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Review article

Towards the definition of a European Digital Building Logbook: A survey

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ABSTRACT

Both the operational phase and embodied emissions that are introduced during the construction phase through the manufacture, sourcing, and installation of the building's materials and components are significant contributors to carbon emissions from the built environment. It is essential to change the current design and (re)construction processes in order to achieve the energy-saving targets for the EU building stock and move toward a society that is net carbon neutral. This change must be made from both a technical perspective as well as from a methodological perspective. To accomplish this, the EU has suggested several regulations and legislative steps to phase out inefficient structures. The most recent of these initiatives propose the idea of a Digital Building Logbook, which serves as a central repository for all pertinent building data, including information on energy efficiency. In this work, we present a survey of the elements that have been taken into consideration for the creation of the Digital Building Logbook to give an overview of what research has been done so far.

1. Introduction

With a target of 32.5% energy savings by 2030, the Energy Union and the Energy and Climate Policy Framework [1] for 2030 have set high goals for Green House Gas (GHG) emission reductions of at least 40%.

Significant carbon emissions from the built environment are caused by both the operational phase as well as embodied emissions that are introduced during the construction phase through the production, sourcing, and installation of the building's materials and components. Embodied GHG accounts for 20-25% of the whole life cycle emissions [2]. Additionally, lifetime emissions from maintenance, repair, replacement, and ultimately demolition and material's disposal are also attributable to the built environment.

The International Energy Agency (IEA)[1] estimates that the existing building stock is responsible for 40% of energy consumption, 36% of greenhouse gas emissions, and 50% of material depletion. It also produces a third of all waste [3]. While the majority of currently constructed buildings (around 80%) will still be in use in 2050, the EU's building stock is regarded as being inefficient in terms of energy use and it is older than 40 years. Also, the EU construction industry has seen a sharp decline in investments in

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[1] https://www.iea.org/.

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new construction projects as a result of the recent economic crisis and the pandemic, which has had a detrimental effect on the performance of the region's overall building stock.[2] In fact, the annual rate of building renovations remains less than 1% of the total building stock, primarily due to the significant costs associated with these renovations. However, the construction sector contributes to about 9% of the EU's Gross Domestic Product (GDP) and provides 18 million direct jobs.[3]

In order to move toward a society that is net carbon neutral and achieve the energy-saving targets for the EU building stock, it is necessary to fundamentally change the current design and (re)construction processes (D&C), both from the technical perspective (use of recycled materials, application of measures for the increase of the energy efficiency) and from the methodological and process perspective (digitalisation in the construction sector throughout the whole life cycle). Regarding digitalisation, the construction sector is one of the least digitalised sectors in the economy [4].

The EU has proposed a collection of directives and policy measures to phase out inefficient buildings in order to achieve this goal. One of these measures is the proposal launched in 2021 for the recast of the Energy Performance of Buildings Directive (EPBD) [5] that, together with the Renovation Wave of 2020 [6], introduces the concept of a Digital Building Logbook (DBL). Recently, in February 2023, the European Commission published an updated version of the DBL definition, previously produced in 2021 in the amended version of the proposal for the EPBD recast [7]. The latest DBL definition is *"a common repository for all relevant building data, including data related to energy performance such as energy performance certificates, renovation passports and smart readiness indicators, as well as on the life-cycle Global Warming Potential (GWP) and indoor environmental quality, which facilitates informed decision making and information sharing within the construction sector, among building owners and occupants, financial institutions and public authorities"*.

Hence, DBL is seen as a key solution to bridge the gap between the great amount of data and information generated during the building's life cycle and the lack of methodologies and tools to safely manage, organise, structure, and share this data. Moreover, DBLs would reduce administrative, compliance, and commissioning costs and facilitate all the procedures related to building renovation and construction and the stakeholders involved in the process.

Among the initiatives and frameworks that promote sustainable practices in the building sector, it is worth considering the LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), and DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) systems. LEED is a widely recognised and internationally adopted green building certification system developed by the United States Green Building Council (USGBC).[4] It provides a framework for assessing the sustainability performance of buildings and promoting environmentally friendly design, construction, operation, and maintenance practices. LEED encompasses a wide range of elements in its evaluation of buildings, including, but not limited, to energy efficiency, water conservation, materials selection, indoor environmental quality, and site development. It offers different levels of certification (Certified, Silver, Gold, and Platinum) based on the number of points achieved in the evaluation. BREEAM is a widely used sustainability assessment and certification system primarily applied in Europe. It was developed by the Building Research Establishment (BRE).[5] BREEAM evaluates and rates the sustainability performance of buildings based on a range of criteria, including energy and water usage, materials selection, waste management, ecological impact, and transportation. BREEAM certification is achieved by scoring points across these categories, with higher scores indicating higher sustainability performance. DGNB is a German sustainable building certification system developed by the German Sustainable Building Council (DGNB).[6] It focuses on evaluating and promoting sustainable practices in the construction industry. DGNB certification assesses buildings based on ecological, economic, sociocultural, and functional criteria. This comprehensive approach considers aspects such as energy efficiency, life cycle costs, indoor environmental quality, adaptability, and social responsibility. DGNB offers different certification levels (Bronze, Silver, Gold, and Platinum) based on the fulfilment of specified criteria. In summary, these certification systems provide standardised criteria for evaluating and certifying the sustainability performance of buildings. By including relevant data and information from these certification processes in the DBL, stakeholders can have a comprehensive overview of a building's sustainability attributes and performance. This integration facilitates informed decision-making, enables benchmarking against sustainability standards, and supports the identification of areas for improvement. It also enhances transparency, accountability, and knowledge sharing among building owners, occupants, financial institutions, and public authorities. Ultimately, the integration of these certification systems with the DBL helps foster a more sustainable built environment and contributes to the overarching goals of energy savings, GHG emission reductions, and efficient resource utilisation.

Despite the attention around the DBL, it is still not clear what a DBL is and what are relevant building data. However, important actions have already been taken to pose some definitions. For example, the EPBD recast identifies EPCs, BRPs, SRIs, and Level(s) indicators (i.e., the life cycle GWP) as the most important building information that has to be included in a DBL. EPCs are at the core of the EPBD as they will be a necessary condition for building construction, sale, or rental. BRP is a document outlining a long-term step-by-step renovation roadmap for the building. It is an evolution of the EPC and it plays a key role in the revision of the EPBD in order to increase the EU's building renovation rate. Moreover, clear connections between the BRP, EPC, and the DBL can be done [8]. SRIs assess how smart a building is in terms of responding to the needs of the occupants, using energy efficient control strategies, interacting with energy grids.[7] On the other hand, Level(s) is a European framework that assesses and reports on the sustainability

[2] Eurostat. People in the EU—statistics on housing conditions https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:People_in_the_EU_-_statistics_on_housing_conditions.

[3] https://single-market-economy.ec.europa.eu/sectors/construction_en.

[4] https://www.usgbc.org/.

[5] https://bregroup.com/.

[6] https://www.dgnb.de/en/index.php.

[7] https://energy.ec.europa.eu/system/files/2022-03/SRI-Factsheet-20220313.pdf.

performance of a building.[8] The EPBD recast highlights the importance of having SRIs and Level(s) connected to the DBL as they support the building's stakeholders in making an informed decision about sustainable and smart building renovation.

Thus, the importance of DBLs is evident and the interest in this topic is growing at the EU level. There are several initiatives on DBLs at the national level in Europe. However, these initiatives differ greatly in terms of their focus (e.g., energy efficiency, materials, administrative data), digitalization features, and the integration of static/dynamic building data. The Building Passport Flanders, Woningpas,[9] was launched in 2018 and it is an integral digital file for every home, automatically generated, that allows the home-owner to have insight about all relevant building aspects of his home. It is both a digital archive and a guide for potential future renovation activities. It aims to realise a dynamic in the renovation market and offer homeowners a tool that helps them in planning renovations, their relationship with the relevant stakeholders, and having control over the building data and information. The Digital Transition Plan for Buildings (PTNB) in France (2018) [9] aims to modernise the construction sector, improve quality and reduce costs in renovation activities and new construction. Among other things, it aims at developing a digital notebook for monitoring and maintaining a dwelling. In the UK, the Residential Logbook Association (RLBA)[10] was formed by several commercial parties to bring DBLs to a common standard and promote data interoperability.

However, there are still some unclear aspects such as the identification of the main functionalities, the identification of the target group(s) and their needs, the interoperability with external data sources, and other data and information that could be included in the DBL to further support informed decision making [10].

With the aim of providing a complete and dynamic building lifecycle evaluation, incorporating building and human-centric performance factors, and effectively using real-time building information and data, a unified European framework is now being developed [11]. Such a framework needs to provide safe and adaptable information flow between stakeholders, raising awareness, promoting collaboration and synergies, as well as has to provide high levels of interoperability between various services (EPCs, commissioning, building operation and maintenance, BRPs, etc.).

In order to provide an overview of what research has been performed so far related to the DBL, in this paper, we present a survey of which features have been considered for the development of DBL. Section 2 illustrates the materials and procedures we have used to write this survey. In particular, it describes the procedure we have carried out to collect the research papers under analysis. Next, Section 3 lists all the papers found using the aforementioned procedure. In particular, in Section 3.1 we indicate the different categories we have identified that group the selected papers. Section 3.2 indicates the connection of the papers to funded European projects and details each of them. Section 3.3 illustrates the data sources that should be fed into a DBL and also indicates the data format to be employed. Section 3.4 presents different types of indicators present in already implemented or to be implemented DBLs. Section 3.5 includes the connection of DBLs with digital twins and building information models. Section 3.6 discusses how semantic technology has been included within DBL. In Section 4 we indicate possible implementation principles for an EU DBL according to all the scientific papers analysed and reports from the European Commission. Then in Section 5 we report the challenges and future research proposals we encountered along the analysed papers. After the focus on the topics identified among the found papers, we introduce the limitations of our findings in Section 6. Finally, Section 7 ends the paper with conclusions and directions on where we are headed.

