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A PROCESS-BASED FRAMEWORK FOR DIGITAL BUILDING LOGBOOKS

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Abstract

Digital building logbooks (DBLs), as repositories of building lifecycle data, can contribute to improving the performance of and decisions about buildings. However, for DBL concept, its required data and the roles of various stakeholders. These are all aspects that need to be investigated. We thus propose a process-based DBL framework integrating data and stakeholder roles. This fulfils key DBL requirements and supports digitalisation of building objects. The research uses a literature review, process mapping, and a focus group to develop and validate the framework. This proposal contributes to the priority actions 1 and 2 of the European Commission's DBL report.

Introduction

Data is regularly collected over the lifespan of a building by various stakeholders and for a variety of decisions that rely on data availability. However, this is challenged by the lack of an established approach that provides the structure for the stakeholders to benefit from this wealth of data. Building Information Modelling (BIM) has been central to digitalisation of processes within the construction industry (Sacks et al., 2018). BIM standards to provide common definitions and processes for information management (as is the case with ISO 19650 standard series) are being developed. According to ISO 19650-1 (2018), BIM refers to the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions. Within a BIM process, information is retrievable from within a file, system, or application storage hierarchy, as an information container. These concepts are very pertinent to the DBL as they enable, for instance, the handover of relevant data about a building to its use phase.

More recently, the concept of digital twins (DT) has been proposed as a new technology-led advancement to support the data-centric decisions across a built asset lifecycle (Shahzad et al., 2022), despite communalities and difference between BIM and DT are not fully understood (Douglas et al., 2021). A digital twin (DT) integrates data from a variety of sources and systems (systems of systems, SoS) (Borth et al., 2019) and can be represented into multi-domain ontologies (multi-layers) (Al-Ali et al., 2020). Although DT applications remain scattered throughout the construction industry, the Internet of Things (IoT) that supports them can be linked to the building data within BIM (Zhang et al., 2022). DT requires a physical element and its digital counterpart – where the knowledge of an as-built artifact's properties is recorded and updated (e.g., through BIM information containers) (Deng et al., 2021).

Digital, interoperable, and traceable data is key for the DBL. Indeed, according to the European Commission (EC, 2021), the DBL is conceived as a common building data repository, facilitating transparency, trust, decision-making, and information-sharing among owners, users, financial institutions, and public authorities. As a result, DBL is likely to act as a receiver of BIM information and an enabler of DTs by setting a structure for all the data required for the digital counterpart (Mêda et al., 2021). However, to date, we lack a clear conceptualisation of DBL's that clarifies its processes, data requirements, relationships with other systems and stakeholders' interactions. This paper contributes to this gap by proposing a process-based DBL framework approach.

We build upon previous research on a digital data-driven construction framework supported by "digital" Data Templates (meaning ISO 23387 compliant) and DBL (Mêda et al., 2021), and we focus on the DBL business processes and their mapping using Business Process Modeling Notation (BPMN) flowcharts (Muehlen & Recker, 2013). The proposed framework can support the DBLs' function according to priority actions 1 (developing a standardised approach and legal framework for data collection, management, and interoperability) and 2 (developing guidelines for linking existing databases) in the final DBL report by EC (2021), by clarifying key DBL components, layers, functionalities, and services – i.e., project outcomes, relevant processes, inherent relations, interactions, and business rules.

The remainder of the paper is organised as follows: first, the research methods used to develop and evaluate the DBL framework are explained. Second, the literature review, focused primarily on DBL state-of-art, is presented. Third, the DBL BPMN process maps are illustrated and explained. This is followed by their validation in a focus group. Finally, the paper concludes with a discussion and some final remarks, including the study's limitations and recommendations for future work.

Research methods

The research involved a literature review search, an empirical analysis through business process mapping, and the synthesis of the results from the two aforesaid methods.

