A prototype tool to embed digital exchange information requirements in construction projects

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Abstract. Construction data can be created and shared in abundance, however, there is a lack of structuring and sharing accurate as-built information especially in large infrastructure projects. Current standards provide a framework that guides practitioners to organise and manage their information, but complex projects with many moving parts generally fails to conform with these standards. The underlying issue is that quite often information is provided retrospectively, and data tends to get quality controlled rather than quality assured. This ultimately leads to human error, leading to poor quality data and low confidence in as-built information. The key findings of this research show that using parsable process maps and information requirements will lead to better data quality and reduce the opportunity for human error. The ability to semi-automatically embed structured data also ensures that as-built information is captured almost instantaneously, reducing the need for suppliers to provide as-built data retrospectively or produce duplicate data. This paper will show the prototype system that was developed which includes process maps, sample information requirements, along with a breakdown of the components of the system. The research also will provide an insight into how these components will link up with industry processes and standards.

1. Introduction

The digitalization of construction processes has advanced rapidly as can been in the construction industry. For example, the National Building Specification in the UK shows that the implementation for Building Information Management (BIM) process increased from 50% in 2015 (National Building Specification (NBS), 2015) to 71% in 2021 with a further 25% aiming to adopt the processes in the next 5 years (Hamil & Bain, 2021). Despite the rapid advancements in the adoption of Building Information Modeling (BIM) processes, which have been mandated for use in several countries (Ganah and Lea 2021; Bolpagni et al. 2022), Efficient transfer of information between parties involved in BIM remains a challenge. As a result of this, suppliers tend to provide information quite often in an unstructured manner, different formats, or just by providing a large volume of data that can overload clients. This then leads to a lack of confidence in the information provided by suppliers, and therefore removes most of the value that is provided by having structure data.

The challenge identified earlier by the researchers (Goonetillake, 2019) shows that large quantities of data tend to be produced in large volumes of data that cannot be parsed directly and therefore might not be machine readable. The challenge therefore is to find a balance between information that is needed for day-to-day operation, large scale maintenance or information that is not valuable at any point in the lifecycle of an asset. To address this the author proposed a basic system that would integrate construction processes with information requirements for geometric models.

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2. Background

There has been a growing trend towards incorporating related information technologies into existing asset management processes. This has led to the development of several standards and guidelines aimed at standardizing processes and producing effective implementation strategies. To ensure effective implementation, there is a need for standardized processes and guidelines. However, the varying nature of projects makes it difficult to define precisely what an information model may require for a specific type of asset. The result is that the implementation of these standards is often ineffective on projects. Studies show that despite recognizing the value of adopting VDC/information management technology and processes, there is still resistance to adoption (Aslam et al. 2021). Experts attribute this to human factors and a resistance to change. Additionally, there is a minimal tangible benefit to clients upfront (Ravenscroft, 2017)(Boutle, 2017), leading to a reluctance to move towards adopting these processes.

There are five broad areas that can be considered to be barriers to adopting digital management processes. They are technology (included interoperability), cost (training, software, and hardware), management (workflows, schedule, and safety management), personnel (training), and legal (laws, regulations, and contracts) (Sun et al., 2015). The literature showed that among the key barriers to implementation were the challenges faced when changing to workflows (Bradley et al., 2016; Costin et al., 2018). As a result, there is a lack of workflows with clear indicators due to the way data is collected on site, which can impact aspects such as safety management (Boje et al., 2020).

A review of global standards showed that each of the analysed standards had disparate requirements leading to confusion among those using them (Sacks, Gurevich & Shrestha, 2016). Looking further into countries that have mandated the use of specific standards, a review of the adoption of information management in 5 large UK government agencies showed that even though there was a mandate, there was no strategic guidance to manage the adoption process to achieve the desired results (Gurevich, Sacks & Shrestha, 2017). The conclusions were similar to the other surveys in the industry in the UK and abroad; there is a digital transformation occurring, and there has been an adoption. 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 recognize their capabilities and take necessary steps to overcome some of the challenges faced. In a longitudinal study that was carried out by Gurevich & Sacks (2020a) on public construction clients showed that even though the ultimate value of digital construction processes was recognised, there still was a need for agency-level information requirements.

