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DEFINING VALUABLE DATA AND STAKEHOLDER ENGAGEMENT IN DIGITAL BUILDING LOGBOOKS: A FRAMEWORK FOR EFFECTIVE DATA STORAGE

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Abstract

This paper introduces a comprehensive Digital Building Logbook (DBL) framework aimed at addressing challenges in managing extensive data generated throughout the lifecycle of modern buildings. The framework establishes a fundamental structure, defining primary valuable data for DBLs to enhance the value of buildings or dwellings. It delineates essential data elements, guides stakeholder prioritization and engagement, and outlines effective storage methods. Additionally, we propose potential applications of the framework in real-world scenarios, extracted from the analysis of existing DBL implementations. This contribution significantly advances the Architecture, Engineering, Construction, and Operation (AECO) sectors by providing a structured approach to DBL development, offering early insights for future implementations.

Introduction

Data is generated at every phase of the building lifecycle, with each phase presenting distinct data requirements (European Commission et al., 2020). Stakeholders naturally seek precise data to address their specific needs at various points in the building lifecycle. However, the AECO sectors traditionally face three technical challenges to perform effective data collection and management within the sector (European Commission et al., 2020).

- The absence of a systematic approach for capturing, storing, analyzing, and organizing valuable data and information, resulting in data loss.
- Fragmented and dispersed data storage across multiple organizations and even departments within the same organization.
- Limitations in the accessibility to and interoperability of the data that is collected and stored by one actor with other stakeholders across the construction market value chain.

Essential data required by the various stakeholders often lacks a centralized repository, and a systematic approach to data collection, organization, and management is absent. Addressing the needs of all stakeholders thus proves to be a challenge. In response, the Digital Building Logbook (DBL) emerges as a proposed solution. As articulated by the European Commission et al. (2020), *"the capturing and maintenance of data and information is the backbone of the DBL."* However, a critical gap persists in understanding what constitutes valuable data for the diverse involved stakeholders. This paper therefore aims to bridge existing knowledge gaps and build a coherent understanding of valuable data in the DBL domain and examine how different stakeholders can engage with that data. The proposed framework adopts the perspective of a local, possibly multi-building, and restricted DBL, emphasizing a constrained data flow and excluding the consideration of national or European databases. The presented framework seeks to establish a versatile DBL capable of accommodating the diverse requirements of various stakeholders rather than being confined to a specific category. Recognizing that stakeholders may possess distinct needs and perspectives on valuable data, this paper endeavours to define valuable data by linking it not directly to stakeholder's needs but rather to indicators outlined in prior studies. These indicators are intended to furnish data or processed data calculations, thereby enhancing the DBL to deliver a multitude of crucial functionalities for all interested stakeholders. Despite this localized focus, the work is forward-looking, aspiring to establish a repository that, while initially limited in scope, is designed to be expansive and interoperable in the near future. Therefore, the main contribution of this article focuses on addressing the gaps that we have identified. To achieve this, the paper will complement the list of indicators proposed in the survey paper by Alonso et al. (2023) with a framework that defines a specific workflow and data flow for a potential DBL framework applicable in various real-world cases. This need constitutes the problem statement of this article. This innovative approach guides our research and aims to provide early insights for implementing DBLs that can adapted to different contexts and enhance their effectiveness in addressing stakeholder needs. In starting the analysis, the subsequent section introduces several recent works around DBLs. Here, particular emphasis is placed on comprehending the present landscape concerning the formulation of DBL frameworks and the comprehension of DBL data. The succeeding sections then present a theoretical framework for storing valuable data in DBLs, beginning with the strategies employed by the authors to elucidate the meaning of valuable data in the context of DBLs, followed by a set of guidelines on how to store this valuable data. The section thereafter presents the hypothetical application and validity of our framework in selected real-world scenarios observed in practice.