The literature review was centred on key concepts such as "DTs in construction" and "DBLs" while allowing the identified set of studies to be extended to cover additional concepts until no new concepts relevant to the search terms could be found (Webster and Watson 2002). To ensure relevance of identified studies, the search terms included also concepts such as "level of information need (LOIN)" and "process framework". To further ensure that the selected set of studies is not too narrow and is representative of the body of knowledge in this area (MacLure 2005), "snowballing" and references-of-references techniques (Greenhalgh and Peacock 2005) were adopted.

The review timespan was between 2016, when early studies featuring the searched concepts started to appear, and 2022. Databases with relevant content were tested using the search terms, and these included Elsevier, Taylor & Francis Online, Google Scholar, WorldWideScience, and Scopus. The initial search results identified a few thousands of papers. After applying relevant filters, Boolean operators and exclusion criteria (Dundar and Fleeman 2017), the resultant set of studied included was reduced to the ones featuring in this paper.

For the empirical analysis, the BPMN-based DBL process-based flowchart was designed using the Draw.io software. Then, it was validated by both a focus group session (Knodel, 1993) held with six experts (two project owners, two Construction Management Researchers, a process mapping expert, and a disaster management (Disaster Man.) expert), and the authors' own input through cycles of "Author-Reader" evaluation method that can ensure the correctness of the process maps (Kassem et al., 2014). The focus group objective was to capture the relevant knowledge from the selected experts in relation to the DBL framework, and discuss both the holistic approach adopted to develop the framework as well as the processes related to specific experts' domains. Table 1 identifies the domains and experience (years) of the focus group participants.

Table 1: Focus group participants

Expert	Background	Experience
#1	Project Owner	32 years
#2	Project Owner	20 years
#3	CM researchers	4 years
#4	CM researchers	18 years
#5	Process Map exp.	12 years
#6	Disaster Man. exp.	25 years

The synthesis of the review results and the empirical analysis followed an abductive reasoning approach through which observations and critical insights are developed by working iteratively between the theoretical constructs and data (Bell et al. 2019).

Literature review

As a concept DBLs can be contextually linked to earlier studies focusing on requirements for collaboration and transformation of data into knowledge (Stillerman et al., 2016), and to more current construction-specific efforts relating to data management through various digital technologies (e.g., BIM and DTs in Boje et al., 2020; and blockchain in Xu et al., 2022). However, a direct conceptualisation of DBLs was not proposed until early 2021 when the European Commission (EC) issues its report on DBLs (European Commission, 2021).

This EC report sets the definition of DBLs as presented in the Introduction of this paper and identifies several relevant initiatives in different countries. However, those do not fully address DBL implementation and do not even adopt the "DBL" term. Instead, they adopt terms such as building passport, electronic building ID, home report, homebook or home information pack (European Commission, 2021).

As part of the EC report (2021), a survey was developed on DBLs' data collection needs and potential services. One of the survey's questions - ("What type of data do you think should be collected in the Digital Building Logbook?" - is highly relevant to the current paper. Of the 18 data fields serving as potential answers to the question, "Building descriptions and characteristics", "Design and plans of the building" (during handover and following interventions), "Energy performance certificate", and "Ownership information", were classified as "Very Important". Moreover, "Taxation information linked to property", and "Dynamic data (smart meters, sensors etc.)", were classified as "Somewhat important".

Within the same year continuing into 2022, several studies focusing explicitly on DBLs became available. These studies have mostly explored the potential of DBLs in specific applications. Kuiper (2021) suggested the DBL described by the EC (2021) as an example of an international BIM-related standard that could be adapted to the Australian context. Sesana et al. (2021) explored its application in the deep-energy renovation of non-residential buildings. Armijo et al. (2021) and Daniotti et al. (2021) investigated the digitalization of renovation processes in residential blocks. Signorini et al. (2021) investigated the renovation topic again, but from the perspective of the service companies' needs and requirements, while Villarejo et al. (2021) focused on the issuing of building renovation passports. Gonçalves et al. (2021) disclosed the minimum DBL data requirements in order to perform large scale fire risk analyses. Finally, Lotz et al. (2022) adopted a value chain perspective to investigate the ways the DBL could be used for circularity in the building and battery manufacturing sectors.

