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Twinning the path of digital building permits and digital building logbooks – Diagnosis and challenges

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ABSTRACT

In the context of the European Union's push for a sustainable and digitally integrated construction sector, this research explores the relationship between Digital Building Permits (DBP) and Digital Building Logbooks (DBL). The study aims to diagnose and identify the synergies and challenges in aligning these data-driven concepts throughout the building life-cycle. Using a focus group methodology, the research gathered qualitative data on the perceptions of DBP and DBL among professionals with diverse backgrounds. The findings reveal significant overlaps and potential for integrated data management, enhancing regulatory compliance, efficiency, and sustainability. While DBP and DBL can function independently, their full potential is realised through a cohesive framework that supports continuous data updates and stakeholder collaboration, facilitating the "golden thread" of information essential for effective digital twin applications. Future research should further explore the detailed processes and data exchanges necessary to implement this framework successfully.

1. Introduction

Despite the histories of success, the construction industry's digital transformation has only sometimes been a frontrunner in the European Union (EU) (Papadaki et al., 2023). However, a new push has come with the Green Deal, where digitalisation is meant to support a more sustainable, efficient, and waste-friendly built environment (European Commission, 2019). This vision brings new and additional requirements more focused on environmental targets and circular economy goals (De Wolf et al., 2023). The ability to collect, exchange, track, and trace data throughout processes becomes paramount. As a result, planning the future of construction is not only about setting new actions and commitments but also about aligning efforts to identify and close critical gaps (Papadaki et al., 2023). Digital Building Permits (DBP) and Digital Building Logbooks (DBL) are determinant elements relying on efficient and smart data management. As such, alignment efforts must be performed, seeking the touch points and overlaps in data, processes, stakeholders, and technology to observe the synergies and set contributions defining and streamlining the role and objectives of each throughout the building life-cycle.

Permitting is the act of allowing someone to do something based on a set of rules that need to be confirmed (Cambridge University Press, n.d. b,). Building permitting constitutes the authority of the local administration based on applying the measures laid down by law, aiming to secure the safety, sustainability, and compliance of buildings with the regulations (Fauth et al., 2024). This means that the building permitting process depends highly on the rules set by the law, either in the aspects to be observed or in the phases or milestones where these need to be checked (Nisbet et al., 2009). Building permitting can be defined as a crucial set of specific steps, well defined in time, where all relevant laws and regulations that ensure construction are enforced (Bloch and Fauth, 2023). A logbook is an official document that records information related to a physical asset (Cambridge University Press, n.d.a). Building logbooks have existed since ancient times, and although the term "logbook" is often not used, what we can find in construction legacy elements or archives is the result of efforts to accomplish that definition. Building logbooks are also set in the EU or country-level legal framework, with more or less detail and focusing on one or several specific topics (Mêda et al., 2023). Details appart, the goal is to compile official documentation related to the asset characteristics for various purposes materializing a repository.

Digital transformation goals for construction seek to improve the

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efficiency of the construction process and, at the same time, use and integrate new technologies that allow a new set of processes, the collection of more data, and the development of analyses that were not feasible some years ago (Samuelson and Stehn, 2023). The DBP outbreaks use digital data as input and output and digital tools to support or automate checking to tackle current limitations derived from analogue documents and processes (Malsane et al., 2015). The DBL aims to set a common framework, expanding the purposes, uses, data collection and integration capacities associated with building characterisation and information. In essence, it aims to materialise the "golden thread" advocated by Hackitt (2020).

DBP and DBL are data-driven concepts. Although the relationship might seem obvious, the existing research lacks in providing their positioning. A gap was observed when seeking overlaps, potential relationships, challenges, and the added-value deriving from mutual developments and implementation. Considering previous research on the subjects and the concern expressed in the transition pathway when it mentions "aligning efforts and identifying and closing critical gaps" (Papadaki et al., 2023), the present work seeks to understand how the industry perceives both concepts and sees the relationship, as well as what can be done to align efforts and work the gaps. Considering these concerns as the motivation, the objectives can be summarised by the following Research Questions (R.Q.).

- RQ1: Are DBL and DBP related concepts? If yes, what relations do they have?
- RQ2: What challenges derive from it at the Data, Technology, Stakeholders, and Processes levels?
- RQ3: What is needed to work further on the potential alignments in strategic and regulatory documents?

The article offers several key contributions to the common understanding and implementation of DBP and DBL. Firstly, it explains DBP and DBL, clarifying their definitions, purposes, and roles in the construction industry's digital transformation. Potential relationships and overlaps are explored, examining how they complement each other in construction processes and life-cycle management of built assets. Furthermore, it discusses the challenges associated with integrating DBP and DBL, categorising them into data, technology, stakeholders, and processes. Insights into these obstacles are provided to facilitate effective transformations. Additionally, the article investigates the construction industry's perception of DBP and DBL, offering insights to align efforts and understand gaps, thus supporting a more sustainable, efficient, and transparent built environment.