Once information Technology such as BIM has been implemented on projects, there is also a lack of good quality data produced. In a study carried out with local authorities in the UK, there were three specific day-to-day issues faced by these organisations (Catton & Parlikad, 2015). They were legal issues, insufficient information quality, and lack of resources to address the first two problems while delivering a public service. The general observations were that the interviewed authorities were averse to implementing Information management systems as they were mis-sold to the sector, and there was generally a lack of ‘good quality data (this included inaccurate data, varying units, and various naming conventions). Other studies with public clients also show that despite contract clauses requiring work using digital Information management, there is a lack of adequate information on quality assurance procedures (Gurevich & Sacks, 2020b). In addition, there generally is a lack of resources to enable the production of information in the desired format as there was 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 produce codes of practice for specific types of infrastructure as processes and information requirements vary by asset type (UK Roads Liaison Group, 2016b)(UK Roads Liaison Group, 2016a). 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 factor into 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.

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 (Goonetillake, Lark & Li, 2018). Several studies in the infrastructure domain have shown that there is still a need to align processes as there still are gaps related to the creation of information and the governance of the production and use of information (Bradley et al., 2016). A review in transport infrastructure further reinforced these observations and showed a lack of alignment of standards with transport industry processes hindering adoption even further (Costin et al., 2018).

The analysis of standards shows that ambiguities in industry standards and terminology can also lead to the lack of adoption or the deviation from the standards (Winfield & Rock, 2018). Therefore, there is a need to ensure those project participants are aware of these challenges and ensure that their current processes are aligned to adopt information management. As a result, several organisations have produced more specific guidelines to help organizations follow a standard procedure on their projects (UK BIM Framework, 2020). The inclusion of concepts related to the standards, transition guidance 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 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, the ISO 19650-1 (British Standards Institution, 2018) 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 are enforced while complying with the ISO standards. Therefore, it is still necessary for clients to ensure that on a project or organisation level, information requirements are specified clearly, and the processes that are going to be used are correctly enforced. In conclusion, the increasing drive to incorporate related information technologies into existing asset management processes has led to the development of several standards and guidelines aimed at standardizing processes and producing effective implementation strategies. However, challenges such as the varying nature of projects and resistance to change still hinder the effective adoption of these technologies.

Numerous methods are available for mapping out processes and information flows. One such method is the Integration Definition for Functional Modelling (IDEF0) which can be used to record inputs, outputs, controls, and mechanisms within a process. This method has been found to be a good alternative to describing a system compared to using prose (Kassem, Dawood & Mitchell, 2011). IDEF0 has been utilized to capture processes on highway projects due to its advantage of not requiring chronological continuity or sequencing, which is essential for the varied nature of procurement and contexts on such projects (Bartley, Mcmahon & Denton, 2016). As a result, this method has the potential to be effective when setting out information requirements.

To bridge the gap between business process design and the implementation of those processes, Business Process Model and Notation 2.0 (BPMN) has gained greater adoption (García-Domínguez, Marcos-Bárcena & Medina, 2012). This notation and modelling standard is regulated by the Object Management Group (OMG). The OMG has 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.

The possibility of creating formalised executable workflows related to Compliant Design Procedures (CDP) to guide the automated audit of digital models against local regulations was explored (Dimyadi, 2016). 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, 2018) was used to render the workflows graphically. Similar efforts have been made to help manage client requirements to improve the quality of built facilities and their related services using an enterprise architecture framework for electronic requirements information management (Jallow et al., 2017).

Overall, the review of state-of-the-art practices in the industry indicates that several challenges are faced when adopting digital information management. There are specific problems with adjusting processes and enforcing information requirements to produce high-quality information. To address these challenges, it is important to (1) identify the type of information currently produced on infrastructure projects, (2) analyze the information produced and the processes followed, and (3) provide a solution that helps to address the specific issues faced during implementation.