Focussing on the 'Golden Thread of Information', as the UK's corresponding concept to the DBL, Watson et al. (2019a) developed key concepts including a comprehensive definition and a framework defining information traceability and traceable unit of information across the lifecycle. This work was subsequently applied into key use cases related to product recall within the construction industry (Watson et al., 2019b) and automation of maintenance and repair activities through blockchain and smart contracts (Li et al., 2020).

Mêda et al. (2021) extended the DBL concept by linking it to DTs. After noting their literature review insights that DTs in construction have mostly been linked to IoT, smart buildings, and smart cities, Mêda et al. (2021) evidenced that DBLs can be enablers for DTs, by providing background data collected from BIM, IoT or other databases. DBLs and data about building operation, collected from IoT and structured within BIM, were identified as necessary parts of an incrementally developed DT (Mêda et al., 2021).

DBL BPMN framework: development and analysis

To act as a repository of building lifecycle data that can be used to improve the performance of and decisions about buildings, it is key that DBL data can be relevant and trusted. Given its whole lifecycle coverage, a DBL starts by compiling the building location related data (e.g., coordinates, land registry, and related finances). This data should then be systematically fitted in an information layer base. The DBL should then be constantly updated and progressively built over the building's lifecycle, by collecting new data or replacing previous data due to interactions, interventions, gateways, and other events – especially from a DT perspective. As such, there are many processes that must be detailed to allow further data collection and management, as well as the identification of interactions.

The DBL's BPMN diagrams that is hereby developed aims to provide a standardised approach for data collection, management, and interoperability, linking existing databases (priority action 1 and 2 in EC's 2021 Report) and revealing key DBL components, layers, functionalities, and services (i.e., project outcomes, relevant processes, inherent relations, interactions, and business rules).

The diagram is structured according to three main stages of the RIBA (2020) plan of work: "Strategic Definition" corresponds to the early phase in which the DBL will be initiated; "Design and Construction" results from the merging of the design and construction phases (as they are strongly interconnected, especially in design-build contracts); and "Use" corresponds to the operation and maintenance phase, where a prospective DT can be materialised.

The three stages are illustrated in Figs. 2, 3, and 4 and each is explained in a dedicated subsection. The adopted BPMN symbology is shown in Fig. 1. The overall flowchart was structured using the bending snake strategy (Lübke et al., 2021).

Strategic Definition (Fig. 2, see next page)

As DBL is initiated at the early Strategic Definition, "Deploy DBL" is the first activity led by the project owner. The purpose of this task is to identify data objects relevant to the project including DBL frameworks, guidelines, and tools. The task involves manual data collection and leads to the selection of the most suitable options for the project.

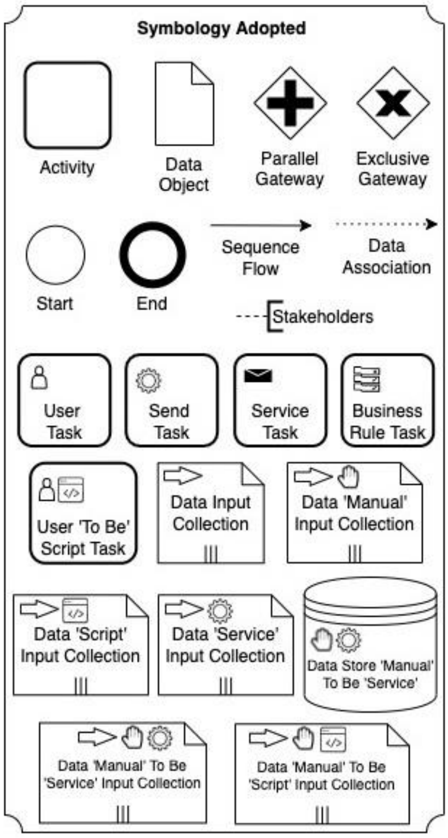

Figure 1: DBL BPMN framework symbology

Depending on the project and owner types, the intervention of other stakeholders can differ. "Consolidate Available Data" is highly dependent on the involved stakeholders. The key data objects to collect here are cadastral data (e.g., land ownership, registration, and finance), as well as parcel attributes relying on regulations (e.g., municipality plans). These manual entries may evolve into scripts or service tasks.