Related Works

In the realm of DBLs, literature is relatively nascent, and consequently, frameworks dedicated to DBLs are still in their early stages of development. While the body of work is emerging, several pioneering studies have laid foundational insights into the domain. Within these studies is worth mentioning Malinovec Puček et al. (2023), where the DBL data structures within the context of the EUB SuperHub project are defined. The framework presented in the article aims to provide an essential set of input data throughout a building's life cycle to compute the passport rating across three areas: energy efficiency, sustainability, and smartness; aligning with EU legislation requirements and anticipating future legislation. One considered research is by Mêda et al. (2022), where the authors focused on proposing a process-based framework for DBLs to address the lack of clear conceptualization of DBL processes, data requirements, and stakeholder interactions. The framework is developed using Business Process Modeling Notation (BPMN) flowcharts and aims to support the EU framework for data collection, management, and interoperability.

Our paper aligns itself with the current trajectory of DBL research, seeking to contribute to the existing body of knowledge by tracking and building upon recent advancements in DBL frameworks and their applications. Another notable scientific publication cited in the proposed paper is a comprehensive survey carried out in 2023 (Alonso et al., 2023), which encompasses all publications on the DBL indexed in prominent scientific search engines such as Scopus, Web of Science, and Google Scholar. This work holds significance as it provides a comprehensive overview of the existing studies on the DBL topic at large, also giving a focus on data storage and DBL indicators.

The publications of Gómez-Gil et al. (2022, 2023) were crucial in defining the parameters of valuable data in DBLs. In their series of scientific works, they first analyze the four most developed European DBL models to provide a defined overview to what constructs a DBL —including the identification of the key stakeholders in the DBL and potential user needs, as well as a proposed structure of indicators, data sources and functionalities— to identify gaps for future developments (Gómez-Gil et al., 2022). Their research then progresses to explore the capacities of DBLs as a gateway to link existing national databases in Spain and Italy, further exploring the available data sources and types that can support the services of a DBL (Gómez-Gil et al., 2023).

For a clearer insight into how valuable data can be employed in the services of DBLs, an understanding of what indicators are and how they process data is needed. In their work, Tupenaite et al. (2017) developed an integrated, hierarchically structured system of sustainability indicators that can be used in the sustainability assessments of new residential projects in the Baltic States. Similarly, Møller et al. (2018) developed the Sustainable Tool for Assessment, Planning, Learning, and Engaging (STAPLE) to create a single common method for a comprehensive and inclusive design and building process for sustainable buildings. How the two publications define sustainability indicators was crucial when building the theoretical framework for the proposed paper.

Apart from scientific publications, two recent European studies on DBLs are fundamental to this paper. First is the European tender [1] led by Ecorys et al.. The study aims to develop a common European model for DBLs (1) to promote tools and protocols that ease data use and sharing throughout the construction ecosystem and (2) to implement DBLs in a harmonious and interoperable way across the EU27 Member States. Findings from the project that are of high relevance to this paper include their final report on *Technical Guidelines for Digital Building Logbooks* (Ecorys et al., 2023), where the guidelines on setting up and operating DBLs under a common EU framework are discussed. The other European project referenced in the proposed paper is Demo-BLog [2] led by TU Delft et al.. Short for *Development and Demonstration of Digital Building Logbooks*, Demo-BLog is a Horizon Europe-funded project that seeks to exhibit how DBL data can serve to advance the current evaluation strategies for climate and energy transition implemented at various levels in Europe. Findings from the project that are relevant to this paper include the state-of-play analysis of selected best practices, where the potential role and scope of the DBL, including the central features, as well as data handling and governance issues are explored with stakeholders. The proposed paper combines findings from both literature and ongoing European studies to delve into the specific data elements that should be included in DBLs, how stakeholders should engage with this data, and how the data should be effectively stored and organized. This approach adds depth and specificity to the previous research on DBLs, providing practical guidance for implementing and leveraging DBLs in real-world scenarios.

Defining Valuable Data in DBLs

In the context of this paper, 'valuable' data is defined as essential files derived from different phases of the building or dwelling lifecycle. These files are deemed crucial for storage in a secure repository, as they contain data that can significantly contribute to enhancing specific categories of indicators.