2. Materials and methods

In this section, we will illustrate the procedure we have followed to collect the research papers we have analysed. We present the existing literature, research, and studies that have been conducted on DBLs to provide a comprehensive understanding of the research landscape. We carried out our research on Scopus, Google Scholar, and Web of Science, all academic search engines and bibliographic databases commonly used by researchers and scholars to find academic literature and citations. The search was conducted in January 2023 and we leveraged these engines by looking for the keywords "digital building logbook" and "digital building logbooks". We excluded the keyword "dbl" from the search because it is a common acronym for genes and different objects within the biology domain, therefore not interesting for our analysis. We looked for the "digital building logbook" in all the fields of the articles, such as titles, abstracts, keywords, authors, and the full text of the article. We decided to search in all the fields because the DBL is a relatively new topic and we did not want to miss any relevant papers. As an example, limiting our research to the title, abstract, and keywords fields allowed us to retrieve only eight articles. By using all the fields, the results of the search included even the articles that mentioned very marginally the DBL, allowing us to understand what other themes and domains the DBL might have intersected. During this phase we identified a total of twenty scientific papers through keyword searching within scientific databases. Besides the scientific papers extracted from the academic search engines, we analyzed one EU Commission publication (not included within the academic search engines previously mentioned). This report is part of a recent tender funded by the European Commission, which began in 2022 and is still ongoing, called "Technical Study for the Development and Implementation of Digital Building Logbooks in the EU". We, therefore, reached a total of twenty-one publications. From this list, we considered only the articles in English. We excluded those in other languages (we found two in Spanish). By merging the results obtained by the three different search engines, and adding the report considered from the European Commission, we ended up with a list of nineteen publications, all eligible and accessible as a full-text article. Lastly, we decided to divide the nineteen articles into two groups, one with the eighteen articles

[8] https://environment.ec.europa.eu/topics/circular-economy/levels_en.

[9] https://joinup.ec.europa.eu/collection/egovernment/solution/building-passport-flanders-woningpas/about.

[10] https://www.rlba.org.uk/about.

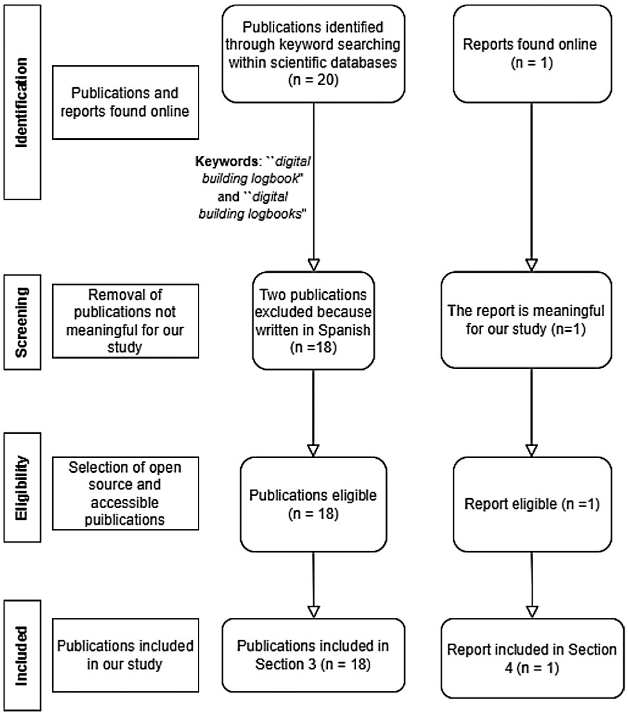

Fig. 1. Articles selection flow diagram.

extracted from the scientific databases, which will be discussed in Section 3, and one group consisting of only the report from the European Commission "Technical Study for the Development and Implementation of Digital Building Logbooks in the EU" (which will be included in Section 4). The article selection process is shown in Fig. 1.

In order to ensure thorough and unbiased data collection, a group of two reviewers analysed and identified data extraction from each report extracted from the considered scientific databases. The reviewers worked independently, and any discrepancies or disagreements were resolved through discussion and consensus. Each reviewer followed a standardised data extraction form. We decided to research the "digital building logbook", "digital building logbooks" and "logbook" keywords in each examined article and review in detail the section and the context where these keywords were cited to gain information on the concepts related to the DBL. Prior to the data extraction phase, the reviewers underwent a comprehensive training session to familiarise themselves with the research objectives, inclusion criteria, and data extraction guidelines. Additionally, inter-rater reliability tests were conducted on a subset of reports to assess the consistency and agreement among the reviewers. The data collection process was helped by regular meetings to address any questions, ensure consistency in data interpretation, and maintain the integrity of the findings.

3. Results

Within the nineteen selected publications, we found three scientific reports from the European Commission about the DBL which have been published as research papers and, therefore, indexed within the scholarly search engines we have used. These reports are all part of an EU tender named "Study on the Development of a European Union Framework for Buildings' Digital Logbook". The first report, through a review of the existing literature and questionnaire sent to various stakeholders, tries to give a formal and shared definition of what a DBL should be and what functionalities it should include [12]. The second report analyses past and current logbook initiatives trying to give a comprehensive view of the state of the art about the DBL [13]. Lastly, we have the "Final Report" of this study that summarizes the previous two reports, defines the gaps that still need to be addressed, and sets three priority actions for the European Commission to consider and potentially carry out to fill these gaps and support the widespread of the DBL [11]. A new tender called "Technical Study for the Development and Implementation of Digital Building Logbooks in the EU", was identified because it can be considered a continuation of the previous tender, aiming to refine the parameters of national DBLs, as well as to create a comprehensive set of guidelines for validating and sharing data, addressing legal and other potential roadblocks, and, ultimately, setting general advice to implement national DBLs in line with European standards. From this tender, we will consider specifically the report [14]. As this report is not a published scientific paper, we put it into an independent group with respect to the papers retrieved from scientific databases search as shown in Fig. 1.

Therefore, as far as the eighteen scientific papers are concerned, in the following, we will describe each of them.

First, we have the three publications from the "Study on the Development of a European Union Framework for Buildings' Digital Logbook" from the EU commission previously presented [13,12,11].

Then the “Review and Analysis of Models for a European Digital Building Logbook” [15], describes and compares four different approaches to the DBL from three Horizon projects and the European reports cited before. To note that in Section 3.2 we discuss the European projects (also those mentioned in [15]) that worked toward the definition of a DBL.

In “Incremental Digital Twin Conceptualisations Targeting Data-Driven Circular Construction” [16], the authors highlighted as digital data templates (DDT) and DBLs are critical elements for improved growth of the Digital Twin Conceptualisations (DTC) during the construction process life cycle, working as enablers and “sense” providers.

In “The Digital Building Logbook as a Gateway Linked to existing national data sources: The Cases of Spain and Italy” [10], the authors conducted an analysis of the mutual connection to existing data sources based on the indicators found in the analyzed data sources with the goal to set a general dataflow structure for the DBL.

In “Trusted DBL: A Blockchain-based Digital Twin for Sustainable and Interoperable Building Performance Evaluation” [17], the authors proposed a Trusted DBL based on Blockchain and Digital Twin (DT) technologies that can be used to report progress on emission reductions, securely connecting different building asset capturing important data at the national, organizational and/or facility level, helping understand the emissions profile of a region and report it as trusted data.

In “Contribution of New Digital Technologies to the Digital Building Logbook” [18], authors analyzed new digital data sources that could fit a DBL, with insights on their indicators and interoperability.

In “Libro del Edificio Electrónico (LdE-e): Advancing towards a Comprehensive Tool for the Management and Renovation of Multifamily Buildings in Spain” [19], the authors introduce a novel approach by combining two tools, the DBL and the Scheduled Renovations Roadmap (SRR), a tool for planning and managing building renovations, providing a strategic roadmap for scheduled improvements, into a unified tool called the Libro del Edificio Electrónico (LdE-e). The main objective is to create a comprehensive building database that facilitates large-scale renovations across multiple buildings. The study extensively examines the data fields of existing building information, assessment, and management tools in Spain, and proposes a new interconnected data structure that reinterprets and integrates these fields. The LdE-e aims to provide a more efficient and cohesive solution for managing building information and driving effective renovation projects. Among the various topics investigated for the LdE-e, it is worth highlighting that the article proposes an implementation of the blockchain through a basic tokenization of some assets, which will be the certificates that are stored in the document repository, a part of the tool structure further discussed in Section 3.3.

In “A Data Structure for Digital Building Logbooks: Achieving Energy Efficiency, Sustainability, and Smartness in Buildings across the EU” [20], the authors present the DBL data structure developed for the EUB SuperHub project, which involved a review of literature, existing DBL structures, and relevant EU legislation. The proposed data structure comprises eight primary categories, as presented in Section 3.4, providing essential input data for computing the passport rating across energy efficiency, sustainability, and smartness domains.

In the previously presented ten scientific publications, the DBL played a central role in the paper. In the following, we will discuss eight more papers where the DBL is only discussed as a support tool without giving much information or technical details for its definition.

In “Digital Twin application on next-generation Building Energy Performance Certification scheme” [21], the authors proposed an architecture for a Building Digital Twin (BDT) and its integration with the BIM model. Further development of this architecture will involve the integration of the DBL which will receive as input the data coming out from the BDT.

In “An Interoperable BIM-Based Toolkit for Efficient Renovation in Buildings” [22] and in “The Development of a BIM-Based Interoperable Toolkit for Efficient Renovation in Buildings: From BIM to Digital Twin” [23], the DBL is presented as a web application, living within the BIMMS (BIM Management System), to give access to the building data to the various stakeholders.