3. Methodology

Several frameworks and standards have been published that focus on the implementation and establishing exchange information requirements on construction projects. However, initial findings showed that even though these initiatives have driven forward implementation, there is still a need for fine-tuning. For example, making sure how information requirements are established and enforced can then ultimately help produce an information model that can be used during the operation of an asset. Therefore, the research plan was set to develop a framework to define 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.

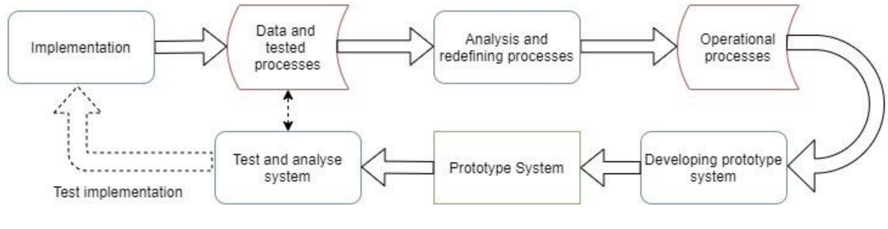

Figure 1 The overarching solution overview - The iteration of collecting information, refining processes, and developing the prototype

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 highways project that involved the construction of a 700m long viaduct. Several components were fed into the project, and this has been 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 ISO 19650 standards were largely derived from the BS 1192 suite of standards, with subtle variances such as those with terminology rather than overall processes (British Standards Institution, 2019). The aim was to implement the processes according to the standards, analyse the breakdown of an Asset Information Model (AIM), identify the challenges faced when creating it, and the potential problems that could have been faced at operation.

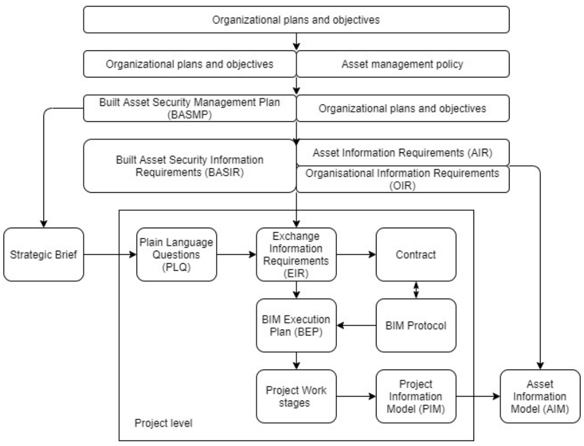

Figure 2 Interaction between policies, standards, and specific information requirements (This diagram is derived from the BS 1192 and ISO 19650 suite of standards as well as the ISO 55000)

To record processes, various methodologies were considered, and numerous possible methods (Dumas et al., 2018) were considered. The three methods considered (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 get an understanding of processes (3) Interview-based discovery – Interviewing experts to identify how processes are executed.

A decision was made to carry out a series of workshops to provide a rich data set based on domain-specific knowledge. They also provided experts the opportunity to discuss their specific requirements based on which stage of a project they were working on. This helped carry out immediate iterations on processes and requirements. To identify information requirements and their related processes, 10 workshops were held, and 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 get expert input in refining the processes that were implemented in the initial project. It was also aimed at capturing information requirements digitally before attempting to implement them at the next phase of the research.

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. The final part of the research was aimed at developing a system that will be able to align these captured processes with graphical information through a prototype system. The system will first be tested against the manual process of linking alphanumeric information against graphical information, and also against a previous iteration of the system both in terms of upload speed, security and usability. The value of ensuring that standardised data formats and structures was recognised, and it is recommended that data is created and managed to standards such as the ISO 23387 (BS EN ISO 23387:2020). The structuring and standardising of construction product information and the management of data dictionaries will be explored in future studies.