The value of both, data and indicators, lies in their ability to assist in the decision-making processes and facilitate actions aimed at optimizing building performance and sustainability. Due to the dynamicity of the data requirements that the construction sector may have, our list of valuable data does not aim to present a comprehensive compilation of all possible data that can be gathered during the building lifecycle, nor are we excluding any type of data that

[1] See `https://www.ecorys.com/case-studies/technical-study-for-the-development-and-implementation-of-digital-building-logbooks-in-the-eu/`

[2] See `https://demo-blog.eu/` for more information

may become valuable in the future. Our list and definition of valuable data, at this stage, is formed by an analysis of the state of the art, documentation from policymakers, and an examination of commonalities in similar approaches. It aims to provide and present our process of defining what is the valuable data as a foundation that can be used as a reference to characterize the information stored in DBLs. This paper departs from the notion highlighted in the conclusion by Alonso et al. (2023) that a DBL should avoid overlapping with other tools, including Building Information Models (BIMs) or Common Data Environments (CDEs). In essence, BIM focuses on detailed 3D modelling and information management during the building process and a CDE serves as a collaborative platform or centralized digital hub where construction project stakeholders can access, share, and manage any project-related data and documents. In contrast, a DBL encompasses a comprehensive repository of essential files from the entire building lifecycle, offering a secure storage solution and serving as a foundation for diverse stakeholder needs by providing enriched functionalities based on specific indicators. The proposed framework therefore aims to establish a foundational structure that helps to delineate the primary valuable data to be stored within the DBL to positively enhance the value of the building or dwelling based on different stakeholder needs.

In the realm of DBLs, data plays a crucial role in assessing opportunities and challenges across diverse optimization scenarios for buildings and dwellings. The services built around the DBL then process the relevant data to encourage energy renovation by providing relevant information to (1) design renovation roadmaps, (2) carry out maintenance strategies and (3) monitor and assess the decarbonisation progress of the building (Gómez-Gil et al., 2022). Such services are called "functionalities" (European Commission et al., 2020).

There are various functionalities available in DBLs to support optimization practices of buildings, from providing building analysis and status to conducting energy performance assessments (Gómez-Gil et al., 2022). To enable these functionalities, several necessary indicators must be defined.

An indicator refers to a specific metric or measurable value derived from the data collected, output, or processed within the DBL. These indicators are intricately linked to the valuable files stored in the DBL, as the data within these files can be extracted or processed to identify meaningful values. These values, in turn, serve as indicators that provide valuable insights into various aspects of a building's lifecycle.

For example, consider an EPC stored in the DBL. The data within this file, related to a building's energy efficiency, can be processed to calculate indicators such as the energy consumption rate, carbon footprint, or overall energy performance index. These indicators then offer valuable information that can be used to provide functionalities such as energy efficiency recommendations, comparison with industry benchmarks, or compliance checks with environmental standards. In this way, indicators play a crucial role in unlocking diverse functionalities within the DBL, tailored to meet the needs of different stakeholders involved in the building lifecycle.

At the moment, the European Union (EU) does not provide an official list of minimum indicators that should be included in the DBL, and there is no consensus among the existing initiatives and proposals (Gómez-Gil et al., 2023). The role of a DBL can be seen to serve as a database for storing and processing diverse indicators, shedding light on the conditions and status of a building. These indicators are contingent on the type of data collected or available within the DBL, influencing the outputs derived. A range of indicator categories that aligns with the various data types should therefore be integrated into a DBL to offer information about the building that is of value. Based on an analysis of all the scientific publications on the DBL and its indicators in 2023, Alonso et al. (2023) derived nine indicator categories in their survey, as can be seen in Table 1 (see next page).