In “Digital Twin solutions to historical building stock maintenance cycles” [24], the authors defined which data could be integrated with the DBL for the maintenance of historical buildings.

Then we have the papers “Identifying Knowledge and Process Gaps from a Systematic Literature Review of Net-Zero Definitions” [25], “A methodology for the digitalization of the residential building renovation process through open BIM-based workflows” [26], “Recyclability assessment at the building design stage based on statistical entropy: A case study on timber and concrete building” [27], and “Opportunities of collected city data for smart cities” [28], that only cited the DBL as a helping tool, respectively, for reaching a net zero building emission, for digitalizing residential buildings, for supporting the building recyclability assessment, and for exploiting smart city data.

3.1. Classifying the collected scientific papers

After conducting a comprehensive review of the literature, we identified several key focus areas that emerged across the analyzed scientific papers. These focus areas were determined based on their frequency of occurrence and relevance to the DBL topic. We have organized these focus areas into the following items, which will be further described in the sections below.

Horizon funding programme: much of the recent DBL research is related to projects funded by the EU Horizon programme that we will discuss in Section 3.2.

Data sources: we analyzed the most common data sources categories and data formats that we found in literature within the DBL. This will be illustrated in Section 3.3.

Indicators: depending on the data used, a DBL can present various indicators to provide different insights related to the conditions and status of a building. This will be covered in Section 3.4.

Digital Twin and BIM models: BIM, DT and DBL are three topics heavily intertwined in literature, and we found, among the analyzed papers, several approaches to integrating them all. This will be seen in Section 3.5.

Table 1
Classification of the analyzed scientific papers. HFP = Horizon funding programme, DS = Data Sources, I = Indicators, DTBM = Digital Twin and BIM Models, STI = Semantic Technology Integration, CBA = Challenges to Be Addressed.

	HFP	DS	I	DTBM	STI	CBA
EU - Definition of the digital building logbook	X	X	X	X		
EU - Building logbook state of play	X	X	X	X		
EU - Study on the Development of a European Union Framework for Digital Building Logbooks Final Report						X
Review and Analysis of Models for a European Digital Building Logbook	X		X			X
Incremental Digital Twin Conceptualisations Targeting Data-Driven Circular Construction	X			X	X	X
The Digital Building Logbook as a gateway linked to existing national data sources: The cases of Spain and Italy	X	X	X			X
Trusted DBL : A Blockchain-based Digital Twin for Sustainable and Interoperable Building Performance Evaluation	X			X		
Digital Twin application on next-generation Building Energy Performance Certification scheme	X			X		
An interoperable BIM-based toolkit for efficient renovation in buildings	X		X	X	X	X
The Development of a BIM-Based Interoperable Toolkit for Efficient Renovation in Buildings: From BIM to Digital Twin	X			X	X	X
Identifying Knowledge and Process Gaps from a Systematic Literature Review of Net-Zero Definitions						
A methodology for the digitalization of the residential building renovation process through open BIM-based workflows	X	X		X	X	
Recyclability assessment at the building design stage based on statistical entropy: A case study on timber and concrete building						
Opportunities of collected city data for smart cities		X				X
Digital Twin solutions to historical building stock maintenance cycles				X		X
Contribution of New Digital Technologies to the Digital Building Logbook	X	X	X			X
Libro del Edificio Electrónico (LdE-e): Advancing towards a Comprehensive Tool for the Management and Renovation of Multifamily Buildings in Spain		X				X
A Data Structure for Digital Building Logbooks: Achieving Energy Efficiency, Sustainability, and Smartness in Buildings across the EU	X	X	X			

Semantic Technology Integration: some new technologies are being integrated within a DBL to enhance its performance and widen the scope. One very promising technology is the semantic web. Some examples of semantic integration and employment of semantic technologies will be given in Section 3.6.

By analyzing these focus areas in detail, we aim to provide a comprehensive overview of the current state of research in this field and highlight the most important findings and contributions in each area. We also aim to identify research gaps and opportunities for future research, which will be discussed in the final section of this survey paper. It is worth to be noted that from this classification we excluded the report from the tender called “Technical Study for the Development and Implementation of Digital Building Logbooks in the EU” since the report will not contribute to the focus areas discussed but it will be part of Section 4. In Table 1 we illustrate the classes we have identified within the collected articles. Note that two articles, [25] and [27], are not classified in any of the classes of interest because they mention the DBL in a very superficial manner but we decided to include them in our analysis because they can still provide insights of other themes that can intersect with the DBL.

3.2. Horizon funding programme

Horizon is the EU’s biggest research and innovation funding program. This program has been running from 2014 to 2020 with a budget of nearly 80 billion euros, and from 2020 until 2027 will be running under the name Horizon Europe with an additional budget of 95.5 billion euros [29]. Within this scope, many innovation and research projects tackling climate change and global challenges have been funded. Among them, we identified those presented in the collected papers mentioned in Section 3 that have, as an important part, the implementation or conceptualisation of a DBL, showing how a DBL can be connected with many research and innovation topics. The aforementioned H2020 projects are:

- iBRoad (mentioned by [13,15,16,10,18]),
- ALDREN (mentioned by [13,15,16,10,18]),
- X-tendo (mentioned by [13,15,10,18]),
- BAMB (mentioned by [13]),
- DigiPLACE (mentioned by [13]),
- PROBONO (mentioned by [17]),
- D2̂EPC (mentioned by [21]),
- BIM4Ren (mentioned by [26]),
- BIM4EEB (mentioned by [13,22,23]).

- EUB SuperHub (mentioned by [20])

In addition, we analyzed other four relevant projects:

- Chronicle [30],
- SmartLivingEPC [31],
- Demo-BLog [32], and
- SmartSquare [33].

In the following, we will provide a brief description of the DBL involved in each of these projects.

iBROAD[11] focuses on demonstrating the concept of individual building renovation roadmaps by providing a tool able to create a step-by-step plan with customised recommendations for each building. Such a tool includes the Roadmap Assistant [34], a web application supported in its functionalities by a repository with all building-related information such as energy performance, executed maintenance, and building plans (the DBL here is called iBROAD-Log). The iBroad-Log architecture is based on a web application and a classical relational database with different data levels containing the topics that every national (or regional) logbook should contain. Logbooks can be used to support the renovation roadmap by providing the necessary data to the Roadmap Assistant.

ALDREN[12] focuses on the development of a building passport, referred to as ALDREN BRP, specifically for non-residential buildings (in contrast to the iBROAD project which focuses on individual residential buildings). The goal is to improve renovation, by providing also a standardised and optimised framework for data storage and processing such as a DBL, that can be used to improve investment decision-making. The logbook (referred to as ALDREN BuildLog) is based on a web application and consists of six modules organised in a hierarchical way where each of them has different subcategories and protocols for data gathering and different degrees of authorisation according to the user's expertise or needs. All modules are nested inside each other and are characterised by a different level of information (LoI), where the first and "biggest" level acts as a sort of "data lake" which contains all the data needed for the other levels.

X-tendo[13] focuses on exploring additional features that can be attached to the EPCs in a way to inspire the next generation of EPCs, suitable for the whole building stock (residential and non-residential). This is done by providing an interface, called CASA+ that acts as a One-Stop-Shop (this can be seen as a DBL), where different stakeholders can input data. The logbook within this project is focused on data related to the EPC databases or similar. This data will be based on the link between existing databases, such as publicly available EPC databases and third-party databases, and present various degrees of authorisation according to the user type. With such data, the system can provide some functionalities and renovation services focused on supporting public authorities and not building owners or other stakeholders.

BAMB[14] focuses on providing a material building passport to move towards a circular building economy by reducing construction and demolition waste. To facilitate the systematic shift where dynamically and flexibly designed buildings can be incorporated into a circular economy, the project is creating and incorporating the following tools: Reversible building designs and Materials Passports, supported by innovative commercial models, policy ideas, and management and decision-making frameworks. Within this project, the logbook is not explicitly implemented, but such a passport can be an important data type to be included in a DBL.

DigiPLACE[15] aims to create a digital platform integrating various technologies, applications, and services related to the Architecture, Engineering, and Construction (AEC) industry where the DBL could be an important part of managing heterogeneous data. This project aims at creating a common European logbook where data from different regions or countries can be stored or accessed or visualised.

The PROBONO[16] project will create various applications and solutions aiming to create a green, zero-emission, and circular building industry. Regarding the DBL, within the project scope, a trusted DBL, that relies on the integration with blockchain technologies and digital twin models, is proposed. The applicability of the implementation of such a DBL will be tested in order to provide reliable data for trusted and informed decision-making and data sharing within the building life cycle. The trusted DBL architecture has three main components: DT, Blockchain and Non-Fungible Tokens (NFTs) [35]. The DT carries out the task of virtual troubleshooting and predictive maintenance. The Blockchain is implemented as a private permissioned network acting as the decentralised infrastructure to store and share the DBL data. Lastly, the interoperable NFTs are used for credibility and trust.

D2̂EPC[17] focuses on creating a next-generation EPC model, enhancing the one already existing, that presents a lot of fragmentation about what data to be included depending upon the country or region that implements it and is often paper-based. The final goal is to make the EPC dynamic and digital by developing the BDT and its integration with the BIM model enriching the EPC with smart-readiness data of the buildings. The data coming out from this implementation and in particular from the BDT and its integration with the BIM environment can be then stored and accessed by a DBL, even if in this project an implementation of it is not foreseen.

[11] https://ibroad-project.eu/.
[12] https://aldren.eu/.
[13] https://x-tendo.eu/.
[14] https://www.bamb2020.eu/.
[15] https://digiplaceproject.eu/.
[16] https://www.probonoh2020.eu/.
[17] https://www.d2epc.eu/en.

The BIM4Ren[18] objective was to create a web-based one-stop platform linked to innovative processes, methodologies, and software, to access and manage BIM data through innovative BIM technology. Within the project, the DBL will act as a single data lake for static and dynamic data providing APIs to apply simulation and calculation.