Following this introduction, the organisation of the work is composed of Section 2, in which the research design and methods chosen are explained. Section 3 presents a systematic perspective of the construction process and information exchanges surrounding the two concepts under discussion. According to the research framework, diagnosis and reflections are performed individually to expose a joint intuition-based reflection. This constitutes a core part of merging the background of DBP and DBL with the perceptions motivating the action using a workshop, detailed in Section 4. It follows with a summary of all the findings, clustering the action contributions and visions based on all aspects shared. The article concludes with Section 6, where limitations and future research activities are listed, as well as the research's main contributions to the body of knowledge.

2. Research design and methods

This research aims to effect changes in DBP and DBL understanding and how they align through the life-cycle of construction entities. Considering all the strategic changes at the EU level, the CIFE Horseshoe Framework was selected as the guiding research framework, given its potential to structure a transdisciplinary research process (Kunz and Fischer, 2007). Intuition is the critical driver for observing the problem, setting the departure point for the research under the framework's first steps (Fig. 1). In this respect, and aligned with the research questions, is the notion that DBP and DBL share data, meaning that some relation should exist. Action Research is used as the main method, adopting a critical/pragmatic paradigm given the lack of awareness regarding the strategic and regulatory alignment if the intuition is proved. According to Fellows and Liu (2022), action research involves active participation by the researchers in the process under study to identify, promote, and evaluate problems and potential solutions (Fellows and Liu, 2022). Its primary purpose is also to effect change, requiring collaboration between researchers and individuals (Lewin, 1958). The critical/pragmatic paradigm option underpins investigating the situation to pursue improvements (Fellows and Liu, 2022).

Following the systems model of action research (Christie, 1992), the input/planning stage comprises systematic perspectives on DBP and DBL. An initial diagnosis and a brief review of relevant literature provide the ground for individual reflections. The plan for the action derives from the final reflection, combining both concepts. The action/transformation stage is composed of a focus group assuming the form of a 90-min online workshop with a structure aiming to produce an iterative diagnosis and data collection process. The participants were invited via email for this event on the 27th of October 2023. A sound knowledge of at least one of the concepts under discussion was a prerequisite for participation. Eighteen individuals were engaged in most activities, positively framing them according to this research's best practices (Jain, 2023). Aligned with the research questions, the goals for the workshop, presented in the beginning, were the following.

- Seek for DBL and DBP connections, and
- Identify or (at least) launch the discussion regarding common requirements, technological features, processes, and regulatory framework.

The workshop structure was established based on several characteristics addressed by Jain (2023) and promoting iterative steps deriving from previous reflections. In brief and as it will be detailed, the workshop was composed of an initial survey, summary presentation of the topics, moderator-led discussion focusing on DBP and DBL data, technologies, stakeholders, processes, and legal framework, sharing open thought, and a final survey partially repeating some of the initial questions. The initial survey comprised a sequence of open questions, launched for contextual understanding and collecting initial and unbiased quantitative and qualitative data regarding the subjects under discussion. Exploration of perceptions and analysis of these contributions opened the way for DBP and DBL overview presentations. The objective was to increase the knowledge maturity levels of the audience and set the background for the moderator-led discussion phase. The discussion part represented more than one-third of the event's duration. Its organisation aimed to collect qualitative data on the potential links between DBL and DBL and requirements at data, technology, stakeholders, and process levels. Questions on the future regulatory framework supporting the concepts were raised. The final part involved sharing open thoughts and conducting a second survey to assess the differences of opinion derived from the event and collect improved DBP and DBL impressions.

The outputs/results comprise the discussion of all impressions and the results of two surveys. Cross-analysis is made for the repeated questions. Cluster analysis (Romesburg, 1984) of the contributions by topic was performed to set the main DBL and DBP characteristics. This was made using all the contributions achieved for each topic. A similar process was performed at data, technology, stakeholders, process, and legal framework levels, seeking common aspects and overlaps, as well as concerns applicable to a single level. These clusters were formed directly from the sequence of topics addressed during the moderators-led discussion. From this, a conceptual vision of the main identified aspects (assumed as challenges and requirements) is aligned with different