The identified indicators require various data to provide the functionalities they can support. To ease the identification of the necessary data, the Demo-BLog project developed a data template that also documents the data types, formats, and sources. The template was initially created to identify a common data language and/or categorisation method that can be applied to the five currently operational DBL initiatives studied in the project: **Chimni** that operates in the United Kingdom, **Woningpas** in Flanders, Belgium, **CLÉA** in France, **CAPSA** in Germany and **CIRDAX** in the Netherlands. The data fields identified in this template can thus be seen as the result of studying every functionality and data field employed across the five initiatives studied, with the terms and scope generalised thereafter to encompass the varying approaches into one universal table. In total, Demo BLog identified 79 data fields across the five cases studied that can be considered valuable to a DBL.

However, a practical challenge identified in Demo-BLog is the inconsistencies in the data structure between various data sources. For instance, while all utility providers furnish data on the energy consumption of a building or dwelling, they do so in different formats and methods. Though valuable data is abundant, the absence of a standardized format or scheme to represent the data remains a barrier for DBLs when coordinating with more than one data source. While this may lead to challenges in data organization and interoperability within a DBL, it does not necessarily depreciate the value of the data stored therein. This paper thus sees the need to compile a catalogue of pertinent files and/or documents associated with a building or dwelling, essential for storage within the DBL. These documents should be accessible to various stakeholders or services, facilitating the computation, storage, or retrieval of indicators crucial for building assessment.

As a starting point, the framework initially emphasizes the

Table 1: Indicators categories, indicators role and metrics as identified by Alonso et al. (2023)

Indicator Category	Indicator Role	Indicator Metrics
Building Information Indicators	Measures the efficiency of the building's information management practices	Accuracy, completeness, ease of access, and security of information
Energy Consumption Indicators	Reveals the building's energy usage, aiding in identifying areas for improvement	Energy consumption over time, meter readings, real-time energy usage
Indoor Comfort Indicators	Provides information on indoor environment aspects	Temperature, humidity, air quality, and lighting levels
Maintenance Indicators	Assists in tracking maintenance tasks such as cleaning, HVAC checks, and equipment replacement	Schedules, checklists, real-time maintenance notifications
Occupancy Indicators	Displays the number of people in the building, optimizing energy use and resource allocation	Number of people
Safety Indicators	Offers information on building safety	Fire alarm status, emergency lighting, evacuation routes
Financial Indicators	Shows financial performance	Operating costs, revenue, return on investment
Sustainability Indicators	Provides insights into sustainability performance	Carbon footprint, water usage, waste generation
Smart Readiness Indicators	Reflect a building's "smartness"	Metrics based on a common EU scheme

inclusion of files or documents that inherently contribute value to the DBL and the building or dwelling. The focus is on saving files without immediate data extraction. Each stored file should be associated with a record entity, allowing users to input essential information, for instance, the issued date for an Energy Performance Certificate (EPC). This record entity serves as a dynamic repository, capable of being updated with information extracted from the files or additional services, thus laying the groundwork for diverse functionalities.
In the following, a non-exhaustive list of valuable files/documents is identified for storage purposes in a DBL for future reference, data extraction, or data processing:

- **Baseline Industry Foundation Classes (IFC) Files**: These files contain the foundational information about a building or dwelling in IFC format that can serve as a reference point for subsequent changes or evaluations.

- **Energy Performance Certificates (EPCs)**: EPCs provide a detailed overview of the energy efficiency of a building, indicating its environmental impact and offering insights into potential improvements.

- **Carbon Bill**: This document outlines the carbon footprint associated with the building or dwelling, detailing the carbon emissions generated through its lifecycle.

- **Building Renovation Passport**: A comprehensive record detailing the history of renovations, upgrades, and modifications to the building, offering a holistic view of its evolution.

- **Selected Renovation Scenario IFC Files**: Similar to baseline IFC files, these documents specifically capture information on selected renovation scenarios, providing a targeted perspective on planned changes.

- **Post-Renovation Analysis**: This file contains assessments, data, and analyses conducted after a renovation, offering insights into the impact of the interventions.