BIM4EEB[19] focuses on providing a multidisciplinary and interoperable toolkit based on BIM for building renewal processes. In this context, the DBL is stored within the BIMMS, and it could be accessed directly from it. The BIMMS is implemented as an open-source web-based platform containing all building data, and for this reason, it can be seen as a Common Data Environment (CDE). The logbook is integrated into this environment to store and access all building-relevant data. Moreover, within the project, researchers have studied how Semantic web technologies and DBL could be implemented together considering all the data in the BIMMS CDE as a resource using the Resource Description Framework (RDF) format [36].

The goal of the CHRONICLE[20] project is to create a comprehensive framework and toolkit for evaluating and verifying the performance of various types of buildings. Here the DBL will act as a (digital) repository where the building's information can be stored and updated, with the possibility of the type of information evolving over time.

The SmartLivingEPC[21] project seeks to establish a digital certification process that utilises advanced tools to gather necessary information on a building's shell and systems. This information will be used to create a new rating system that provides insight into the building's overall performance. The digital certificate will be compatible with digital databases, such as building renovation passports and DBL, to ensure seamless integration of building energy performance data. The certification will be applied to entire building complexes to provide neighbourhood-level energy certification.

Demo-BLog [32] is a new project (started on January 2023), that will combine five different DBLs, which collectively contain 4.5 million registered units and involve a diverse range of stakeholders, thus having a large and diverse offering. The demonstrated DBLs in this project could potentially encompass the entire building lifecycle by offering unrestricted access to data, allowing for limitless input and output, and facilitating data exportation.

The objective of the SmartSquare[22] project is to create and provide suitable tools and applications that will facilitate the adoption and implementation of intelligence assessment of buildings in Europe using the SRI scheme. The project also involves exploring the integration of SRI in DBL, to enable seamless integration of the SRI certificate and its relevant information in the future.

Finally, EUB SuperHub project,[23] has developed an online platform with the goal of revolutionising building certification and rating systems to support the EU's transition to decarbonized, intelligent, and sustainable buildings by 2050. The platform consists of four key modules: the planning and verification tool (PVT) module, e-passport cockpit (e-cockpit), virtual marketplace (VM), and e-training module. The e-cockpit serves as a cloud-based interactive database that provides stakeholders with essential information about existing buildings and relevant certificates. The PVT module enables building owners to upload, share, and store comprehensive building-related information, while the VM facilitates connections among building users, auditors, solution and funding providers, and other industry participants. Additionally, the e-training module offers educational resources to platform users. By integrating these modules, the platform serves as a centralized hub, meeting the diverse needs of the construction sector value chains in one accessible location.

3.3. Data sources

"*The capturing and maintenance of data and information is the backbone of the DBL, as consistently emphasized by the interviewed and surveyed experts.*"

This important statement has been reported by the European Commission in the Definition of the DBL [12], specifying that managing the data sources and the data itself is one of the most important aspects to consider within a DBL.

According to the literature that we have analysed there are four main categories of possible data sources that can feed data in a DBL:

- national or regional initiatives and databases,
- BIM models,
- building monitoring related sources, and
- European frameworks and initiatives.

The national or regional initiatives are databases that can be accessed to retrieve some kind of building data. The majority of them and the easiest to access are the ones that are distributed as open data, like, for example, the CENED ("Certificazione ENergetica degli EDifici") dataset,[24] a practical list of EPCs for the energy certification of buildings of the Lombardy Region in Italy. In [10], a deep study on the already existing data sources of two regions, Lombardia in Italy, and Aragon in Spain, is conducted. This study

[18] https://bim4ren.eu/.
[19] https://www.bim4eeb-project.eu/.
[20] https://www.chronicle-project.eu/.
[21] https://www.smartlivingepc.eu/en.
[22] https://www.smartsquare-project.eu.
[23] https://eubsuperhub.eu/.
[24] https://www.dati.lombardia.it/Energia/CENED-Certificazione-ENergetica-degli-EDifici/rsg3-xhvk.

highlighted how the data sources vary regionally or nationally and suggest how a more detailed analysis of their interoperability needs to be done on a case-by-case basis, focusing on mandatory initiatives in the territories covered by the case studies. Moreover, the authors proposed how the data-gathering processes of these sources need to be homogenised and updated since there are vast collections of heterogeneous data, hard to access or use for a DBL if not extensively preprocessed. Among these data sources, we can consider the relatively new smart city datasets, which can have interesting data for a DBL, and that will grow more and more in the future, as investigated in [28].

In the article about the EUB Super Hub project [20], the authors investigated the data sources of interest for the DBL related to the project. They investigate existing national building-related databases from countries involved in the project (Austria, Croatia, France, Germany, Hungary, Ireland, and Italy) as potential data sources for the DBL. However, these databases may have limited public accessibility. To ensure compliance with the proposed revision of the EPBD, the authors highlight how it is required that all national EPC databases need to be integrated and interoperable with the DBL. It is said that the EPBD directive will serve as a catalyst for the adoption of DBL, which aims to consolidate these data sources into a unified platform, providing a common gateway to access the information they contain.

Another important analysis is shown in [19], where an inspection is conducted at the national level in Spain aiming to identify the data sources for the LdE-e formalisation. In this article, the authors identified the following data sources.

- Building Logbook (LdE): The LdE is a mandatory instrument for new buildings in Spain and contains information generated during construction. It includes a conservation manual for implementing maintenance plans. However, it is often outdated for multifamily buildings without a professional facility manager.
- Existing Building Logbook (LEDEX): LEDEX is a recently created instrument for existing buildings in Spain, particularly those constructed before 2000. It assesses a building's condition, potential for improvement, and includes a use/maintenance manual and renovation action plan. LEDEX's data structure is extensive, but data provision relies on the expertise of technicians.
- Certificate of Occupancy (CdH): CdH ensures minimum hygienic conditions of dwellings and is required for first occupancy and subsequent occupancies. CdH regulations vary across autonomous communities, and specific requirements are established by each region.
- EPC: The EPC aims to provide transparency regarding energy consumption and CO2 emissions of dwellings. It helps inform buyers, tenants, and sellers about the energy efficiency of buildings. However, its effectiveness in Spain has been debated.
- Technical Building Inspection Report (IITE): The IITE, in Spain, is mandatory for buildings over 50 years old. It assesses the building's conservation status and basic accessibility conditions. It incorporates the EPC rating and recommendations for energy efficiency improvements.
- BIM and DT data: limited to new buildings, given the ease of using the methodology from the initial process of building design and construction. For the format of these data see Section 3.3.1.

The analysis of these existing instruments reveals data gaps and redundancies due to their separate operation. The LdE-e aims to address these issues by integrating and harmonizing the data from these sources.

From these data sources the authors proposed a data structure for the LdE-e. Such a structure is composed of three main components that we introduce in the following.

- Document Repository (DR): it consists of a data and document asset section, containing certificates from assessments (e.g., EPCs), and a warehouse section, storing supporting files and documents throughout the building's life cycle (e.g., property deed).
- Interconnected Data Structure (IDS): it consists of five packages. Technical/formal data, legal data, identification of deficiencies, one-off actions, and maintenance and repair schedule. These packages store information on building construction systems, ownership, deficiencies, one-off incidents, scheduled maintenance, and improvement measures, enabling a comprehensive record of building performance, maintenance, and necessary renovations.
- SRR: the IDS enables the creation of the SRR, which is linked to the DR. This linkage allows for the updating of certificates (CdH, EPC, and IITE) when required. By integrating data, the SRR can improve the prioritization of renovations based on technical, economic, and functional considerations, meeting the needs and aesthetic preferences of owners/users.

It is worth noticing how the LdE-E data sources are mainly related to national or regional initiatives but some of these sources can be considered to have a wider scope, like, for example, the BIM models.

BIM models can be considered one of the main data sources for a DBL since they contain a large amount of information relating to the design, construction, and maintenance of a building. As analysed more in detail in Section 3.5, BIM models have a strong connection with DT and DBL, as these three elements have various intersections in functionalities and data usage. In [26], it is highlighted how, currently, not all BIM model applications have a standardised approach suitable for the automation of the renovation process. For this reason, they propose "OPEN BIM" workflows[25] aiming to enable interoperability and efficient integration of tools and processes. In this context, the DBL acts as a tool (in the specific case as a data lake) to support this process allowing data exploitation.

[25] https://user.buildingsmart.org/knowledge-base/openbim-workflows-explained/.

Building monitoring data refers to data collected from sensors and other monitoring devices installed in the building during its operational phase. This data can include information about energy consumption, indoor air quality, temperature, humidity, occupancy, and other factors. Building monitoring data is typically used to optimize building performance, reduce energy consumption, and improve occupant comfort and health. This type of data can be contained in some national or regional databases like those we discussed earlier or can be the source for a DT. IoT (Internet of Things), is a technological field that is growing exponentially [37], and through which building monitoring data is produced.

In [18], it is highlighted how the IoT technologies, including smart devices and sensors, along with others like AI (Artificial Intelligence), virtual reality (VR), and augmented reality (AR) are being implemented to enhance building monitoring, BIM models, DTs, and DBL.

Other important sources are some current European initiatives and frameworks. As indicated in [18], we have:

- Smart Readiness Indicators (SRI),
- Level(s),
- Digital Product Passport (DPP), and
- Building Renovation Passport (BRP).