4. Construction project outcome

Previous work carried out by Goonetillake (2019) showed that the Project Information Model (PIM), contained 26,401 individual files (these included 3D models, documentation, drawings, and images). Based on the Exchange Information Requirements (EIR) 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 3. The results confirmed the observations made in previous studies as more than 90% of the AIM was document-based (Bartley, Mcmahon & Denton, 2016; Mazairac & Beetz, 2013). 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 is an integral part of the information to be handed over. A part of the enrichment of the model involved producing Product Data Templates (PDTs) in a standardized format which were filled in by various suppliers, and then linked to the graphical model which was a time consuming and potentially error prone process given the volume of data and scale of the project.

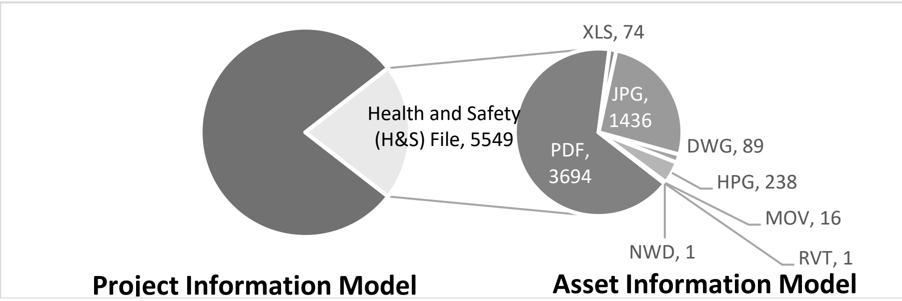

Figure 3 Breakdown of the data produced after the first stage

5. Workshops outcome

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. There also was the challenge of not being able to check the quality of the data produced as a large proportion of the data was produced in non-machine-readable formats. 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 that data can be captured automatically or semi-automatically. Based on the given feedback, several strategic process maps were produced to give an overview of 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 4, to understand the flow of information from different points of view. Then more specific sub-tasks were mapped out based on the overall process as shown in Figure 4.

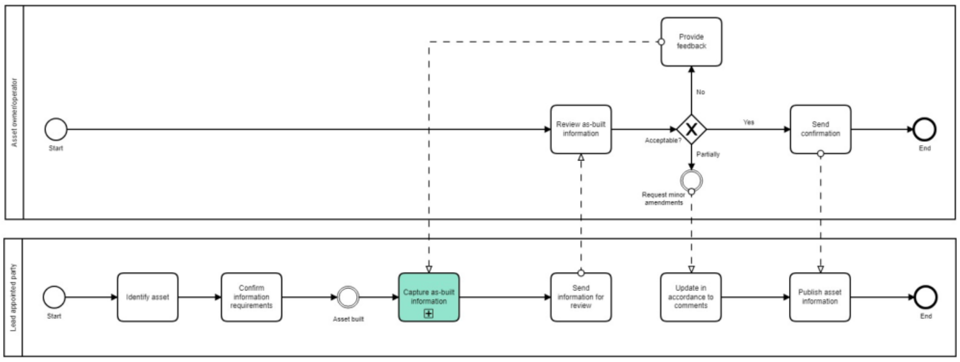

Figure 4 Process map describing the process of capturing as-built information

The operational process models where then utilized to set specific information requirements against each task and help automate or semi-automate each of those tasks. This method of breaking tasks down and identifying specific information requirements then aided 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 5, where specific processes are identified for a project and then integrated within an BIM Execution Plan (BEP).