- **Facility Management Reports**: Detailed records on facility maintenance, operations, and management activities.

- **Sensor Data Logs**: Selective storage of sensor data in a DBL, focusing on key metrics such as occupancy and temperature that are relevant for building operations and efficiency, rather than comprehensive data like in a digital twin.

- **Fire Alarm System Reports**: Documentation and analysis of the status, functionality, and events related to the fire alarm system within a building.

Table 2 links each of the specified valuable files with the associated indicator categories that are previously outlined. This establishes a direct correlation between the valuable files and the pertinent data they contain that contribute to the indicators, and further, functionalities, within the DBL. Consequently, this connection aligns with the overarching objectives of the DBL, enhancing the overall value proposition for the building or dwelling.
In conclusion, is worth noting that the valuable files outlined in this section do not constitute an exhaustive list of all possible files that can be stored in a DBL. Instead, they

Table 2: Association of Valuable Files with Indicator Categories. BII = Building Information Indicators, ECI = Energy Consumption Indicators, ICI = Indoor Comfort Indicators, MI = Maintenance Indicators, OI = Occupancy Indicators, SI= Safety Indicators, FI = Financial Indicators, SuI = Sustainability Indicators, SRI = Smart Readiness Indicators

	BII	ECI	ICI	MI	OI	SI	FI	SuI	SRI
Baseline IFC files	X			X					X
EPC	X						X		
Carbon Bill		X					X	X	
BRP	X							X	
Renovation Scenario IFC	X			X					
Post-Renovation Analysis	X	X		X					
Facility Management Reports				X		X			
Sensor Data Logs		X	X		X				
Fire Alarm System Reports						X			

represent foundational information that is present in real-world scenarios. These files are instrumental in generating valuable data, thereby enhancing the overall value of the building and augmenting the utility of the DBL.

Valuable Data and Stakeholders

Stakeholders along the construction and built environment value chain are essential in gathering, extracting, and processing valuable data intended for storage in the DBL. How this paper defines a DBL stakeholder is grounded on the findings of the study on the development of DBLs in the EU, funded by the European Commission, where five main user groups are defined (Ecorys et al., 2023):

- **Governmental agencies** that need data for evidence-informed policy-making, the issuing of licences and the enforcement of regulation and disaster management. This user group comprises all levels of governance, including national, regional and local levels.
- **Construction companies** need data to obtain and report building-related information during the design and execution phases of a building lifecycle. The sector encompasses various building professionals, including architects, engineers, contractors and real estate developers, and the collaboration between the relevant stakeholders is crucial to identifying the varying data needs and responsibilities.
- **Building owners and users** who need data on their buildings for monitoring, maintenance and necessary interventions. Building owners have an added responsibility to provide direct or indirect access to building information to not only the building users but also to other relevant stakeholders of the DBL.
- **Financial institutions** that need data to perform various analyses on the assets market and its developments, to gain a better understanding of building transactions. Here, increased transparency and data quality provided by the DBL is key.
- **Utility companies** that need data that provides information on the connection of utilities and the analyses on how they are used to provide detailed information with regards to the building use or performance.

To contextualize stakeholders' interests in data types with real-world DBLs, we have compiled a table that correlates each stakeholder group with the valuable data types that can effectively add value for them. This association is derived from the description of the stakeholders' groups and the data commonly used in their activities. Additionally, the table indicates the indicator groups related to each stakeholder group. These associations are detailed in Table 3.

Moving forward, in the subsequent part of this section, we will examine three real-world DBL implementations among the five studied in the Demo-Blog project, as presented in Section *Defining Valuable Data in DBLs*, to explore their operational mechanisms, identify the most valuable data for each, and present realistic use cases that use some valuable data previously identified.