The SRI, introduced through the 2018 EPBD Review [38], is a set of indicators developed by the European Commission to measure the capacity of a building to use new technologies and electronic systems to enhance its performance. Buildings' technical readiness preparedness is evaluated by the SRI in light of interaction with their occupants, interaction with connected energy grids, and operation that uses less energy. The Level(s) framework [39] includes a set of six indicators that cover different aspects of building sustainability, including energy performance, resource efficiency, circularity, indoor environmental quality, cost, and resilience. These indicators are designed to provide a comprehensive view of a building's sustainability performance and to support decision-making throughout the building lifecycle, from design and construction to operation and renovation. Throughout a building's whole life cycle, Level(s) measures the effects on carbon, materials, water, health, comfort, and climate change. The DPP [40] is an important component of the Circular Economy Action Plan's (CEAP) Regulation on Ecodesign for Sustainable Products. It is a digital document that includes a range of information about a product, including its composition, production processes, environmental impact, and end-of-life options. The DPP is still a relatively new concept and is currently being developed and tested in a range of sectors, including electronics, textiles, and construction materials. The BRP is a document that often includes historical and current information on the property, its construction, and a digital record of renovations at the property level. Furthermore, it outlines a long-term step-by-step roadmap (up to 15 to 20 years) for the major renovation of a building. The BRP was introduced through the 2018 EPBD Review [38], is still evolving, and is expected to play an important role in supporting the renovation of existing buildings and promoting the transition to a more sustainable and energy-efficient built environment in the European Union.

All these European initiatives or frameworks share some key aspects that make them useful as data sources for a DBL.

- Energy Efficiency and Sustainability: all of these initiatives and frameworks are focused on promoting energy efficiency and sustainability in the building sector. This means that they provide data on energy consumption, building performance, and renewable energy sources, which can be used to track building performance over time.
- Standardisation: many of these initiatives and frameworks include standardised requirements and guidelines for building performance and technology integration. This standardisation helps ensure that the data collected is consistent and reliable, making comparing building performance across different buildings and regions easier.
- Policy Support: these initiatives and frameworks are often used to support the development of energy efficiency and sustainability policies at the national and European levels. This means that the data collected can be used to monitor and evaluate these policies' effectiveness and identify improvement areas.
- Collaboration: many of these initiatives and frameworks involve collaboration between different stakeholders, including industry, research organizations, and government agencies. This collaboration helps ensure that the data collected is relevant and useful for a wide range of stakeholders, and that reflects the latest trends and developments in the building sector.

The DBL data sources identified in this section are summarised in Fig. 2.

3.3.1. Data formats

Diverse interviews conducted in [12] have reported, as one of the main obstacles to the correct development of a DBL, the poor interoperability between the various data sources that could feed data to a DBL. This problem is heavily related to the fact that there is no homogeneity or consensus in the data formats a DBL should support or use to represent the data collected. In [13] among all the building logbooks analyzed, for a total of 21 initiatives of different structures and purposes, the authors identified in 70% of them a structured approach to data divided into many categories, in 10% of them a structured approach presenting macro categories and in the last 20% of them an unstructured data approach, considering each data as a document. Through the analyzed literature and DBL initiatives, we see that a DBL should be able to receive and represent data with different formats to be as more interoperable as possible.

In the following, we tried to group the different data formats that a DBL can receive and represent them into four main categories:

- document data,

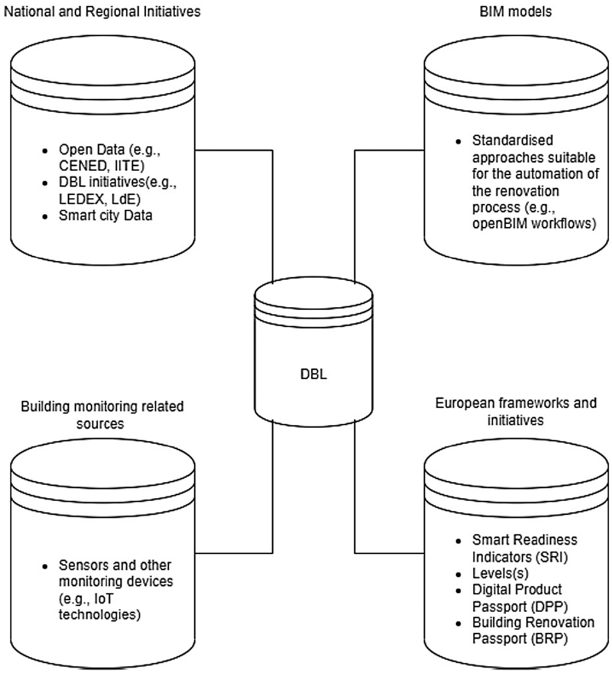

Fig. 2. DBL data sources.

- key-value pair data,
- (semi-)structured data, and
- unstructured data.

It is important to highlight that the mentioned data types are not mutually exclusive, since in some cases the boundaries may be fuzzy or overlapping: for example, there may be documents with structured content (e.g., XML) or files in a semi-structured format such as JSON that include key-value pairs.

Among document data, we can have binary or text documents. Binary data refers to any data that is stored as a stream of bytes. Examples of binary data that might be relevant for a building logbook could include documents in PDF (permits, reports, etc.), images (photographs or drawings of the building, equipment, or other assets), videos (recordings of building systems or equipment in operation) or 2D/3D design files among others.

Text data refers to data that is stored in a textual format, like text files, some documents using character stream-based open standards, or for example the International Standard Industry Foundation Classes (IFC)[26] format. IFC is a neutral, open data model for building and construction data that is used for communication and collaboration, especially within BIM models. It enables the exchange of information between different software applications used in design, construction, and facility management.

Key-value pair data refers to data that is stored in a paired format, where a key-value pair represents each data item. Some examples of key-value pair data that could be uploaded to a DBL could include sensor data (from IoT sensors), and energy usage data.

(Semi-)structured data refers to data that is not fully structured but contains some elements of structure or organisation. The most common data format for this category that could be uploaded to a DBL is the JSON file format, which could include almost any type of data. As part of the semi-structured data, we include general logs. Log data refers to data that is generated by systems and stored in a log format, typically with a timestamp and other metadata. Some examples of log data that could be uploaded to a digital building logbook include Building Automation System (BAS) logs (logs of system events, alarms, and errors), and Security system logs (logs of access control events, such as door entries or failed authentication attempts). Log data can also refer to the actions that users take within the DBL itself, such as uploading, modifying, or downloading data. This type of log data can be helpful in tracking user activity, ensuring data integrity and auditing changes made to the logbook.

Lastly, we include the unstructured data type, data that does not have a predefined structure or format. To handle this type of data, techniques such as natural language processing, machine learning, or other data analytics tools should be employed to extract meaning and insights from the data. Data might also be stored in a flexible format that can accommodate a wide range of data types and structures, such as a document database or a data lake. By doing so, we can ensure that the DBL is prepared to handle unstructured data that may come in the future.

[26] https://technical.buildingsmart.org/standards/ifc/.

3.4. Indicators

The indicators of a specific DBL provide insights related to the conditions and status of a building. They strictly depend on what data type is collected or available. Many different types of indicators can be included in a DBL. The categories of data collected by a DBL directly impact the categories of indicators that can be derived from it. The availability and nature of data types determine the specific insights and indicators that can be generated within the DBL. A wide range of data categories can be included in the DBL, allowing for diverse indicators that provide valuable information about the conditions and status of a building. For example, if the DBL collects data on energy consumption, temperature, and occupancy, indicators related to energy efficiency, thermal comfort, and occupancy patterns can be derived. In [15], the authors leveraged indicators present in implemented DBLs within three Horizon 2020 projects discussed in Section 3.2: iBRoad, ALDREn, and X-Tendo. They also used indicators from stakeholders' interviews within the European study on DBL [12,13]. Within the projects iBRoad, ALDREn, and X-Tendo, the authors grouped the indicators into five categories: general and administrative information, construction information and materials, building technical systems and smart readiness, energy performance, operation and use, and finance.

Although such a classification, there is no homogeneity in the papers we have analysed where authors used other ways of grouping indicators. In [10] authors presented the indicators they found from digitally accessible building data sources of two regions, Lombardia (Italy) and Aragon (Spain). This research highlights how the indicators could vary depending on the country's or region's needs. Authors in [18] proposed six indicator categories based on the analysis conducted in [10] and according to new European tools to support circular design and innovation in buildings such as the Level(s) framework [39,41,42] and the DPP [43]. These six categories are the same previously mentioned and proposed by [15], plus a new one: conservation status and pathologies. In the study about the data structure of the EUB SuperHub project [20], the authors defined eight main categories of data that they have included in their DBL. These categories affect which indicators to be included in the DBL, and are: i) administrative information, ii) general building information, iii) building element information, iv) building operation and use, v) building performance, vi) smart readiness, vii) finance, and viii) building documentation BIM.

As different other papers came up with different classes, we analysed them and defined nine categories that incorporated all of the identified classes.

Building information indicators: measures the efficiency of the building's information management practices. It can include metrics such as the accuracy and completeness of the building's information, the ease of access to information, and the security of the information.

Energy consumption indicators: show how much energy the building is using and can help identify areas for improvement. They can include or provide data for graphs of energy consumption over time, meter readings, and real-time energy usage displays.

Indoor comfort indicators: provide information about the indoor environment, such as temperature, humidity, air quality, and lighting levels.

Maintenance indicators: help building managers keep track of maintenance tasks, such as cleaning, HVAC checks, and equipment replacement. They can include schedules, checklists, and real-time notifications of maintenance needs.

Occupancy indicators: show how many people are in the building and can help optimise the building's energy use and resource allocation.

Safety indicators: provide information about the safety of the building, such as fire alarm status, emergency lighting, and evacuation routes.

Financial indicators: show the financial performance of the building, such as operating costs, revenue, and return on investment.

Sustainability indicators: provide information about the building's sustainability performance, such as carbon footprint, water usage, and waste generation.

Smart Readiness Indicators (SRI): these indicators are a set of metrics that measure the level of a building's "smartness" based on a common EU scheme.[27] They provide a comprehensive assessment of a building's readiness to adopt new technologies. SRI metrics are designed to help building stakeholders understand how well-prepared their building is for innovative technology integration and to identify areas for improvement.