Depending on different national contexts, the registration and financial data can already be found in one or more databases, where gateways can be set. Moreover, a Prior Information Request to authorities can generate data on parcel attributes (e.g., potential uses and construction properties of the land). As the EU INSPIRE Directive applies here (Radulovic et al., 2017), the manual input will tend to become a script.

With the understanding of what is possible to build, the following activity will "Define the Database framework", where "Construction Preliminary Requirements" constitute the technical data produced by the design team in their first construction concepts. At this stage, most data inputs are assumed to be manual.

The Strategic Definition activities end with the confirmation of whether the project can be built. "Validate Legal requirements" is a key activity relying on the analysis and authorizations that need to be provided.

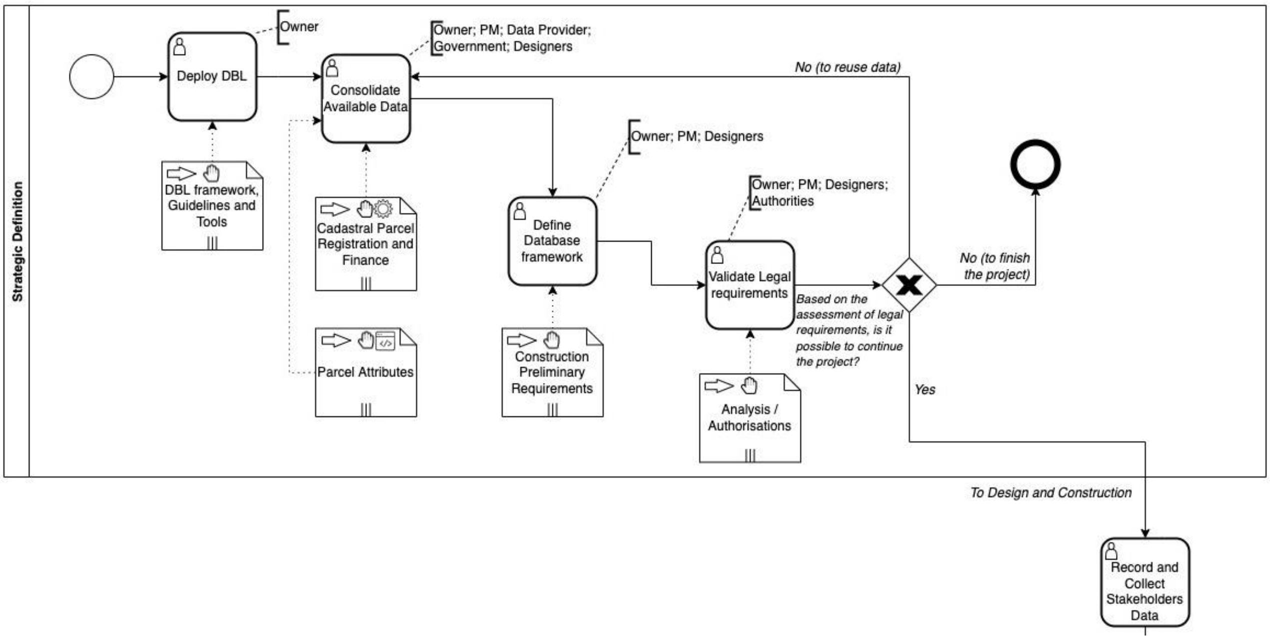

Figure 2: DBL BPMN flowchart framework – Strategic Definition stage

Commonly, this task is performed as a manual data entry in municipality systems. Several projects have been exploring the digital issuing of permits, which could transform this task to a service or a business rule (Noardo et al., 2020). The agreement (or not) on the technical aspects and the budget leads to an exclusive gateway of go/no-go options, where several scenarios can occur.