- The **Woningpas** DBL initiative in Flanders, Belgium, is automatically available to building owners, including individuals and housing companies. Owned by four Flemish Government bodies, it aims to enhance energy efficiency in housing stock. Key stakeholders, including government agencies like VEKA and OVAM, collaborate to ensure energy labels meet regional standards. The Energy Performance Certificate (EPC) is a crucial document supporting this goal by providing essential data for planning energy efficiency interventions and continuous improvement efforts in homes.
- The **CLÉA** DBL, owned by Qualitel, emphasizes user-friendliness. It offers an equipment module with user guides and maintenance alerts for HVAC systems. This feature connects building owners with utility companies to ensure home comfort. Facility management reports tracking service changes are vital for this functionality.
- The **CIRDAX** DBL is a commercial digital materials database operating in the Netherlands and Belgium. It catalogues building components and materials obtained through 3D scanning and manual services. Its focus lies in creating a marketplace for secondary materials, connecting demand with supply for building

Table 3: Association of Stakeholder Groups with Indicators and Valuable Data from Table 2

Stakeholders	Indicators	Valuable Data
Governmental Agencies	BII, ECI, MI,Sul, SRI, FI	IFC files, EPC, BRP
Construction Companies	BII, ECI, MI, OI, SI, FI, Sul, SRI	IFC files, EPC, BRP, Renovation scenario IFC, Post renovation analysis, Fire alarm system report
Building owners and users	BII, ECI, ICI, MI, OI, SI, FI, Sul, SRI	All valuable data in table 2
Financial institutions	FI, Sul, SRI	IFC files, EPC, Carbon bills
Utility companies	SI, SRI, BRP	EPC, Facility Management reports

reuse. Key documents like the baseline IFC file, detailing building construction, and the carbon bill, calculating embodied carbon, engage the construction sector in circularity goals by providing crucial data for material reuse and carbon impact assessment.

The examples highlight the importance of considering the unique context of each DBL — including its founding goals, stakeholder domains, and primary target market — when designing and testing data storage, extraction, processing, and transfer methods. Considering the DBL as a tool that can accommodate various perspectives, priorities, and challenges is crucial in this process. With this in mind, the following sections present a framework that could be utilized in these scenarios. Subsequently, in the next section titled *Framework Alignment*, we will illustrate how our framework could be applied to these case examples, leveraging the valuable data previously presented to provide insights to different stakeholder groups.

Data Storage Guidelines

In this section, we anchor our approach in the context of a local DBL. These guidelines are crafted to establish a framework applicable to individual buildings or local DBLs, laying the foundation for potential expansion toward interoperable or national DBLs. Recognizing the dynamic nature of the DBL landscape, our focus is on constructing a framework that leverages existing technologies and data processes, minimizing the costs associated with creating new ones.
The suggested strategy operates under the premise that the DBL functions as a cloud-based solution. Consequently, the data storage for the DBL is also envisioned as cloud-based, ensuring data availability.
Our approach conceives the DBL as a "sink" for data, serving as a central storage repository where building files containing valuable data are stored. Consequently, our approach concentrates on DBLs focused on data archiving and not on having pointers or links to data in external tools.
Another important point, crucial for security, is to encrypt every file in the DBL. Access to these encrypted files will be strictly controlled by an access management system, ensuring that only authorized stakeholders can retrieve them. Access can be facilitated through either a user-friendly interface or an Application Programming Interface (API). This solution needs to accommodate three primary types of files: (1) documents and binary data formats, (2) computer-readable data, and (3) key values. By encompassing these categories, we aim to cover the entire spectrum of considered valuable data.
To support these types and formats of data and to be flexible in both formats and semantics, an architecture with a data layer that manages these different options is considered. This layer should allow higher layer components (e.g., the aforementioned semantic analysis) to manage and handle this data, before its presentation to the user.
In this framework, files remain unaltered once uploaded, accompanied by a record detailing vital file characteristics. Stakeholders responsible for uploading, whether users or services, must store this record simultaneously with the file, enabling other services to access files, extract crucial information, and insert it within the record or as an output calculated with that information.
To enhance interoperability, the record entity is intricately linked to one or more files, allowing users or authorized services to systematically append relevant information. To address the absence of a unanimous consensus on defining a clear data structure for DBL data, we propose storing significant files alongside a flexible Record structure. This structure, while inherently flexible and customizable for various needs, should incorporate standardized essential metadata, such as the associated building, upload date, user responsible for the upload, and a log documenting any modifications.
Embedded within this framework, a fundamental entity representing the building or dwelling will encapsulate key information, including address, the number of floors, and other pertinent details. This central entity will serve as the linchpin connecting each record to its associated building. By referencing the building entity in all records, we establish a cohesive structure that facilitates the organization of valuable data and files in a scalable manner. This design choice not only enhances the coherence of the DBL but also contributes to its scalability, accommodating a broad spectrum of building types and configurations.
For instance, imagine a scenario that highlights the flexibility of the record structure within a DBL, particularly with storing a BRP. Stakeholders uploading records have the option to include additional details such as issuance and expiration dates, or they may choose to provide only mandatory information like the associated building. This dynamic structure allows for various use cases and enables modifications to align with semantic model structures.
In essence, our data storage guidelines are rooted in practicality to provide a scalable and adaptable framework that aligns with existing technologies, while simultaneously