In [22], we can observe how some of the previously mentioned indicator categories can be related to Key Performance Indicators (KPIs) [44] within the construction domain. The KPIs are properties used to compare and evaluate the level of achievement of a specific objective for a specific tool or process, where the tool is not necessarily the DBL. The mentioned KPIs in [22] are: Environmental and Safety KPIs related to Environmental indicators and Safety indicators, Human Comfort KPIs related to Environmental Indicators, Energy Performance KPIs related to Energy consumption indicators, and Economic Performance KPIs related to Financial indicators. Since these specific KPIs, related to the BIM4EEB project,[28] are associated with different tools and processes, this leads us to the conclusion that indicators for the DBL in some cases could be overlapping with tools to measure specific performances of other building innovation tools such as DT and others within the BIM ecosystem.

3.5. Digital Twin and BIM models

A BIM is a holistic process of creating and managing construction information integrating multidisciplinary structured data to develop a digital representation of an asset. It is a collaborative process that involves creating, managing, and exchanging information

[27] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/what-sri_en.

[28] https://www.bim4eeb-project.eu/.

throughout the entire lifecycle of a construction project, from its conceptualization to demolition. BIM is based on a three-dimensional (3D) model that contains intelligent data elements called "objects". These objects represent the various components of the building, such as walls, doors, windows, HVAC systems, electrical systems, and more. The 3D model serves as a central repository of information, allowing architects, engineers, contractors, and other stakeholders to work together and access the same data. BIM goes beyond a mere 3D visualization tool. It allows for the integration of additional dimensions, such as time (4D) and cost (5D), which provide insights into the project schedule and budget. Furthermore, BIM facilitates the analysis and simulation of various aspects, including energy performance, structural integrity, clash detection, and facility management. The key benefits of BIM include improved collaboration and coordination among project participants, enhanced visualization and communication of design intent, reduced errors and rework, increased efficiency and productivity, and better decision-making throughout the project lifecycle.

A digital twin (DT) is a virtual representation or replica of a physical asset, system, or process. It encompasses both the physical and digital realms, providing a real-time and dynamic connection between the physical entity and its digital counterpart. DTs are commonly used in various domains, including manufacturing, healthcare, transportation, and, of course, the built environment. In the context of the built environment, a DT represents a building, infrastructure, or entire urban environment in a digital form. It integrates data from multiple sources, including sensors, IoT devices, BIM models, and other data repositories, to create a holistic and real-time representation of the physical asset. The benefits of DTs include improved asset performance and efficiency, predictive maintenance, reduced downtime, enhanced sustainability, better resource allocation, and the ability to simulate and test scenarios without impacting the physical asset. DTs also facilitate the integration of emerging technologies like AI, ML, and advanced analytics to unlock further value.

BIM and DTs are interconnected concepts. BIM can be considered a foundational component for creating and maintaining the digital representation that serves as a basis for the DT. The information and intelligence embedded within BIM models can be leveraged to create and update the DT throughout the asset's lifecycle. In summary, BIM is primarily a collaborative design and construction methodology, while DTs extend the concept by incorporating real-time data and providing ongoing monitoring and optimization capabilities throughout the asset's lifecycle. With regard to the integration of the BIM model with the DBL, it is worth highlighting that, in [12], a survey among different participants (for the majority of researchers, public authority, and members of the construction value chain) has been conducted about the functionalities that a DBL should include. The outcomes of this survey show as one of such functionalities is the "automatic input of data from 3D/BIM model". This integration between BIM models, DT, and DBL is implemented, or discussed, in some of the analysed papers that we are going to summarise in the following, and even in the projects presented in Section 3.2 such as ALDREN, X-Tendo, PROBONO, D2EPC, BIM4Ren, and BIM4EEB. The interoperability between DT and DBL is shown, for example, in [16] where the DT is seen as a System of System (SoS), called Digital Twin Construction (DTC). This interoperability could be represented, for instance, from a sensored lighting system consisting of regular light fixtures and sensors, in place of traditional light switches. This physical lightning system can be digitally linked with the DTC, and the sensor data can be sent to a DBL that acts as an information container for further analysis. In [17] among the three pillars of the proposed Trusted DBL, the discussed DT is focused on describing various building's physical aspects such as its energy systems, allowing bi-directional data flow where the sensors feed data to the DT (data that is sent to the DBL), and DT can actuate physical smart devices, for example, to reduce consumption based on some previous calculation. In [21] the authors presented the Building Digital Twin (BDT): a DT oriented towards the process of creating an enhanced version of the EPC through the integration of the BIM environment and AI and IoT technologies. They mentioned that the BDT could be easily extended to operate with a wider range of technologies, such as a DBL. In [22,23] the authors introduced the architecture of an interoperable BIM-Based Toolkit, where there are various tools developed to serve different stakeholders' needs. All these tools are developed as independent applications built on top of the BIMMS while a DBL is also developed as a tool but is stored within the BIMMS and can be accessed directly from it. In [26], an "Open BIM" paradigm focused on developing a collaborative BIM process and standard methodologies to enhance interoperability between different applications is presented. Within these applications, the Open BIM will lead to the generation of a DBL, enabling data to be exploited, and a DT, collecting static and dynamic data from building IoT sensors. In [24] it is shown how the DT approach can be applied along with the BIM tools to enhance the historic building stock, particularly in relation to some historical buildings in Rome. In this context, the DBL is integrated with the DT and is seen as an archive that is used to store and access strategic documents.

3.6. Semantic technology integration

One important element that should be considered within the building industry development is the interoperability between different applications, such as those BIM-based. In this regard, the IFC format introduced in Section 3.3.1 can be encoded in different ways, such as the ifcOWL and the Building Topology Ontology (BOT), which provide a representation of the IFC data schema in the Web Ontology Language (OWL) [45]. In [22] and [23], an architecture scheme for the BIM4EEB project was presented, as discussed in Section 3.2. There, an open CDE based on linked data was introduced. All the data and metadata of the CDE were considered resources through the use of the RDF. This semantic representation was created through the conversion from IFC items to Linked Data enabling the exploitation of the IFC data. In this context, the DBL, stored within the BIM Management System, has to work with semantic data enabling better interoperability and facilitating the exchange of data and knowledge learned thanks to the inference capabilities of semantic technology. Within the project, a set of ontologies was developed and existing ones were extended to widen the reuse of existing knowledge. In this context, the logbook acts as an archive of all building-related information: having that linked information with external ontologies will augment the capabilities provided by the DBL to handle and manage data. A similar approach was adopted in [26] where the DBL acts as an archive of all types of data, with the static data stored in a geometric and semantic model. In [16], future work is referred to as a semantic construction digital twin [46]. Three different degrees of maturity of the DT are defined and correlated to the progressive use of a semantic-based approach aiming to achieve a "self-reliant, self-updatable and self-learning" platform. Providing the highest interoperability between the DBL and the DT and among the data that the DBL will handle is therefore of interest for the means that the DBL will be able to offer.

Moreover, the final report of the "Study on the Development of a European Union Framework for Buildings' Digital Logbook" [11], suggests that the main goal of an EU harmonisation and standardisation process for a DBL should be to create a standardised dictionary of all building-related terms that may be used in a DBL context and define how they should be understood and used. This will help establish a semantic data model of the core DBL elements. This semantic model should define the essential elements that a DBL requires to work with other databases, have the possibility to integrate functionalities, and support data exchange between different users. For example, it might contain a data template that has essential EU-level data fields and country-specific requirements. Additionally, it could provide guidelines for the organisation of logbook data and protocols for data capturing.

To address the need for a standardised dictionary of building-related terms and a semantic data model for the core elements of the DBL, other technologies such as Brickschema [47] and ProjectHaystack [48], not mentioned before, that facilitate interoperability and standardised data management in the building environment may come to help. Brickschema and ProjectHaystack have gained traction within the building industry and are recognised as valuable tools for achieving interoperability and efficient data management. Both frameworks emphasise the importance of semantic understanding in building data. They offer approaches to assign meaning and context to data points, enabling better interpretation and analysis of building-related information. Brickschema focuses on providing a semantic modelling framework and ontology for representing building-related information comprehensively. It covers a wide range of building assets, systems, and components, offering a standardised vocabulary and structure. ProjectHaystack specifically targets building automation and control systems. It provides a standardised tagging methodology and data modelling approach to organise and describe data points from smart devices and equipment systems within buildings. Brickschema offers a more granular and comprehensive approach to representing building data, covering a broader range of building-related terms and concepts. ProjectHaystack, on the other hand, focuses on the specific needs of building automation systems and provides a more specialised approach.

4. DBL implementation principles

The European Commission in the last years is promoting research and conducting several actions to further define and clarify the definition and use of the DBL. The output of one of these actions consists of three reports based on the study of the development of a European Union Framework for DBLs [13,12,11].

As we presented in Section 1, in one of these reports [12], the EU Commission already gives a first definition of the DBL.

In the final report of the same study [11], nine gaps to be filled to support the widespread of the DBL are introduced (already mentioned in Section 5).

To try to address these gaps, and all the other challenges and future research topics illustrated within Section 5, the European Commission funded another important ongoing tender in 2022 titled "Technical Study for the Development and Implementation of Digital Building Logbooks". In the remainder of this section, we will dig into the technical elements provided by one report of this tender [14].

This report involves various stakeholders through surveys and webinars with the final aim of developing an EU model for DBLs. It also aims at creating a DBL framework shared within the EU member states to enhance harmonisation, efficiency, and effectiveness. Additionally, it seeks to improve the organisation, sharing, and utilisation of data in the construction and built environment sectors. Furthermore, the framework is designed to support stakeholders and end-users by providing a reusable platform for various use cases such as energy efficiency and construction materials.

