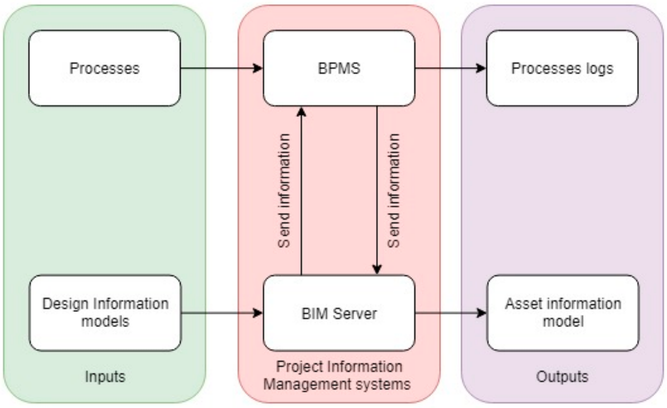

Figure 12. Overview of the expected inputs, systems, and outputs.

In order to test the processes, the two main components were the Open BIMServer [47], which was used to host the 3D model, and an Open-source Business Process Management System (BPMS), which was developed by Camunda, as shown in Figure 13. The information requirements were set as HTML forms produced within the process modelling tool, where forms can be created within each task [48].

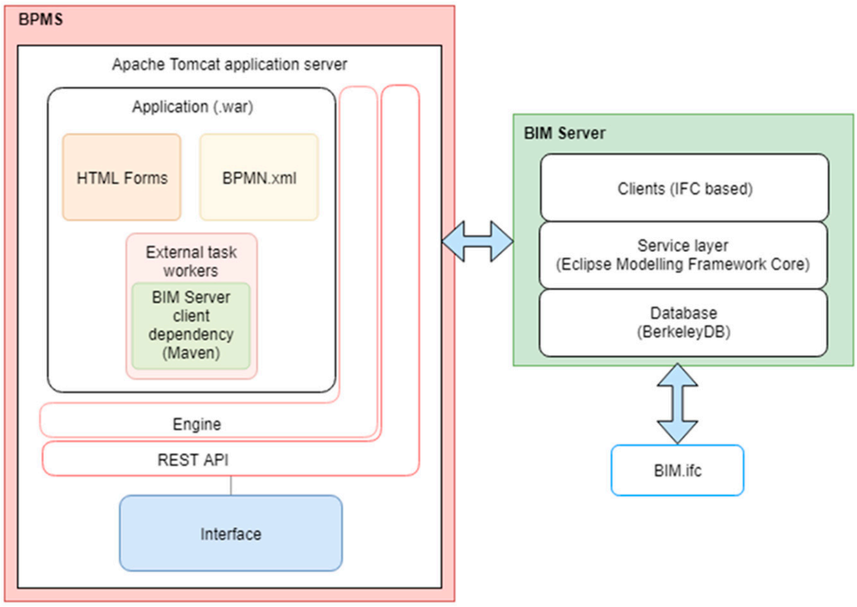

Figure 13. System components.

A comparison of the graphical and non-graphical information between a typical modelling scenario (Figure 14) and a scenario using the system (Figure 15) is presented. The system can be used to provide information directly within a model to a relevant component without having to depend on a modeller to link the information between the graphical and non-graphical information. When a form is being filled, an identifier related to the graphical component can be provided. Next, when the form is filled and transferred, the information is automatically linked with the component. The tasks with a cog symbol in Figure 14 are automated tasks; when visualised within the BPMS, the users assigned to complete the task will be notified and will receive the HTML to fill out.