laying the groundwork for potential future developments.

Framework Alignment

In this section, we will explore the hypothetical application and validity of our framework in the use cases introduced in the *Valuable Data and Stakeholders* section.

Aligned with the proposed framework, the DBL employs a robust data storage strategy. Each file, including the EPC, the facility management report, and the building IFC is encrypted to ensure security. Access is meticulously controlled, permitting only authorized stakeholders – homeowners, government agencies, energy consultants, or service providers – to retrieve these files. Stakeholders can access files through a user-friendly interface or APIs, emphasizing accessibility.

As previously mentioned, to maintain data integrity, uploaded files remain immutable, and stakeholders or applications responsible for uploading the data are required to accompany each file with a dynamically structured record. This record, linked to the file, is populated with metadata providing essential details such as the date of issue or expiry.

Stakeholder engagement is a pivotal aspect. In the **Woningpas** use case, homeowners, responsible for storing documents, enjoy flexibility in contributing additional details to the associated record. Although the identity of the stakeholder uploading the EPC might not be certain, the process remains straightforward, facilitated through either the user interface or APIs. Upon EPC upload, a record entity is created, detailing the associated building, the uploader, and the upload date.

This structured framework facilitates collaboration. Stakeholders with access can download the EPC and utilize it for various calculations. The outputs, which could range from Key Performance Indicators (KPIs) to specific energy values or recommended interventions, can be stored as files with a record linked as the case of valuable data or even only with a record. This process, whether through user interaction or automated APIs, reinforces the scalability and adaptability of the framework, promising future expansions in the DBL landscape.

Within the **CLÉA** scenario, a facility management report is primarily generated by utility companies that provide services and products such as energy provision and HVAC equipment to homes. The collected data, encompassing both their professional insights and meter-recorded utility usage, can be efficiently uploaded to the DBL through APIs or the user interface. The data may take a static form, such as documents containing processed information handed over to homeowners as statements or transaction receipts, effectively serving as the facility management report.

In our DBL framework, for simplicity, we focus on static data uploaded as files, which will not change over time. From this file, key stakeholders can perform calculations to determine when the next services, possibly maintenance tasks or updates, are scheduled to take place. This process, seamlessly integrated into the DBL, aligns with our framework's emphasis on practicality, scalability, and adaptability. It provides a robust foundation for potential expansions in the DBL landscape while ensuring valuable data remains organized and accessible.

Lastly, in the **CIDRAX** scenario, the baseline IFC file stored in the DBL is created collaboratively by stakeholders involved in the construction or renovation processes. The document serves as a comprehensive snapshot of the building's construction, offering a thorough understanding of its structure. It includes intricate details about the type and quantity of materials used, their spatial distribution within the building, and other relevant specifics. The active participation of stakeholders such as architects, material providers, and contractors is thus essential during the construction or renovation stages to ensure the accuracy of this data. This information is then stored in the DBL, making it accessible to authorized stakeholders.