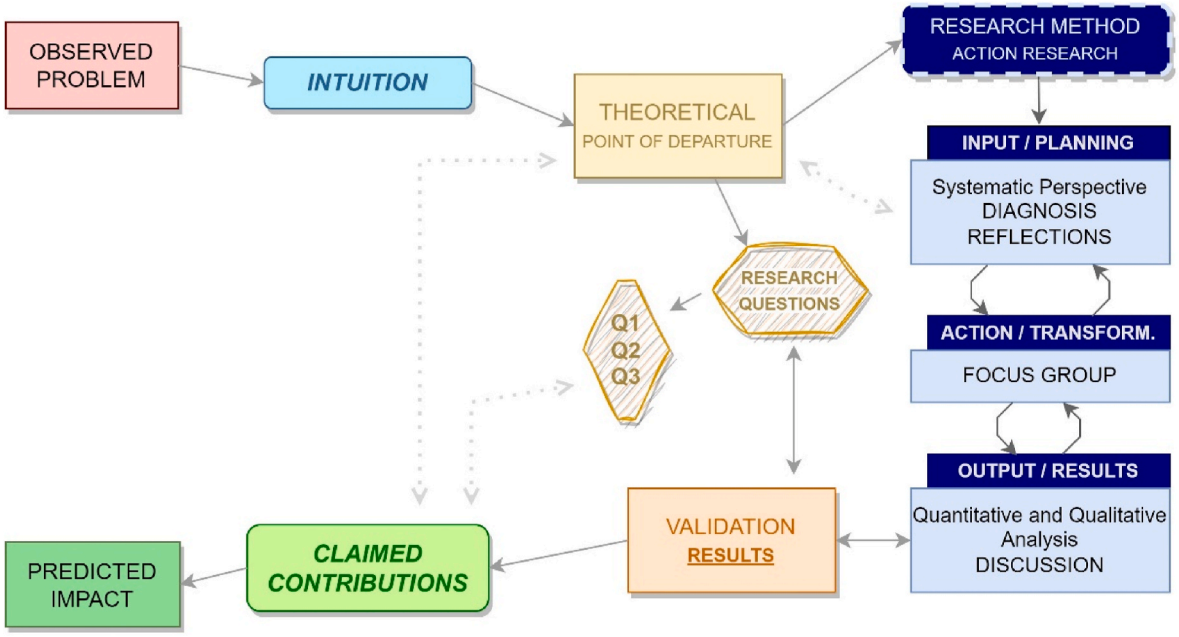

Fig. 1. Action Research method embedded in CIFE Horseshoe Research Framework.

dimensions and a proposal for a framework linking DBP and DBL throughout the construction process and building life-cycle.

3. Systematic perspective

3.1. Construction value-chain and information production

Before becoming real and useable, buildings and civil engineering works must be strategically defined, technically detailed, and constructed (Eurostat, 1998). This sequence of events is part of the construction sector value-chain practices as a way to iteratively "mature and realise" the idea. The underlying processes involve the production of large amounts of information. If this was entirely materialised in paper some decades ago, now it can vary substantially from a mix of paper and digital documentation to digital documents, metadata, and models (Bernstein, 2018; International Standards Organization, 2018). Recent events reveal how this way of managing information, combined with the increasing requirements to be observed, can lead to flaws, mistakes, and, ultimately, tragedies (Hackitt, 2020; Ozturk, 2020). Unquestionably, all built assets are mirrored by a structure of information that aims to forecast, record, or simulate relevant characteristics of the assets to be built. It is also unquestionable that compliance checks, authorisations, and certifications are made and issued upon this.

If changes cannot be tracked, the abovementioned actions can be questioned as there is no way to confirm to which extent the changes can produce harm or compromise specific requirements. For the construction sector to build assets, it must produce massive amounts of data (Svetel and Kosić, 2022). A detailed perspective on how the information is produced, by whom, for what purposes, and for which life-cycle phases is essential for understanding the problem. In the definition phase, the objectives and requirements for the project need to be set, namely the location, the purpose, the type and level of service, the overall technical characterisation, the existing space, and the budget, among many others.

Considering, as an example, a process for a school building and applying some of the mentioned aspects, there must be a definition regarding the type of school (kindergarten, primary school, university), number of students, type of facilities (laboratories, I.T. classroom, sports room), organisation, main areas, number of classrooms, and viable budget, to name few. Once the project objectives, requirements, and constraints are agreed upon, it is possible to proceed with the design process. This comprises different phases, where the idealised requirements will be detailed, virtually materialised, and technically translated into construction solutions by designers. All these elements compose a significant amount of information that should be well documented and organised to be kept, further detailed, or changed during subsequent phases. Before construction starts, several moments may exist where public authorities or other stakeholders perform compliance checks to assess viability concerning the land's constructability and potential uses, construction codes, or financial evaluation. These processes often imply exchanging project information and performing technical analysis to observe if compliance is assured, resulting in issuing a certificate or approval. During the construction phase, new requirements are set, detailed, confirmed, or changed, meaning that information related to the object being built, its components and activities, and involved stakeholders is added or versioned. At this point, it is essential not to forget compliance issues associated with the construction activity and the mandatory deliverables, as they can have a similar process regarding information exchange and authorisation/certificate issuance, as mentioned. This situation extends to the moment of handover when all related information should be delivered together with the built asset. Permits issuing might exist during handover. Throughout the use phase, stakeholders will need to use the information produced for different purposes, from maintenance to systems operation, recall after components replacement, or development of pre-deconstruction audits prior to interventions. In addition to the issues of collecting, structuring, tracking, and tracing information, it is relevant to set the data ownership and/or responsibility framed by purposes as the following examples.

- Information associated with fire safety regulations to firefighters' authority and for final approval before use,
- Information from contractors and sub-contractors for public authorities' verification of working conditions (health and safety compliance in construction sites),
- Thermal conductivity (U-value) properties of relevant products to develop the energy performance certificate,
- Information from the different construction products for owners to detail the asset management strategy or renovation works, and
- Update the idealised requirements to become part of the owner cadastre system.