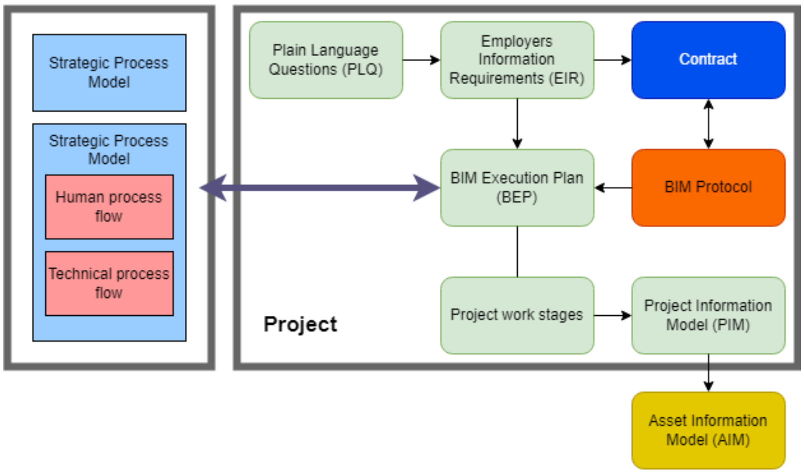

Figure 5 Process discovery on a project level

6. System architecture and future development work

A focus was made on how processes could be executed to produce an Asset Information Model that can be integrated within an asset management system. To test the processes, the two main components were the Open BIMServer (Beetz et al., 2010) which was to host the 3D model, and an Open-source Business Process Management System (BPMS), which was developed by Camunda (Camunda, 2019b). The information requirements were set as HTML forms produced within the process modelling tool where forms can be created within each task.

When the system was tested by a project team working on an airport, they provided their specific information requirements that were then translated into an HTML form. When attributes were added in the first instance, there were manual tasks involved with 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. Giving information requirements as a form (as shown in Figure 7) allowed for enumerated lists and Booleans, which helped ensure that the information provided was consistent. When assessing the speed at which attributes can be associated with the models, the process took close to 3 minutes to associate a group of 18 attributes to a model. However, the process that was executed via the BPMS took just under 20 seconds to associate the 18 attributes. One concern that was highlighted was that of 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 being associated with the AIM.

As a part of the future development work of this concept, research is being carried out to develop a web platform which will bring together the BPMS and the digital construction management system utilising libraries such as ifc.js. Figure 6 and Figure 7 are images of the user interface being developed for the next phase of this research. This will then be validated for its effectiveness by first comparing it with the existing system both for speed (quantitative) and ability to use (qualitative).