Authorized stakeholders, including companies like CIRDAX, can retrieve this stored baseline IFC file from the DBL. The document becomes a valuable resource for CIRDAX's objective of promoting circular building practices. By analyzing the detailed information within the baseline IFC file, stakeholders can identify the availability of reusable materials, quantification of materials and optimization of construction practices. After identifying this information, it can be incorporated into the DBL as an immutable file, accompanied by a record entity. This ensures accessibility for all stakeholders while being securely stored in a protected repository.

This section lays the groundwork for conceptualizing DBLs as repositories of pertinent information. Starting from such realistic scenarios, derived from empirical observations of the data types already used in real-world DBLs and their purposes, we generalized the processes to establish paradigms on how a DBL should function. This information will be the source for the definition of an architecture and the elaboration of a platform that can be validated by using empirical data and quantitative and qualitative indicators. Qualitative processes such as user satisfaction surveys and stakeholder interviews can provide insights into the usability and effectiveness of the framework. On the quantitative side, metrics such as the average time taken to retrieve information and analysis of API usage patterns, including the frequency and volume of API calls and the data used by different stakeholders, can measure the efficiency and relevance of the data.

In conclusion, the hypothetical application of our proposed framework across diverse real-world use cases demonstrates its robustness, scalability, and adaptability within the dynamic landscape of DBLs. Our emphasis on data security, controlled access, and the integration of dynamic record entities ensures the reliability and integrity of valuable data. Stakeholder engagement remains at the forefront, providing flexibility for various users to contribute and access information through user-friendly interfaces or APIs. The structured framework not only supports current needs, as illustrated in the presented use cases but also promises a foundation for future expansions in the evolving DBL landscape. Through this approach, we aim to facilitate collaboration, enhance data organization, and uphold accessibility, fostering a more effective and sustainable management of building-related information.

Conclusion

Buildings generate increasing amounts of data and information, which end up scattered in disparate databases. This volume and distribution of data lead to difficulties and challenges in making informed decisions based on it. DBLs have emerged as a key solution to bridge these data availability and archiving challenges.

However, not all data is equally important for making decisions during the building life cycle. Plus, there's still no clear agreement on what DBLs should do, what data they need, and how they fit with other construction software.

It is important to recognize that certain aspects, such as the detailed structure, components, and features of the DBL that will implement our framework, require further elaboration and exploration. These areas should be considered as part of future work to enhance the understanding and implementation of DBLs in real-world scenarios. By acknowledging the need for continued research and development in these areas, we aim to contribute to the ongoing advancement of DBL frameworks and their effective utilization in the construction industry.

The analysis done in this article also allows us to identify some research gaps, which will enable us to frame future work. Specific aspects of these research gaps include:

- **An Undefined Criteria for Valuability**: The absence of universally accepted criteria for categorizing data as "valuable" in the context of DBLs. This article has attempted to find some common ground and offer suggestions on this topic.
- **Inconsistencies in Data Structure**: The absence of a standardized format or scheme to represent valuable data, leading to inconsistencies in data organization and challenges in interoperability between different stakeholders.
- **Limited Stakeholder Engagement**: A knowledge gap exists among various stakeholders, including architects, engineers, and maintenance personnel, regarding a standardized approach to systematic data collection and storage.
- **Overlapping and Interoperability Challenges**: The lack of clear differentiation between distinct solutions in the construction ecosystem (e.g. Common Data Environments, Digital Twins, Construction Management Software), what data each manages, processes or stores and how they interoperate.

Our future work is in line with addressing these gaps and defining an optimal architecture to support the data mentioned in the article. This, together with research on ontologies, such as Smart Applications REFerence (SAREF)[3], which can be used to enrich the data, will allow us to design an efficient and adaptable reference DBL, and properly compare and evaluate the available DBLs.

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[3]See `https://saref.etsi.org/` for more information