Design and Construction (Fig. 3, see next page)

Due to the wide range of procurement routes, modes of stakeholder involvement and country based processes, this process map was conceived in such a way that the included activities and roles can be generalised.

"Record and collect stakeholders' data" is a key activity to assure the golden thread of information, as it sets the

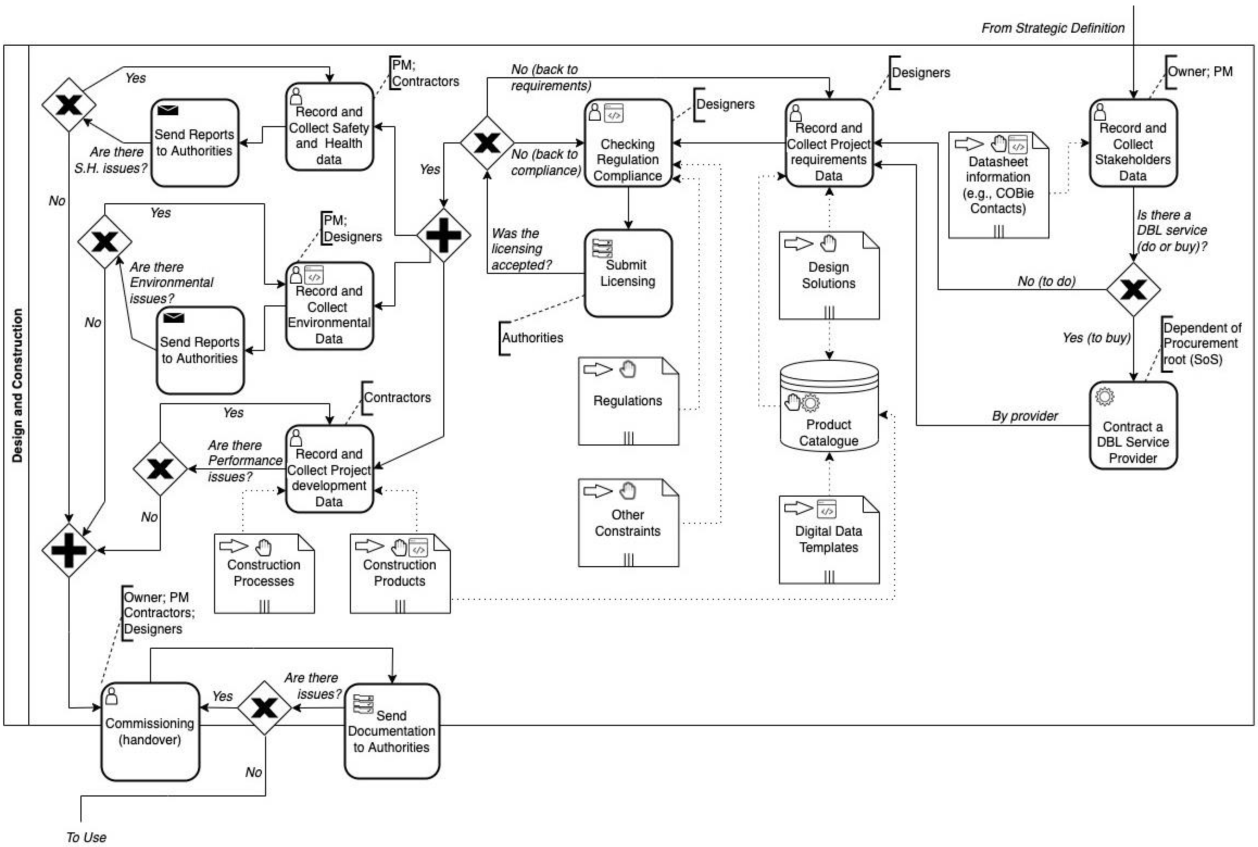

Figure 3: DBL BPMN flowchart framework – Design and Construction stage

roles and ownership of all future data. As there are several systems and tools supporting this functionality, the task is likely to become a script. At this stage, it is also essential to evaluate the need to "Contract a DBL Service Provider" as part of the framework of agreements to be set.