These goals will be supported by the development of several systems, where the most important will be an EU semantic data model for DBLs. Technical guidelines will also be produced for implementing interoperable DBLs that can work and benefit from the semantic model. This semantic data model will be composed of an extendible ontology and a dictionary following the guidelines set by [11] as introduced in Section 3.6.

Moreover, the report mentioned above set five guiding principles to follow for the development of an EU DBL model:

- Simplicity
- FAIR Principle
- Data quality
- Levels Of Information Need (LOIN), and
- Keep data at its source.

The simplicity principle aims to achieve optimal functionality and usability, meaning that developers should aim for simplicity in designing the DBL while ensuring that essential features and user experience are not compromised. This requires eliminating any extraneous elements and focusing on delivering a straightforward and uncluttered application.

Next we have the FAIR principle[29] which suggests that DBL data should be:

[29] https://www.go-fair.org/fair-principles/.

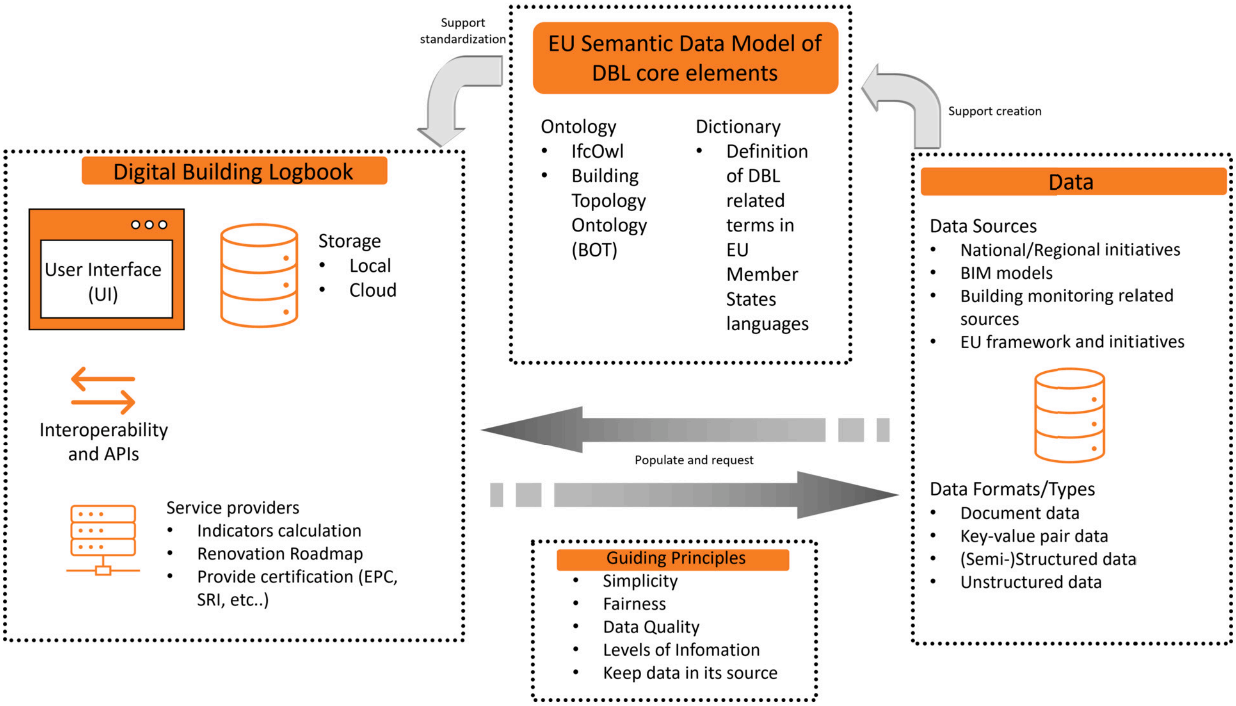

Fig. 3. DBL definition according to the surveyed papers and reports from the European Commission.

- Findable: Data should be easy to find and identify, with clear and consistent metadata and unique identifiers.
- Accessible: Data should be accessible and available to users through user management, thus with different levels of accessibility and security.
- Interoperable: Data should be structured in a way that allows for easy integration with other data sources and tools.
- Reusable: Data should be properly licensed, and its use and reuse should be specified and encouraged.

Then, it is essential to ensure high-quality data by maintaining the relevance, completeness, and consistency of datasets. Poor quality data can hinder its reusability and result in errors, potentially leading to incorrect decision-making. Thus, it is crucial to prioritise data quality to ensure the reliability and usefulness of the DBL.

The fourth principle is based on the Levels Of Information Need (LOIN). The LOIN is a way of defining how much information is needed for a specific purpose. It helps to ensure that only the necessary information is delivered, avoiding the delivery of too much information which can be wasteful. In the DBL, the LOIN consists of three levels. The first level is alphanumerical data sets, also referred to as semantic data, while the second level is geometric data sets that provide explicit information about locations or shapes. Lastly, the third level is represented by documents that contain unstructured information.

The proposed DBL framework considers all three levels and also incorporates a combination of meta-level and content-level information.

The last principle, keeping data at its source, emphasises that rather than exchanging or transferring data by copying it, the focus needs to be on sharing and linking to the data in its original location. This approach reduces the need for creating multiple copies and requires distributed or federated solutions where data is made available without being centralised.

On top of these principles, a DBL should be designed and implemented in a way that makes it easy to share and reuse data across different systems and applications. It should have metadata that is clear and consistent, data formats that are standardised, and licensing agreements that are proper. Additionally, the DBL should be structured in a way that makes it easy to integrate with other building management and maintenance systems such as HVAC or lighting systems. This will enable more efficient building management and maintenance.

Moreover, the DBL should provide a user interface easy to understand and use and should provide also internal storage to support some services such, for example, a renovation roadmap, indicators calculation, and others.

We summarise the DBL definition we presented here and in the other sections within this article in Fig. 3.

5. Challenges and future research

In this section, we will review all the future research proposals and posed challenges related to the DBL that we found in the analyzed scientific papers to give some directions for the forthcoming research works that deal with DBL.

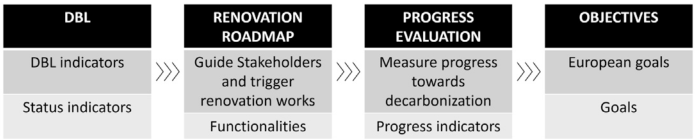

Fig. 4. Future research scheme extracted from [15].

In the EU Commission "Study on the Development of a European Union Framework for Buildings' Digital Logbook", and particularly in the final report [11], the authors introduced nine gaps that need to be addressed to support the widespread of the DBL at EU, national, regional and sectorial levels. These nine gaps are:

- Lack of a sound funding model,
- DBLs benefits not being clear to all the stakeholders,
- Inconsistency around the scope and purpose of the logbook,
- User-friendliness not optimised,
- Barriers to updating the DBL,
- Challenges linked with interoperability of the repository,
- Issues with data governance,
- Lack of defined legal framework,
- Uncertainty around the role of EU and MS level policy.

Moreover, the report highlights that to support the harmonisation and standardisation process for the DBL would be helpful to create a standardised dictionary of all building-related terms that may be used in the DBL initiative and define how they should be understood and used. This will help establish a semantic data model of the core DBL elements.

In [15] the authors proposed a schema (shown in Fig. 4) for future research that starts from a clear definition of the DBL indicators, through which the involved stakeholders will define some renovation roadmap with functionalities based on the collected indicators. Then, following the defined roadmap, it should be possible to measure the progress toward a more sustainable and green building by the indicators values. These steps will have the final purpose of meeting the European goals like the one for GHG emission reductions and more.

In another article [16], it is raised the issue for future research of the DBL integration with the DT and the DDT. As DT, DBL, and DDT are three concepts with various overlaps, the authors proposed to examine different case studies to precisely determine the intersections of data among these concepts. At the DBL level, it is proposed to identify the appropriate data for collecting and developing a framework for organising, managing, capturing, and sharing data to be used for integration with the DT and the DDT.

Moreover, as we found in [10], the primary objective of future research is set to establish a precise collection of indicators that are appropriate for the DBL's forthcoming services. These services will include, among others, the generation of a maintenance and renovation plan, the update of the EPC, and the assessment of the decarbonisation progress. Additionally, future research will encompass the comprehensive definition of the European DBL architecture, starting with the analysis of data sources.

In [22] and [23] the proposed BIM-toolkit will be utilized to manage renovation projects for a significant number of buildings constructed in the past century that require improvements in their performance and quality. The distinctive interoperability characteristics of the toolkit will enhance the exchange of information among the applications involved, including the DBL. To enhance this exchange, an ontology was developed to support future data standardisation. Moreover, the toolkit will support future research in the integration of real-time data to monitor the status of a building.

In [28] it is highlighted how in cities, due to the digitalisation in various sectors, the amount of data will increase and this will raise the need to combine data sources and increase data quality to support various decision-making situations related to different contexts. One of them, for example, may be the usage of geospatial data that can intersect with the development of DBLs.

Authors in [24] presented a work about Traditional Historic Buildings (THB) that emphasises that DBL, combined with the DT, should become an essential tool for monitoring the condition of historical buildings. In this context, the DBL can be important because it can help to identify and categorise situations that pose a risk to THB and it can support planning long-term maintenance, renovations, and structural consolidation to enhance the quality of the buildings. The DBL also aids in achieving maximum energy efficiency levels and reducing seismic vulnerability, enabling THBs to adapt to modern standards.

Then, authors in [18] indicate that future research will focus on rethinking the relevant indicators for the DBL, based on existing literature and DBL models, as well as exploring new approaches like assessing decarbonisation progress, gathering information necessary for designing a renovation roadmap or conducting lifecycle assessment. Moreover, further steps will be taken to address interoperability issues by investigating how to interconnect existing and forthcoming data sources with the DBL.