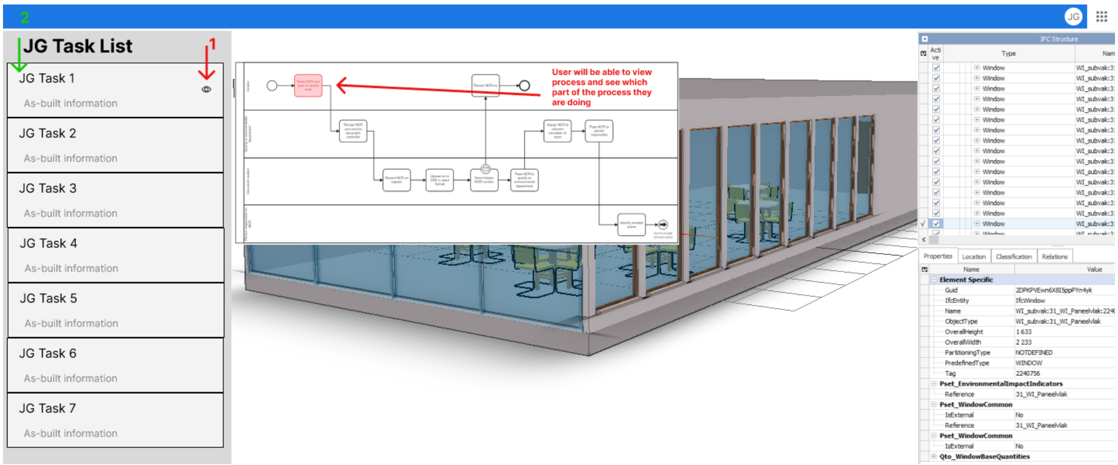

Figure 6 Process discovery on a project level

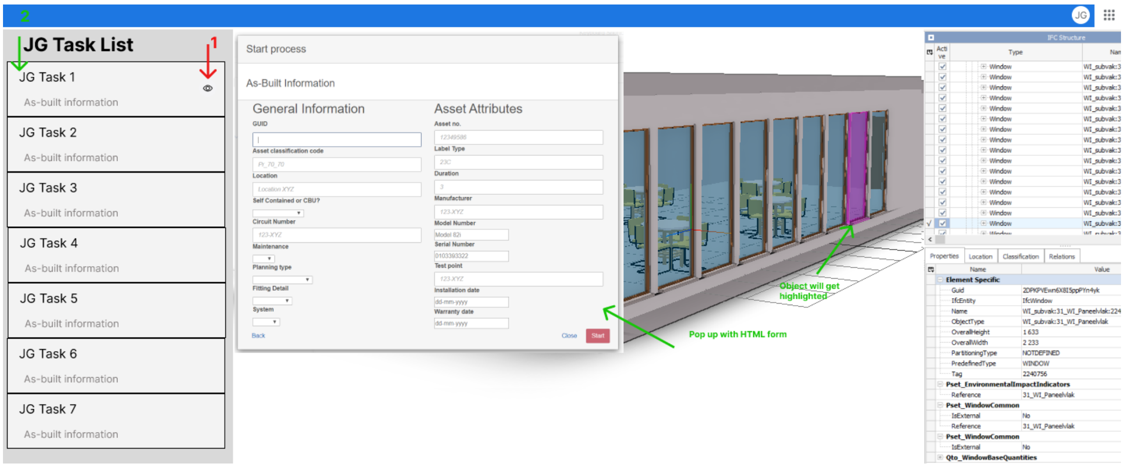

Figure 7 Sample PDT

7. Conclusion

The research showed that a large volume of information that is produced on projects is file-based. Given the existing asset management systems and organisational requirements, it 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 highways network.

The proposed solution had many benefits including time savings by automating tasks such as associating asset attributes with 3D models, facilitating the provision of machine-readable data, pinpointing to the assets they are attributing the information to, and better structured information.

Future work will focus on developing a platform built on a NoSQL server utilising the IFC.js library and linking the BPMS to automate mapped out processing. 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 machine-readable.

References

Bartley, T., Mcmahon, C. & Denton, S. (2016) Information Flows in Highway Project Delivery. *Proceedings of the 32nd Annual ARCOM Conference*. 2 (September), 777–786.

Beetz, J., van Berlo, L., de Laat, R. & van den Helm, P. (2010) bimserver. org – An Open Source IFC Model Server. In: *Proceedings of the CIB W78 2010: 27th International Conference–Cairo, Egypt*. 2010 pp. 16–18.

Boje, C., Guerriero, A., Kubicki, S. & Rezgui, Y. (2020) Towards a semantic Construction Digital Twin: Directions for future research. *Automation in Construction*. 114, 103179. doi:10.1016/j.autcon.2020.103179.

Boutle, A. (2017) *UK BIM adoption: reality is difficult to fathom*. 2017. BIM+.

Bradley, A., Li, H., Lark, R. & Dunn, S. (2016) BIM for infrastructure: An overall review and constructor perspective. *Automation in Construction*. 71, 139–152. doi:10.1016/j.autcon.2016.08.019.

British Standards Institution (2019) *BSI Standards Publication Transition guidance to BS EN ISO 19650*.

British Standards Institution (2018) *National BIM standard-United States (version 3)*.

BS EN ISO 23387:2020 *Building information modelling (BIM) - Data templates for construction objects used in the life cycle of built assets - Concepts and principles*.

Camunda (2019a) *BPMN Modeling Reference - All BPMN 2.0 Symbols explained | Camunda BPM*. 2019.

Camunda (2018) *bpmn-js: BPMN 2.0 rendering toolkit and web modeller*. 2018.

Camunda (2019b) *Camunda 7.11*. 2019.

Catton, P. & Parlikad, A. (2015) *Asset information management for local authority asset owners*. (October).

Costin, A., Adibfar, A., Hu, H. & Chen, S.S. (2018) Building Information Modeling (BIM) for transportation infrastructure – Literature review, applications, challenges, and recommendations. *Automation in Construction*. 94, 257–281. doi:10.1016/j.autcon.2018.07.001.

Dimyadi, J. (2016) *Automated Compliance Audit Processes for Building Information Models with an application to performance-based fire engineering design methods*.