Then, the project's conceptualisation and technical development lead to "Record and collect project requirements data", supported by the definition of the envisaged design solutions and their properties. This activity and group of related tasks deal with the data identified as essential for DBL functionalities. This task is considered as a manual data input, despite several existing technological solutions or the possibility for a product catalogue based on "digital" Data Templates (as envisaged in ISO 23387 (2020)) can help in automating this task. The rationale is that detailing this scenario and the associated relationships as they are, is thought to strengthen interoperability requirements.

During the design process, new authorizations might be needed to check the compliance with Regulations and/or other applicable constraints. "Checking Regulation Compliance" is similar to "Validate Legal requirements", although the related data and the requirements can be far more complex. There are already several Licensing tools here that can support the processes submission. The Authorities will then decide whether the elements and data are compliant, or changes are needed. With a "Yes" as Gateway outcome of this activity, construction can start.

In this stage, three main parallel activities are considered, due to the different requirements set by EU Directives on "Safety and Health" and on "Environment". Due to the reporting requirements, there will be periodic tasks of sending recorded and organised data to the Authorities in both dimensions. Then, "Record and Organise Project Development Data", manage data related to the technical execution of the building, which involve constructing the physical elements in accordance with their digital counterparts, or updating the digital counterpart with on-site changes affecting the characteristics of the physical element. Data traceability and reliability requires that checks must occur to assure that new processes and products are compliant with the design definitions and regulations. In these activities, the Project Manager, Design Team, and Contractor, are envisioned to be involved.

The last activity at the interface between Construction and Use stages is the "Commissioning/Handover", where the verification of the Owner requirements, the delivery of all data to Authorities, and the acceptance of said data without issues, allow the building to initiate its operation. The data relationship between the Owner and the Authorities uses mainly Business Rules (for submission), but other types of integration could be envisioned.

Use (Fig. 4, see next page)

As identified in the literature review, the survey within the EC report (2021) denoted that, among others, the Use-related data fields "Design and plans of the building" (during handover and following interventions), and "Energy performance certificate" (i.e., data on the building's consumption of energy), were very important for the development of DBL framework, while "Dynamic data (smart meters, sensors etc.)" was somewhat important. This survey's outcome is important to DTs as they rely on static, quasi-static, and dynamic data. By merging these two notions and through the specification of data types (that can later be structured in more detail within layers of information, functionalities, interfaces or services), the Use stage is composed of a parallel gateway of several activities during the operational life of the built object – with different types of interactions and data types, governed by different stakeholders.

Static and quasi-static data are mostly legacy data related to long-living construction elements or characteristics of the built object (e.g., street number, ownership). However, due to maintenance activities, modifications of use, refurbishment actions, or other similar events, changes can occur, leading to updated requirements. Moreover, there can be unprecedented or force majeure events with a stochastic nature that can impact the built project (e.g., earthquakes, firestorms) and its built objects and, unavoidably, its DBL. As static or quasi-static data, most of those records will have to be updated via a manual input. Depending on the type of event, the update can be performed by the Owner, the Designers, or other authorities and/or service providers. At this stage, it is considered that most of the inputs will be made manually, despite the ability of some tools to set scripts or business rules for interaction.

The record and update of Dynamic Data is found to be key for advanced DT capabilities. In this activity, all interactions are framed as a service, with IoT sensors set on the built object. Depending on the corresponding SoS and the available solutions, several stakeholders can be involved in this activity. In the current framework, the representation of this type of activity was simplified although the challenges and complexity involved in dynamic data recording and management in order to transform it into useful information (as in the data ownership and governance) are acknowledged.