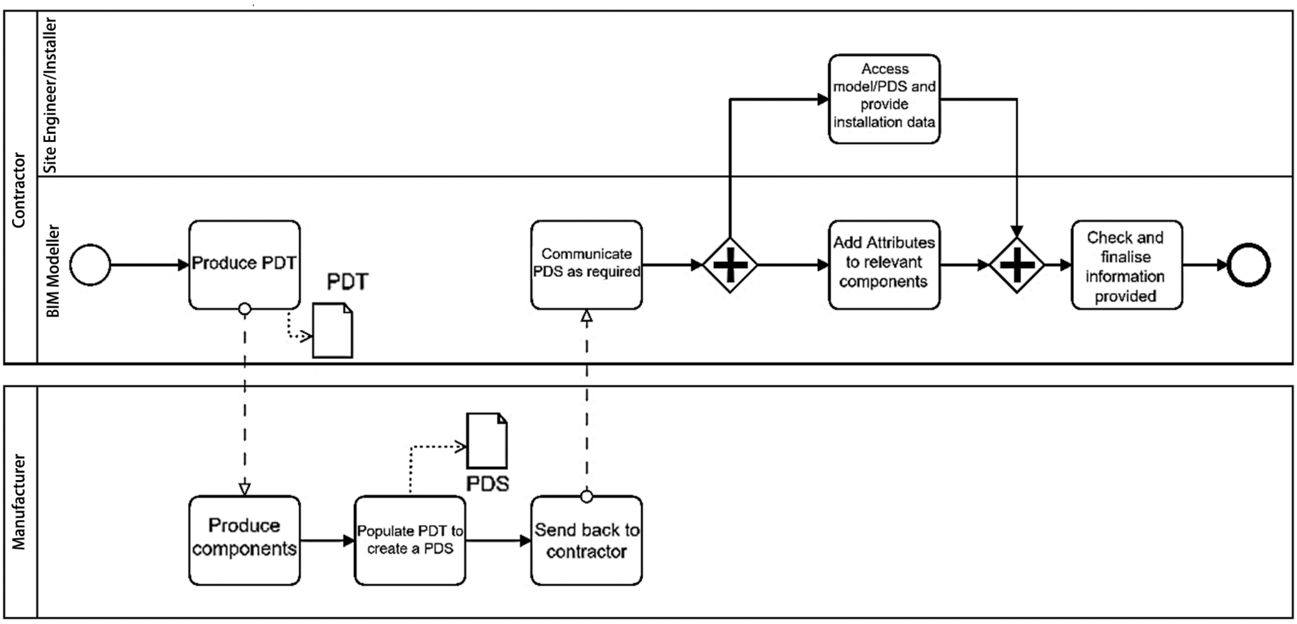

Figure 14. The process followed when linking non-graphical information to a graphical model.

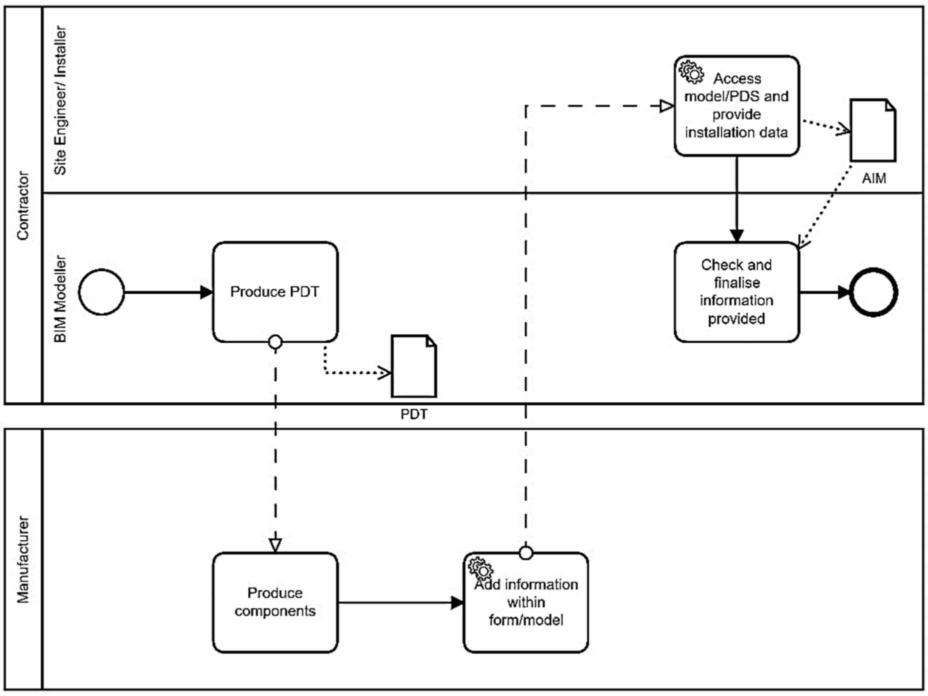

Figure 15. The process once the developed system was introduced.

When the system was tested by a project team working on an airport, they provided their specific information requirements, which were then translated into an HTML form. They provided a model that was uploaded onto the BIMServer. They tested the system by following the processes that were set out, including those described in Figure 14.

When attributes were added in the first instance, there were manual tasks involved in receiving information from manufacturers and coordinating the model to match it with the correct object. This was a relatively slow process, and this meant that a third person, a modeller, would have to link the attributes to the model. However, as described in Figure 14, the attributes can be added directly via the process management system with the semi-automated process. Giving the information requirements as a form (as shown in Figure 16) allowed for enumerated lists and Booleans, which helped ensure that the information provided was consistent. When assessing the speed at which attributes could be associated using the models, the process described in Figure 14 took close to 3 min to associate a group of 18 attributes to a model. However, the process that was executed via the BPMS took just under 20 s to associate the 18 attributes.