The industry's sustainability challenges also rely on improving its capabilities in terms of information management and tracking (Gómez-Gil et al., 2022; Ataide et al., 2023). DBP and DBL are two critical instruments for this accomplishment.

3.2. DBP diagnosis

Issuing a permit for a building, independently of the phase, is a crucial milestone for any construction process. Despite being a small part of the mentioned life-cycle, all relevant laws and regulations that ensure construction quality, user safety, and environmental safety, among others, are enforced (Bloch and Fauth, 2023). Given the tight bond with the regulatory landscape, a permit is understood differently from country to country, assuming very different requirements and moments during the construction process life-cycle. In addition, depending on the compliance checks to be made, the process can be lengthy, prone to errors, and overly complex (Ataide et al., 2023). According to Eastman, the building permit process is among the most promising use cases for automation via digital processes and digital data about buildings and the built environment, bringing relevant savings concerning the current processing (Eastman et al., 2009).

To support a digital transformation in the building permit domain, a basis of knowledge was needed, including not only the technological aspects of supporting industry in the development of the systems infrastructure but also the involved procedures, legislation on different levels, and the involvement of various organisations (Fauth et al., 2024). The DBP gained a specific space and attention under the EUnet4DBP initiative (Noardo and Malacarne, 2020). Requirements and reviews were developed to clarify, provide awareness, identify common data and processes, and forecast common frameworks for DBPs (Noardo and Guler, 2022b; Fauth et al., 2024). DBP aims to streamline and automate the permit process, reducing the time and complexity involved. For instance, the taxonomy for building permit systems organises knowledge for building permit digitalisation, supporting various procedures, moments, and compliance checks in different countries within a common framework (Fauth et al., 2024).

Researchers have been exploring the issues and potential improvements in building permits for a long time and from different perspectives, such as processes, information technologies, relation with BIM, standardisation, automated compliance checking, and geographic information systems (GIS). For example, the process model for international building permit benchmarking provides insights regarding core problems by comparing the building permit process in Israel with other countries (Fauth et al., 2023a). Similarly, the ontology for building permit authorities (OBPA) uses tacit knowledge and data sets to enhance the assignment process in digital building permits (Fauth and Seiβ, 2023). Moreover, evaluating innovations in DBP highlights using advanced digital technologies for specific processes. This use of advanced technologies for an open BIM building permit process is described by Urban et al. (2024) and (Fischer et al., 2024; Urban et al., 2024).

In contrast, manual processes remain, indicating the potential to leverage digital permits to streamline the entire process (Ataide et al., 2023). Additionally, the research on the BIM-based building permit process identifies enablers and challenges, guiding stakeholders in the adoption of BIM-related processes aligned with permitting (Ullah et al., 2022). Understanding the current status, maturity, and prospects of digital transformation in building permits through a critical state-of-the-art review further underlines the significance of digital innovation in this domain (Noardo and Guler, 2022b). Ultimately, the promise of automated compliance checking and integrating GeoBIM highlight the opportunities and challenges in developing a high-level harmonised workflow for automating the planning permits process (Amor and Dimyadi, 2021; Noardo and Malacarne, 2020).

This perception stems from a search performed in multidisciplinary scientific databases such as Scopus and Web of Science (WoS) in March 2024. When performing a search querying "Digital Building Permit" in Web of Science (WoS), 487 results were obtained. Most were out of scope or only mentioning one of the words from the query. The list was analysed individually to confirm adhesion to the construction sector, leading to 14 valid results. The exact process was repeated using Scopus. From 190 results initially obtained, there was a complete overlap with the valid results, and three others were added. A possible explanation for the almost total alignment of the databases might derive from the topic's novelty and the concentration of sources (indexed in both databases). Table 1 summarises the results, highlighting the main contribution and notes on DBL.

It is relevant to mention that most research on "DBP" started in conference works and, more recently, gained relevance in journal papers. Except for one work published in 2016, the results date from 2019 onwards, with incremental growth since 2022, demonstrating the interest in the topic concerning the EU strategic trends. Table 1 integrates a column to highlight to which extent the DBL concept is part of the DBP research works. It is interesting to note that none of the others addresses the concept except for work from 2022, where the Digital Building Logbook is mentioned as part of the strategy for data traceability in construction (Noardo and Wu, 2022a). Some implicit references express that the data needed and produced during the permitting processes should be available and stored in a data repository, assumed as databases, BIM, or building information repository (BIR). This strengthens the intuition on the existing research gap, where the full integration of DBL and DBP processes is still underdeveloped or to be perceived, pointing to an area ripe for further investigation and development. VOS viewer software is used to conduct a visual analysis of the results. From Fig. 2, it is possible to identify three clusters of concepts. From a chronological perspective, it is interesting to note that concepts such as "paper" or "BIM" deserve to be highlighted. Others, such as "building permit", "permit process", just "process", or "building permit process", are presented as foundational concepts concerning the other clusters. Finally, when addressing the most recent terms, emphasis is placed on "digitalisation". "Building" alone is also a mentioned concept. However, it can appear in other clusters associated with other concepts.