Another type of activity is the link between a (potentially) smart building with a (potentially) smart city infrastructure – where there is an integration or services gateway allowing for establishment of the relationship of the built object with its surroundings, and vice-versa. This necessitates a high level of technological integration and as such, few relevant data are expected to be inputted manually.

Focusing on the value of preserving an updated DBL (as required in the Golden Thread of Information) which includes all relevant information, the Product Recall activity is deployed – inspired by relevant research on product recall (Watson et al., 2019a,b). This activity aims to confirm and expand the concerns raised for changes in the static and/or quasi-static data due to interventions, which might lead to an under-performance of the built object when compared with its state before such interventions, or even its as-designed state. This activity

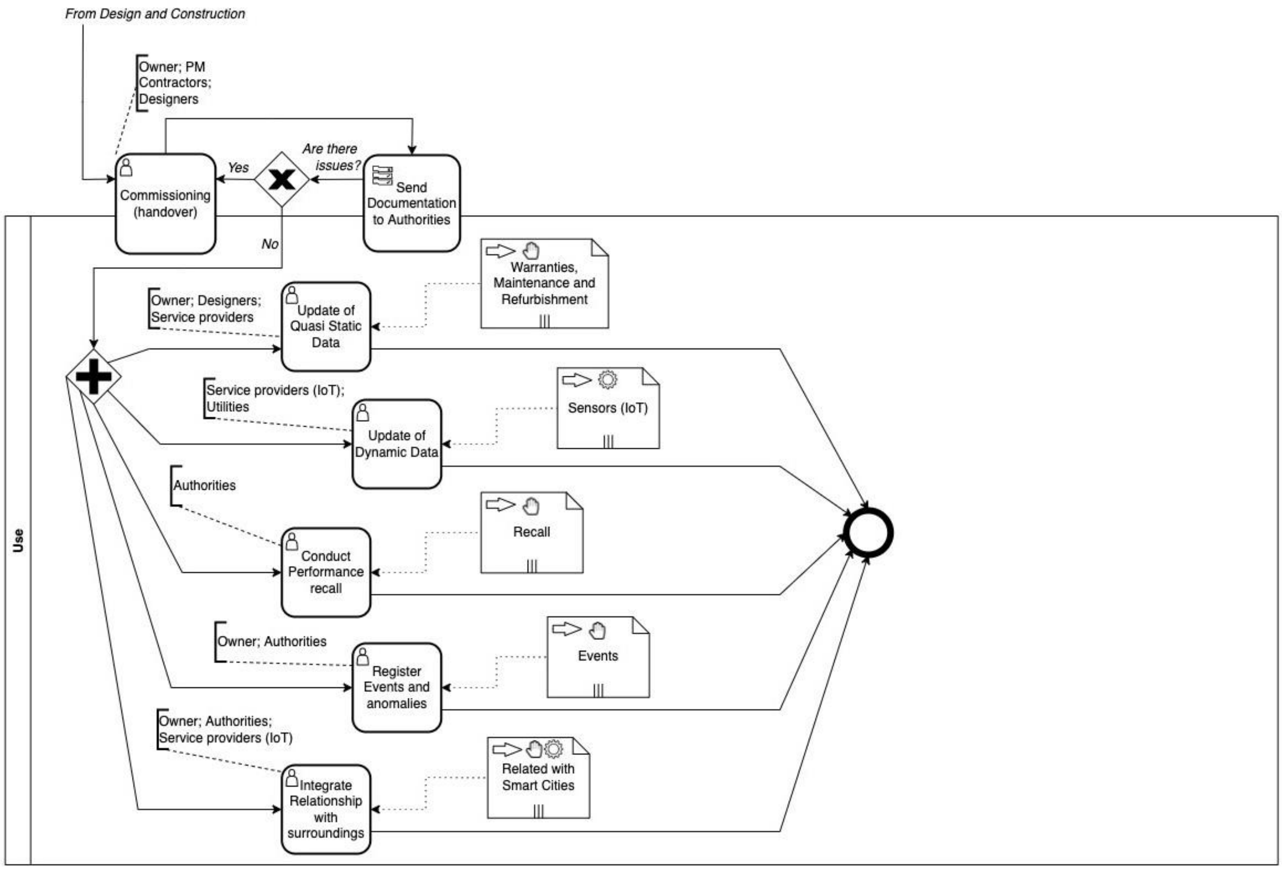

Figure 4: DBL BPMN flowchart framework – Use stage

can also allow revisiting the compliance of the built object to a certain regulation that was updated. At this stage, the Recall is defined to be a manual data input, mostly due to the general infancy of the concept – although, it should be noted that some progress is being made on this topic in some contexts, as in the industrialized construction sector in Sweden, including some conceptualisation of this problem by Li et al. (2020). This activity's relationship with compliance issues and other types of interventions requires its connection to other types of interactions and activities defined in the previous stages.

The end of the DBL is marked with the end-of-life of the built object although some discussions can be raised regarding the use of DBL's processes, services, and potential uses of DBL data for the object's deconstruction. However, these are outside the scope of this paper.

Discussion/findings

The development of the DBL BPMN flowchart was achieved in iterations. It started with the review of the main processes within a building's lifecycle that produces or consumes data; the process itself, data types and instances. In parallel to this activity, the development considered the key requirements for the DBL's functionalities and services included in the EC (2021) framework which were extended by conceiving the DBL as a complementary concept to DT. The merging together of the two concepts (DBL and DT) assumes that assurance of information, which is a key requirement for DBL, can be guaranteed and maintained. Indeed, validations can occur during the Design and Construction stage and during the Use stage against relevant codes, regulations, or performance benchmarks.