Dumas, M., La Rosa, M., Mendling, J. & Reijers, H.A. (2018) *Fundamentals of Business Process Management*. Berlin, Heidelberg, Springer Berlin Heidelberg. doi:10.1007/978-3-662-56509-4.

García-Domínguez, A., Marcos-Bárcena, M. & Medina, I. (2012) A Comparison of BPMN 2.0 with Other Notations for Manufacturing Processes. *Key Engineering Materials*. 502, 593–600.

Gilligan, B. & Kunz, J. (2007) *VDC Use in 2007: Significant Use, Dramatic Growth, and Apparent Business Opportunity*.

Goonetillake, J., Lark, R. & Li, H. (2018) A Proposal for the Integration of Information Requirements Within Infrastructure Digital Construction. In: I. Smith & B. Domer (eds.). *25th EG-ICE International Workshop 2018*. 2018 Lausanne, Springer International Publishing. pp. 378–390. doi:10.1007/978-3-319-91638-5.

Goonetillake, J.F. (2019) *A Framework for the Integration of Information Requirements Within Infrastructure Digital Construction, A thesis submitted to Cardiff University School of Engineering in partial fulfillment of the requirements of the degree of Doctor of Philosophy.* Cardiff University.

Gurevich, U. & Sacks, R. (2020a) Longitudinal Study of BIM Adoption by Public Construction Clients. *Journal of Management in Engineering*. 36 (4), 05020008. doi:10.1061/(asce)me.1943-5479.0000797.

Gurevich, U. & Sacks, R. (2020b) Longitudinal Study of BIM Adoption by Public Construction Clients. *Journal of Management in Engineering*. 36 (4), 05020008. doi:10.1061/(asce)me.1943-5479.0000797.

Gurevich, U., Sacks, R. & Shrestha, P. (2017) BIM adoption by public facility agencies: impacts on occupant value. *Building Research and Information*. doi:10.1080/09613218.2017.1289029.

Hamil, S. & Bain, D. (2021) *Digital construction report - 2021*.

Hevner, A., March, S., Park, J. & Ram, S. (2004) Design Science Research in Information Systems. *MIS quarterly*. 28 (1), 75–105. doi:10.2307/25148625.

Jallow, A.K., Demian, P., Anumba, C.J. & Baldwin, A.N. (2017) An enterprise architecture framework for electronic requirements information management. *International Journal of Information Management*. 37 (5), 455–472. doi:10.1016/j.ijinfomgt.2017.04.005.

Kassem, M., Dawood, N. & Mitchell, D. (2011) A structured methodology for enterprise modeling: A case study for modeling the operation of a british organization. *Electronic Journal of Information Technology in Construction*. 16, 381–410.

Mazairac, W. & Beetz, J. (2013) BIMQL - An open query language for building information models. *Advanced Engineering Informatics*. 27 (4), 444–456. doi:10.1016/j.aei.2013.06.001.

National Building Specification (NBS) (2015) *National BIM Report - 2015*.

Ravenscroft, T. (2017) *Round table asks: what happened to the BIM bang?* 2017. BIM+.

Sacks, R., Gurevich, U. & Shrestha, P. (2016) A review of Building Information Modeling protocols, guides and standards for Large construction clients. *Journal of Information Technology in Construction*.21 (21) pp.479–503.

Sun, C., Jiang, S., Skibniewski, M.J., Man, Q. & Shen, L. (2015) A literature review of the factors limiting the application of BIM in the construction industry. *Technological and Economic Development of Economy*. 23 (5), 764–779. doi:10.3846/20294913.2015.1087071.

UK BIM Framework (2020) Information management according to BS EN ISO 19650 - Guidance Part 2: Processes for Project Delivery. *UK BIM Alliance*. (3) p.42.

UK Roads Liaison Group (2016a) *Better Information Management: Guidance for infrastructure bodies*.

UK Roads Liaison Group (2016b) Well-Managed Highway Infrastructure A Code Of Practice. *Department for Transport*.

Winfield, M. & Rock, S. (2018) *Winfield Rock Report - Overcoming The Legal And Contractual Barriers Of BIM*