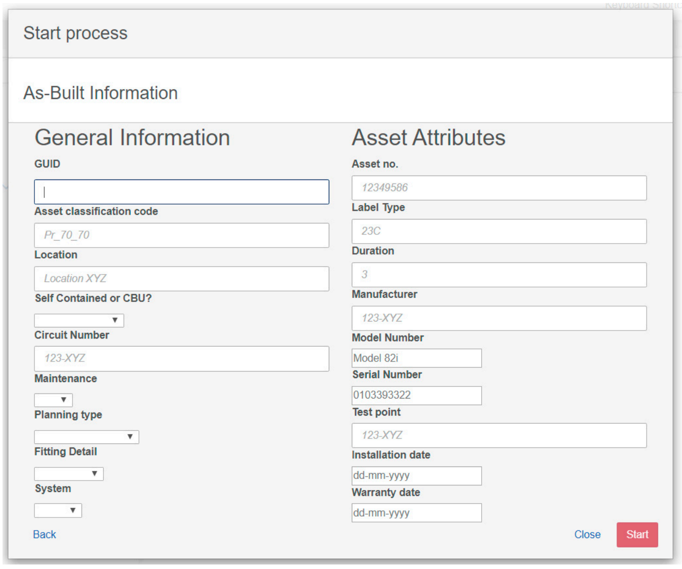

Figure 16. Sample HTML form produced.

5. Discussion

For object information, this study leverages BPMN alongside Product Data Templates (PDTs) by creating an automated process anchored in the Project Information Model (PIM). The work was the realization of an integrated, automated process linking data templates to digital models, essentially forging a dynamic, adaptive project information management workflow. The BPMN played a pivotal role as the bedrock of our automated process. Known for its standardization and adaptability, it allowed the project to create a comprehensive visual guide for complex procedures and workflows. At the same time, the PDTs ensured that the data were not only consistent, but also compliant with international standards. To enrich the system interface, the BIM data in accordance with the product data templates were evaluated. This used to be a convoluted, manual process, vulnerable to human error and inconsistencies. In this study, we broke through this barrier by establishing automated algorithms that could dynamically update the BIM data, pulling from the PDTs as their source. The result was a substantial increase in efficiency, as well as a marked reduction in errors and delays. After this, the hitherto unsolved issue of the BPMN's inability to seamlessly integrate with project data management methods was solved. An intermediate software layer can harmonise BPMN workflows with project data management protocols. This layer bridged the existing data, and the processes were no longer disjointed but part of an integrated system.

Except for the data perspectives, an interface was also requested to consider the system efficiencies and flexibilities plaguing information management in building projects. At this point, the web platform was requested to create an integrative space in which the BPMS and digital construction management systems can collaborate seamlessly. The adaptive nature of the BPMS needed to be harmonised with the rigid, often fragmented, landscape of traditional digital construction management systems. The platform in this study used IFC. Js; this is a library that acts as a linchpin, bridging the two systems in a way that amplifies the strengths of each. ifc.js has proven to be an invaluable tool and has brought an unprecedented level of flexibility and interoperability, allowing for data interchange and real-time collaboration. The application of this library paved the way for versatile modelling, data extraction, and processing data capabilities. It turned the ambitious idea of merging the BPMS with construction management systems from a conceptual dream into an operational reality. The user interface of this web platform is engaged with end users, architects, and project managers to ensure that the platform is navigable. The platform displays adaptability in its modular architecture, which ensures that additional features and updates can be integrated with minimal disruption (Figure 17).