As different countries have different practices and are likely to adopt diverse process protocols, the processes set in the DBL BPMN flowchart were generalised. This makes the process maps adaptable to different construction industry contexts in different countries. An interesting aspect in this regard is the potential availability of different gateway options for the interaction of data objects with activities. The comparison of these options among various practices including the differing automation levels involved (e.g. digital permits) is an interesting area for future research.

The DBL BPMN maps provides a seed process-based framework which can form the starting point for future detailing. The experts, consulted during the focus group, confirmed that most of the activities involved in the process maps are important steps towards the establishment of a DBL and in particular those within the Strategic Definition and Design and Construction phases. One of the focus group's participants, with extensive experience with city-level projects, recognised the different activities and the DBL facets defined for the Use phase as relevant for data record, update and analysis on both the building scale and the city scale.

The author-reader cycles for verifying the process maps and the focus group raised the importance of providing a suitable the level of data detail for each activity, and addressing data ownership as some of the key areas for further development.

Finally, limitations in terms of the low granularity level of the BPMN maps and their partial compliance with BMPN symbology (e.g., use of lanes, exchanges) were acknowledged.

Conclusions

This aim in this paper was to propose a process-based framework for Digital Building Logbooks (DBLs) that defines the activities, the data and stakeholder involved across the built asset lifecycle from early conceptual and feasibility, through design and construction, to use/operation. To this end, Business Process Modelling Notation (BPMN) maps were developed and verified. The BPMN maps evidenced the range of interconnected activities involved in a DBL including the functionalities and services that can be linked to DBLs. The proposed framework was conceived in a way that it contributes to the EU framework outlined in the EC report (2021). The framework also considered the potential role that a DBL can play in supporting Digital Twins and vice-versa. Despite the low level of granularity and lowest level of full compliance with the BPMN symbology, the proposed BPMN proved that it can act as a starting point for discussion around DBL to be further detailed in future. The framework can also support the understanding of important areas of DBL applications such as the Golden Thread of Information that is key for assuring the veracity, traceability, transparency, and security of critical information for built assets.

Recommendations for future work include, developing the DBL BPMN maps to a higher granularity level in accordance with the BPMN modelling conventions; conducting more focus group validation sessions with experts from a wider variety of contexts and backgrounds; and focussing on specific DBL use cases and services using country based situations and practical services to be provided.

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