Building permitting is undergoing a digital transformation, with some countries taking significant steps towards integrating Building Information Modeling (BIM) into the process. Singapore leads the way, having allowed the submission of BIM models as part of the permit documentation since 2016. The city-state's Building Construction Authority has developed guidelines for BIM submissions, and its CORENET e-Plan Check system automates much of the regulatory compliance review (Preidel et al., 2021). Recently, Singapore is working on CORENET X, providing advanced automated checks (Singapore BCA, 2022). In Estonia, a digital permit system was introduced in 2017, based on BIM principles, enabling stakeholders to submit documents electronically and track the process online. A prototype project launched in 2019 aims to create a software solution for BIM-based permitting, though full implementation is still pending. Since 2024, more than 40 regulations can be checked automatically against the building code. All building information goes to the national building registry as well as to the national digital twin project (e-ehitus teemaveeb, 2020).

Meanwhile, Finland is set to make BIM models mandatory for permits by 2025, becoming the first country to recognize the IFC format for archival purposes. Although some authorities already use BIM for compliance checks, a fully automated system has yet to be established (buildingSMART International, 2023).

Highlighting the European Union's commitment to streamlining the digital building permitting (DBP) process, several research initiatives are underway. The CHEK (Chek Consortium, 2023), ACCORD (ACCORD consortium, 2023), and DigiChecks (DigiChecks consortium, 2023) projects, running from 2022 to 2025, are exploring various aspects of digitalisation, including the automation of regulations, process digitalisation, ontological representations, and interoperability. Additionally, the "BRISE Vienna" project (City of Vienna, 2023), led by the City of

Table 1
DBP review systematisation, highlighting main contributions and notes on DBL.

Title	Contribution	Type	Ref.	Is DBL mentioned?
Taxonomy for building permit system-organising knowledge for building permit digitalisation	Taxonomy supporting a wide range of procedures, moments, and compliance checks in different countries, placed into a common framework.	Journal	Fauth et al. (2024)	implicit
Process model for international building permit benchmarking and a validation example using the Israeli building permit process	As-is building permit process in Israel to understand the singularities and the commonalities with other countries. A process model framework providing insights regarding the core problems.	Journal	Fauth et al., 2023a	No
Ontology for building permit authorities (OBPA) for advanced building permit processes	Ontology for the assignment process in digital building permits using tacit knowledge, data sets and a sample case study (implementation and test).	Journal	Fauth and Seiß (2023)(Fauth and Seiß, 2023)	No
Digital Transformation of Building Permits: Current Status, Maturity, and Future Prospects	Evaluation of innovations, namely using advanced digital technologies for some “pocket" processes, while manual processes remain. Leveraging permits to streamline the entire process.	Journal	Ataide et al. (2023)	implicit
The unbalanced research on digitalisation and automation of the building permitting process	Fundamental research and individual investigation of the sub-processes involved in a building permit hindering digital adoption. Detailed mapping of the sub-processes supporting filling the gap.	Journal	Bloch and Fauth (2023)	No
Understanding processes on digital building permits - a case study in South Tyrol	BIM-oriented building permit review using qualitative expert interviews from a specific location to define the classification of the information needed and compare it with other realities.	Journal	Fauth et al. (2023b)	implicit
Conceptual Framework for Building Permit Process Modeling: Lessons Learned from a Comparison between Germany and the United States regarding the As-Is Building Permit Processes	By-right and non-by-right cases of building permits are compared using Germany and the USA as cases to obtain knowledge and an overview of lessons learned that can be widespread.	Journal	Fauth and Soibelman (2022)	No
Unveiling the actual progress of Digital Building Permit: Getting awareness through a critical state of the art review	State-of-the-art regarding digital building permits using critical analysis of the literature and an overview of the main aspects discussed and their relevance for future adoption.	Journal	Noardo and Guler (2022b)(Noardo and Guler, 2022b)	implicit
The BIM-Based Building Permit Process: Factors Affecting Adoption	Identifying enablers and challenges respecting the BIM-based building permit process and guiding stakeholders in adopting BIM-related processes aligned with permitting.	Journal	Ullah et al. (2022)	implicit
IFC models for semi-automating common planning checks for building permits	A bottom-up approach setting data availability as a starting point and working alignments with IFC to scale, and ensuring widespread process reusability.	Journal	Noardo and Wu (2022a) (Noardo and Wu, 2022a)	Yes, strategic vision
The promise of automated compliance checking	Review of evolving approaches for automated compliance checking presenting main challenges and forecasting future pathways.	Journal	Amor and Dimyadi (2021)	implicit
A reformative framework for processes from building permit issuing to property ownership in Turkey	The reformative framework proposition for the building permit process in Turkey based on 3D city model databases (challenges and enablers).	Journal	Guler and Yomralioglu (2021)	Implicit, Building Information Repository
Opportunities and challenges for GeoBIM in Europe: developing a building permits use-case to raise awareness and examine technical interoperability challenges	Exploring GeoBIM opportunities and challenges through the demonstration of a high-level harmonised workflow for automating the planning permits process.	Journal	Noardo et al. (2020)(Noardo, 2020)	Implicit, Repository
Integrating expertises and ambitions for data-driven Digital Building Permits - The EUnet4DBP	EUnet4DBP workshop results identify the process, rules and requirements, technology levels, and plans for future activities for the network.	Conference	Noardo and Malacarne (2020)(Noardo and Malacarne, 2020)	No
GeoBIM for Digital Building Permit process: Learning from a case study in Rotterdam	Development of a methodology integrating various data sources (BIM and GIS) for the specific case study of the municipality of Rotterdam, highlighting the interpretation and formalisation of regulation for building height, overhang and tower ratio.	Conference	Noardo et al. (2020)(Noardo et al., 2020)	No
BIM for public authorities: Basic research for the standardized implementation of BIM in the building permit process	Information requirements for the implementation of a BIM-oriented building permit	Conference	Plazza et al. (2019)	No
Translating building legislation into a computer-executable format for evaluating building permit requirements	Translation of a “traditional" building act into a computer-executable format focused on the building permit requirements, namely automated design assessment.	Journal	Lee et al. (2016)	Implicit, building act database