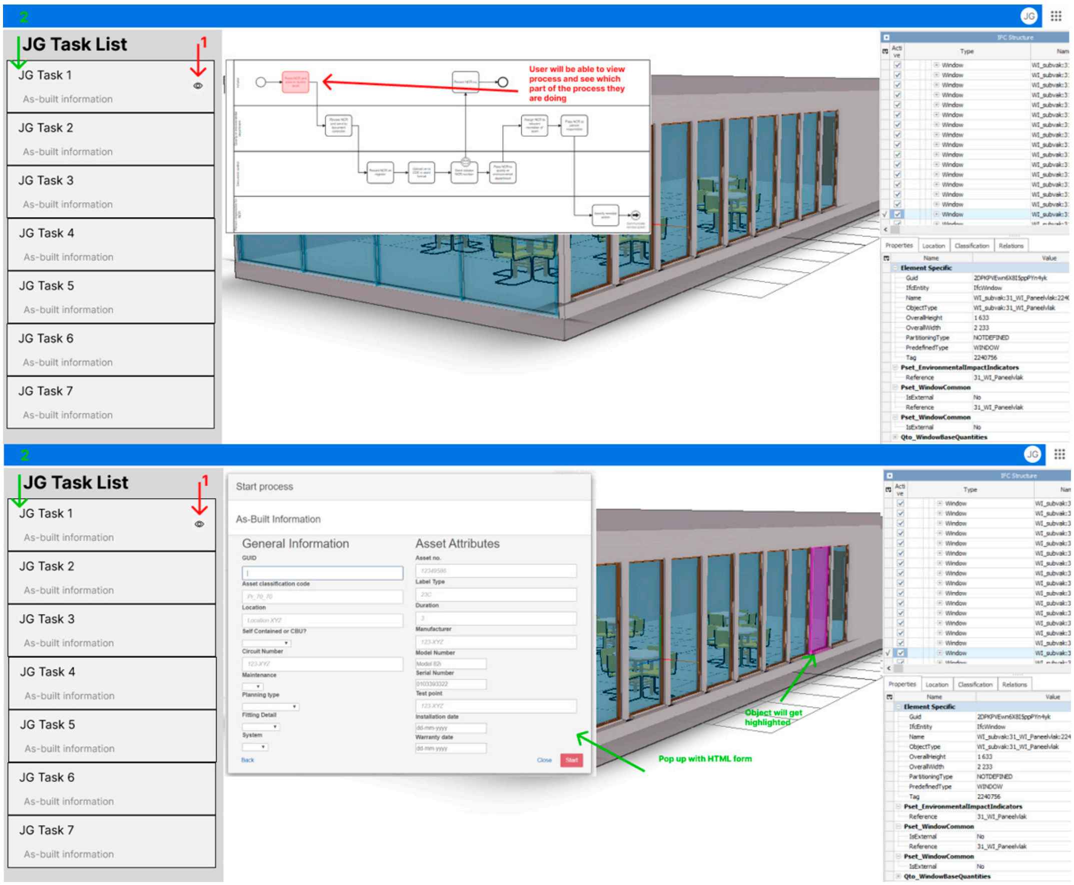

Figure 17. Integrating the BPMN and PDT using IFC.JS.

The proposed prototype system performed the tasks efficiently (20 s compared to 3 min) and enabled direct input within models, which is useful when it involves enriching the digital twin of a large project or a network of assets like highways or bridges [49–52]. The process management system also keeps a log of transactions between models and can display forms and tasks based on which user logs into the system. One concern that was highlighted was the quality of information that suppliers might provide. Therefore, an approval task was added for the modeller to review the filled-out form before it is associated with the AIM.

6. Conclusions

The research showed that a large volume of the information produced on projects is file based. Given the existing asset management systems and organisational requirements, this is unavoidable. However, it was shown over the course of the research that it is possible to efficiently capture information on an object level. This type of system can then be used when producing information such as maintenance manuals and installation details. Machine-readable information stored at an object level such as this can be queried efficiently, mainly when operating an extensive network of assets such as a highway network. The proposed solution had many benefits (as shown in Section 4):

1. Time savings—Automating tasks such as associating asset attributes with 3D models (adding structured information manually initially took 3 min, but that time was reduced to 20 s for the same number of attributes).

2. Accuracy—Allows suppliers to provide details in a machine-readable format, pinpointing the assets they are attributing the information to.
3. Better structured information—The information produced can be catered towards project-specific Exchange Information Requirements (EIRs), which can then ensure that information is produced directly according to the requirements and will not create a bottleneck at handover.

The research achieved innovations in the application and management of digital construction processes, especially in addressing the challenges of information overload and adapting to asset management requirements. By conducting a thorough analysis of standard digital construction processes in linear infrastructure projects, the study uncovered deficiencies in existing workflows. Based on these findings, a new framework was developed, aimed at optimizing the generation of critical project information, with a particular focus on meeting the specific needs of organizations responsible for the operation and management of built assets. The framework, developed through expert workshops and applied in actual projects, demonstrated its potential benefits and certain limitations. This study not only provides deep insights into existing digital construction processes, but also offers practical solutions in order to improve these processes, making them more effective in serving the specific needs of organizations.

Future work will focus on fine-tuning the integration between the Information management Server and the BPMS. Testing the process management system with other databases would also be valuable, as testing was carried out only between non-graphical and graphical information. This system has the potential to be applied when developing documentation that will be more easily read by machines.

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