Future research on the Spain logbook LdE-e presented in [19] should focus on different topics, including investigating the cost and financing aspects, addressing regulatory barriers, adapting legislation to accommodate the LdE-e, establishing an effective governance structure, exploring BIM implementation policies, and, mainly, in integrating additional data packages such as financial analysis and value increase evaluations to enhance the logbook's services for owners, public administration, and stakeholders in the sustainable real estate market.

We summarised and grouped the challenges and future research proposed in the analysed scientific articles in Table 2.

Table 2
Challenges and future research within the analysed scientific articles. PI = Propose Indicators, IPS = Improve Provided Services (e.g. Renovation roadmap), REG = Reach European Goals, DTI = Digital Twin Integration, ADS = Analyse Data Sources, DS = Data Standardization, DI = Data Interoperability, SMD = Semantic Model Development.

	PI	IPS	REG	DTI	ADS	DS	DI	SMD
EU - Study on the Development of a European Union Framework for Digital Building Logbooks Final Report					X	X	X	X
Review and Analysis of Models for a European Digital Building Logbook	X	X	X					
Incremental Digital Twin Conceptualisations Targeting Data-Driven Circular Construction				X	X			
The Digital Building Logbook as a gateway linked to existing national data sources: The cases of Spain and Italy	X	X	X		X			
An interoperable BIM-based toolkit for efficient renovation in buildings						X	X	X
The Development of a BIM-Based Interoperable Toolkit for Efficient Renovation in Buildings: From BIM to Digital Twin						X	X	X
Opportunities of collected city data for smart cities					X		X	
Digital Twin solutions to historical building stock maintenance cycles		X		X				
Contribution of New Digital Technologies to the Digital Building Logbook	X	X			X		X	
Libro del Edificio Electrónico (LdE-e): Advancing towards a Comprehensive Tool for the Management and Renovation of Multifamily Buildings in Spain		X						

6. Discussion

The presented survey article aimed to provide a comprehensive overview of the existing research on DBLs and their related concepts. However, it is important to acknowledge the limitations inherent in the evidence included in this review and the processes used.

One notable limitation is the scarcity of scientific papers specifically focused on DBLs. The concept of DBLs is still relatively new, and the adoption and research surrounding it are in the early stages. Consequently, the available literature on DBLs is limited, which poses challenges in terms of obtaining a broad range of studies for analysis. Despite this limitation, this survey paper contributes to the field by presenting almost all the available contexts and concepts that intersect with DBLs, thereby offering a comprehensive understanding of the topic. Furthermore, the reliance on a limited number of databases, such as Scopus and Web of Science, for data collection may have led to the inadvertent exclusion of relevant studies published in other sources. While efforts were made to ensure a thorough search strategy, the possibility of missing some studies cannot be completely ruled out. However, it is important to note that Scopus and Web of Science are widely recognized databases in the academic community and cover a significant portion of relevant scientific literature.

Another aspect to consider is the potential bias introduced during the data collection and analysis process. Despite efforts to maintain objectivity, the interpretation and extraction of data from the selected studies can be influenced by subjective judgments and researcher bias. However, to mitigate this, a team of experienced reviewers was involved in the data collection process, working independently and engaging in regular discussions to reach a consensus on any discrepancies.

While acknowledging these limitations, it is worth emphasizing that the strength of this survey paper lies in its ability to present a comprehensive overview of the context, concepts, and available research on DBLs. By synthesizing the existing evidence, this review provides valuable insights for researchers, practitioners, and policymakers in understanding the current state and potential future directions of DBL research.

In conclusion, while the scarcity of scientific papers and the inherent limitations pose challenges to this survey article, the comprehensive nature of the presented context and concepts surrounding DBLs enhances its significance. Future research endeavors should aim to address these limitations by expanding the body of scientific literature on DBLs, thus further advancing knowledge and understanding in this important domain.

7. Conclusions

We are in a context in which a rather outdated building stock, with deficient energy performance characteristics, together with an energy crisis and climate change impact reduction targets are coinciding.

Different initiatives are arising at the international, national, and regional levels, which address these problems and propose an efficient renovation of the residential stock. Targets such as GHG emission reductions and net carbon neutrality are on the agenda of many of these initiatives.

Along with these initiatives, the DBLs are emerging, a concept that suggests a common repository for the aggregation and retrieval of relevant building documentation, allowing on the one hand a history of data and on the other hand having relevant information to support decision making and planning actions: maintenance, renovation or energy efficiency, among others.

Within these data and documents, there are not only BIM models but also EPCs, BRPs, and SRIs.

Another main element of DBLs is the possibility to share information among different stakeholders so that the activities to be performed can be coordinated efficiently. Building owners and occupants can collaborate with each other and with service providers, public bodies, and other stakeholders so that decisions are informed and traceable.

This article focuses primarily on this element, on the DBL, and on the efforts being made in Europe for its definition, integration, and implementation.

We have started with a review of the state of the art. The term Digital Building Logbook is still a relatively new term in the construction sector. While in other sectors maintenance and lifecycle monitoring logbooks are common, in the construction sector the closest approximation was the maintenance books that some buildings keep. We have obtained more than a dozen reference documents and articles related to DBL, which we have enriched with official initiatives and research projects.

Since our goal was to present a survey of the current state of the art of DBL, we have analysed these sources and labelled them in several categories (e.g. according to data sources, their integration with BIM and DTs, or the use of semantic analysis techniques). We then went into detail on each of these categories and analysed how they were addressed in each article and initiative.

We started with the comparison and analysis of several initiatives and funded projects to see the current state of research in DBL. We then classified the data sources into different groups and then focused on the indicators, which are key and common elements in multiple initiatives related to DBL. We analysed and grouped them into nine different categories, including information on efficiency, energy, sustainability, and others. Lastly, we explored how a DBL can be integrated into an ecosystem that includes BIM and DTs, given that both are becoming more and more rooted in the construction sector, to conclude with an analysis of the possibilities related to the integration of semantic technologies that allow interoperability.

During the process of preparing this survey, we have not only analyzed and compared the state of the art. We have also tried to discover the challenges that arise when designing or developing a DBL. For this, we started not only from the state of the art but also from the document *“Definition of the digital building logbook”* of the European Commission. We have defined eight challenges to be taken into account, among them challenges of integration and interoperability, or even of data models and formats. On the latter, we have also included our contribution. We consider a DBL as an element that has to support not only the data available today but also has to be open to future formats and data, therefore, based on literature and initiatives, we have detailed the types of data that DBLs should support.

Overall, the process of analysis and comparison has also helped us to identify some immediate points, which may cause functional limitations or even implications in the use and growth of DBL.

Apart from the already mentioned openness to support different types and formats of data (structured and unstructured or even data streams from sensors), the integration and interoperability, and the symbiotic relationship with the DTs. There is a clear problem of lack of standardisation and agreement on what a DBL entails and what a DBL has to provide. Documents such as the one mentioned above from the E.C. are a good starting point. Still, throughout this document, different approaches can be observed: from DBLs oriented to be a data repository to almost being a *de facto* Digital Twin enhanced with a few documents.

This issue is also related to the overlapping of the functionalities of DBLs with other tools being used in the construction industry. It seems to us that, as the functionalities are unclear, there is some overlapping with, for example, CDEs, Construction Management Software type solutions, and even in some cases Building Management Software. This is a key point that needs to be addressed in the future.

In addition to these previous points, and as the next activities, we consider the enrichment of the DBL data by means of Big Data techniques and solutions interesting. Also, as we have already mentioned, the idea of linking DBL research with semantic analysis can contribute to the organisation and sharing of information stored in the DBL. Finally, the representation and consumption of DBL information is an important point to address, especially given the multiple data and formats (from key-value pairs to 3D models) that can be stored.

In general, this article presents one of the first overviews of the field of DBLs, starting from public documents and initiatives, articles, and projects, comparing a number of them and detailing some of the challenges that can be encountered when researching, designing, or developing a DBL.

CRediT authorship contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

No data was used for the research described in the article.

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Appendix A. Acronym

In Table 3 we included the list of acronyms we reported in the paper.

Table 3
Acronyms defined along the paper.

Acronym	Description
GHG	Green House Gas
GWP	Global Warming Potential
RICS	Royal Institution of Chartered Surveyors
D&C	Design and Construction
IEA	International Energy Agency
EU	European Union
GDP	Gross Domestic Product
EPBD	Energy Performance of Buildings Directive
DBL	Digital Building Logbook
EPC	Energy Performance Certificate
BRP	Building Renovation Passport
SRI	Smart Readiness Indicator
PTNB	Digital Transition Plan for Buildings
RLBA	Residential Logbook Association
SRR	Scheduled Renovations Roadmap
LdE-e	Libro del Edificio Electrónico
DDT	Digital Data Templates
DTC	Digital Twin Conceptualisations
DT	Digital Twin
BDT	Building Digital Twin
BIM	Building Information Modelling
BIMMS	BIM Management System
LOI	Level Of Information
AEC	Architecture Engineering and Construction
NFT	Non-Fungible Token
API	Application Programming Interface
PVT	Planning and Verification Tool
VM	Virtual Marketplace
API	Application Programming Interface
CDE	Common Data Environment
RDF	Resource Description Framework
SRI	Smart Readiness Indicator
CENED	Certificazione Energetica degli Edifici
IoT	Internet of Things
AI	Artificial Intelligence
VR	Virtual Reality
AR	Augmented Reality
DPP	Digital Product Passport
IFC	Industry Foundation Classes
BAS	Building Automation System
HVAC	Heating, Ventilation, and Air Conditioning
KPI	Key Performance Indicator
SoS	System of System
BOT	Building Topology Ontology
OWL	Web Ontology Language
MS	Member States
THB	Traditional Historic Buildings
LOIN	Level Of Information Need
DR	Document Repository
IDS	Interconnected Data Structure
CDH	Certificate of Occupancy
IITE	Technical Building Inspection Report

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