Vienna as an Urban Innovative Action until 2023, investigated the use of open BIM to optimize the building permitting process in Vienna. These efforts reflect a coordinated push towards enhancing the efficiency and consistency of DBP across the EU.

3.3. DBP reflections

The following section aims to provide reflections anchored on the review of scientific works, EU reports, and the authors' knowledge of the foundational characteristics of DBP. These reflections are intended to identify and address existing gaps in the current framework. DBP encompasses a comprehensive range of building permitting processes, from the early design phases to the handover and commissioning of buildings or infrastructure. These processes are primarily driven by regulatory obligations and managed by public authorities or designated bodies. Despite regional variations in information requirements and compliance checks, there are significant similarities in how these processes should operate. The efficiency and success of DBP are closely tied to the ability to streamline these processes within a constrained timeframe. A key aspect of issuing permits is the structured collection and

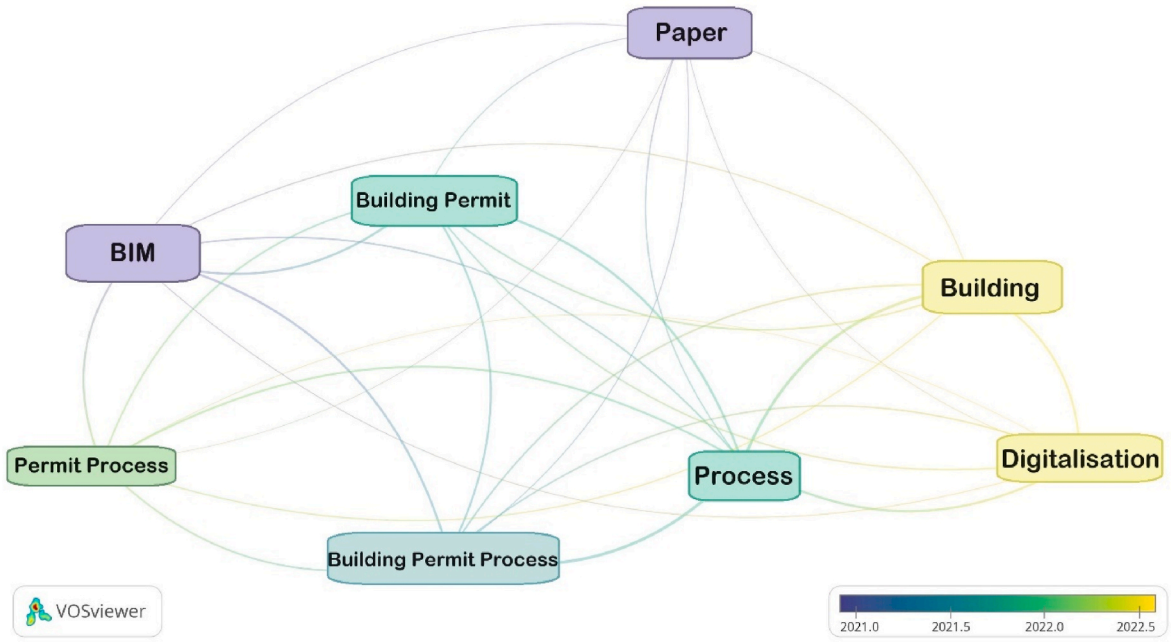

Fig. 2. Network map using VosViewer of the most relevant concepts associated with DBP research works considering the time frame of their publication.

storage of relevant information, which must be maintained throughout the construction life-cycle. As buildings frequently undergo modifications and may require additional permits, having immediate access to historical data is highly beneficial.

In this context, the DBL concept becomes increasingly relevant for DBP. DBLs ensure comprehensive records of all building-related information are maintained and easily accessible throughout the building's life-cycle. While explicit references to DBL are limited in existing research, the implicit need for centralised data repositories—often utilising databases, BIM, or building information repositories—is widely acknowledged. This highlights the necessity for a more integrated approach to managing and storing data generated during the permitting processes. A structured approach to organising knowledge for building permit digitalisation is essential. This approach supports many procedures, moments, and compliance checks within a common framework, facilitating efficient handling and storage of permit-related information. Comparing international building permit processes can provide valuable insights into standardising practices, ensuring that stored information meets diverse regulatory requirements and enhancing the overall utility of DBP.

Systematic data organisation significantly improves the management and retrieval of building permit information. This supports the integration of DBL, ensuring that all building-related data is consistently updated and readily available for compliance checks or future permits. Leveraging advanced digital technologies can further streamline the entire permitting process. Although some manual processes remain, the availability of well-organised data, as envisioned in DBL, facilitates this streamlining and enhances overall efficiency. Furthermore, developing ontologies for building permit authorities and evaluating innovations in digital building permits underscore the importance of advanced digital technologies in improving permit processes. These technologies help to automate compliance checking and integrate BIM and GIS, providing a more cohesive and efficient approach to permitting.

3.4. DBL diagnosis

The definition of DBL was first presented in December 2020 as part of the study's final report on developing a European Union Framework for DBL (Dourlens et al., 2021). One year later, it would become part of EU law with the publication of the revision of the Energy Performance of Buildings Directive (EPBD) (European Commission, 2021). Although very recent in terms of definition, the DBL aims to cluster and link functionalities and data fields/information that already exist in different databases, documentation, or records but lack some characteristics that are becoming critical. In addition, it aims to collect, store, and provide relevant information that often gets lost due to the absence of regulations or guidelines. Several recent initiatives contributed to the present understanding of the DBL concept. With a strong background in the real estate sub-sector, it is worth highlighting the developments surrounding the "building passport" concept (GABC and UNEP, 2021).

Another example is the work that led to the "renovation passport" concept, which focused on the strategies for refurbishing residential and non-residential buildings and fostering the reuse and recycling of components (Fabbri et al., 2016; Sesana and Salvalai, 2018). EU projects on the energy efficiency dimension also focused on the framework, data requirements, and challenges of collecting data to deliver digital energy performance certificates (EPC) (Gómez-Gil et al., 2022b; Malinovec Puček et al., 2023). The DBL aims to contribute to several EU initiatives by fostering data transparency and increasing data availability on buildings-related properties to market players, including property owners, tenants, investors, financial institutions, and public administrations (Dourlens et al., 2021). According to Gómez-Gil et al. (2022a), through the generation of high-quality data, the DBL will be able to produce the following services/objectives.

- To provide data to develop renovation roadmaps and maintenance plans,
- To enable the measurement of the progress towards decarbonisation, and
- To provide data for life-cycle assessment to promote circularity (Gómez-Gil et al., 2022a).

These represent the most relevant services/objectives if the focus is sustainability. Comprehensively, this dimension is very relevant and the major driver for the developments. However, DBL can have a relevant impact on other dimensions and opens a broad scope of possibilities.

The research community has been following DBL developments and providing insights on the potential contributions of this instrument for

the construction industry and built environment. Similarly to DBP, when performing the search query "Digital Building Logbook" in Scopus and WoS during February 2024, 17 and 9 valid results were found, respectively. Validation was performed by observing adhesion to the construction sector and by confirming the DBL concept on the title and/or in the abstract of each result. A complete overlap of the results between databases was noted. The observed differences are justified by the number of results corresponding to indexed conference papers that WoS did not capture. As it will be further detailed, the option was to proceed with the most extensive sample.

When looking at the results landscape, it can be observed that the topic has been approached almost as much in journal papers as in indexed conferences. Almost 90% were produced during 2022 and 2023, demonstrating how the topic is becoming more relevant and a growing trend in construction studies. As previously mentioned, when using VOS viewer software, Fig. 3, for the analysis, it is possible to identify two clusters of concepts that are more frequently addressed. In parallel, it is also possible to observe how these concepts are mentioned during the time frame from 2020 to 2023, demonstrating likewise a solid adhesion to the strategic trends.

The first cluster is composed of concepts more associated with the digital transition, such as "BIM", "Information Management", "Architectural Design", or "Project Management", and are prevalent in 2020 and 2021. "Digital Twins" is also part of this cluster, although relevance was only gained from 2022 onwards. The second cluster is associated with the green transition. Concepts such as "Energy Performance", "Energy Efficiency", "Energy Performance Certificate", "Building Renovation", or "Building Renovation Passport" gain relevance and attention from the research community. The abovementioned impressions are supported by the analysis systematised in Table 2., where all results are organised, and each work's contribution is summarised. From this, it is understandable that around 41.2% of the works derive from energy efficiency, sustainability, or circular economy concerns.

From the concept landscape, a small group belonging to one of the clusters responsible for setting the links is worth highlighting. These could be positioned at a different level and clustered as DBL foundational concepts. This group is composed of the "DBL" itself and the following: "Buildings", "Life-cycle", "Construction Industry", and "European Union". Their foundational characteristic could be translated in a sentence as follows: The Digital Building Logbook is an EU initiative aiming to leverage data management of buildings throughout their life-cycle, contributing to the sustainability of the construction industry.

As in Table 1, the DBP concept was also analysed in the results presented in Table 2. With the expectation of Mêda et al. (2022), permits are featured only as a topic in DBL research in 2023 and always as general references. It was observed that a significant number of works address other dimensions, such as data sources, data flows, information management, or digital technologies, and it is worth highlighting BIM, blockchain, and digital twins. In addition, several reports have been produced as part of EU initiatives (Grow, 2023).

As mentioned, despite the DBL novelties, several aspects have been a concern for a long time. Corporations and even countries started to act even before the beginning of most discussions around the topic, structuring and delivering initial tools to the market that aim to accomplish some functionalities and services now set for the DBL. At the country level, it is worth highlighting the e-construction platform led by the Estonian Government. Envisioned from 2015 (Estonian Ministry of Economic Affairs and Communication, 2018), the Estonian Government e-construction platform was structured to become a digital database for the built environment with the capacity to gather several services and provide the exchange of standardized and trustworthy data between all stakeholders throughout the building lifecycle (Pärn et al., 2022). This platform aims to cover also the permitting procedures. At the same time, and led by specific objectives, such as improving energy efficiency/digitalise energy performance certificates, improving the re-use of construction products or pursuing the implementation of a digital golden thread following the Grenfell Tower fire (Hackitt, 2020), several companies have developed specific tools. Chimni Residential Property Logbooks (Chimni (n.d.)), Capsa (2024), Cléa (Cléa - Qualitel, 2023) or Cirdax (2024) as some examples of developed software that partially cover DBL functionalities. The EU-funded Demo Blog project (Hwang, 2024) is one of the DBL projects that will assess how these and other tools comply with the DBL requirements, and which further developments are needed at the EU level (in terms of the framework) and software level.

The diagnosis of gaps for DBL accomplishment was performed as part of the EU framework for DBL, and it constitutes a relevant part of the reflections section. According to Dourlens et al. (2021), nine gaps were identified, ranging from financial, data, and legal aspects to user expectations. It is relevant to consider five of them, namely Gap #2 - DBL benefits not transparent to all the stakeholders, Gap #3 - Inconsistency around the scope and purpose of DBL, Gap #5 - Barriers to updating the DBL, Gap #6 - Challenges linked with the interoperability offered by the repository and Gap #8 - Lack of defined legal framework (Dourlens et al., 2021). A sequence of actions labelled "A" to "O" was also set to fill the gaps.

3.5. DBL reflections

The following section aims to provide reflections anchored on the review of scientific works, EU reports and authors' knowledge of the foundational characteristics of the DBL. These reflections also aim to deliver contributions that are aligned with the identified gaps. Most research works focus on individual DBL aspects, from the processes level

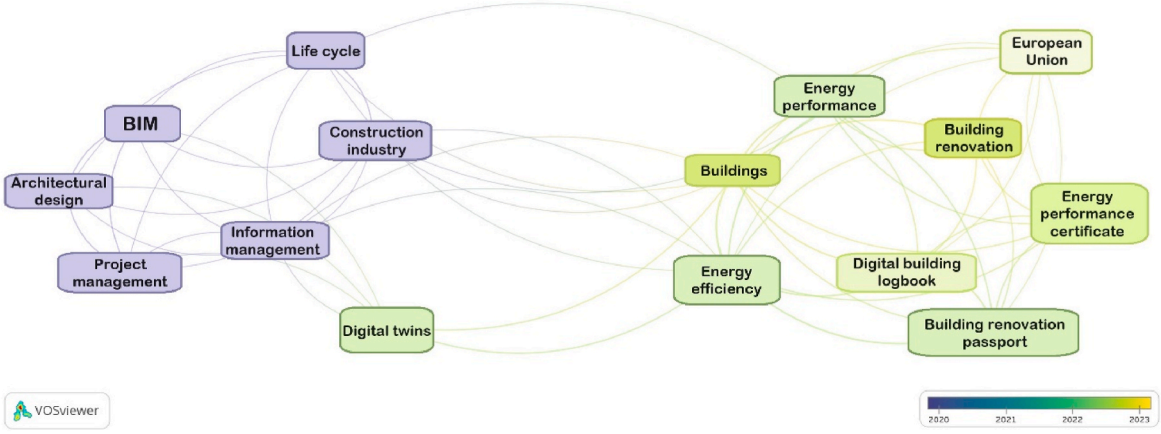

Fig. 3. Network map of the most relevant concepts from DBL research works considering the time frame of their publication (using VosViewer).

Table 2
DBL review systematisation, highlighting main contributions.

Title	Contribution	Type	Ref.	Is DBP mentioned?
Towards the definition of a European Digital Building Logbook: A survey	Identifying features and data sources to be considered when developing DBL based on review and survey.	Journal	Alonso et al. (2023)	Yes, in general
A Data Structure for Digital Building Logbooks: Achieving Energy Efficiency, Sustainability, and Smartness in Buildings across the EU	DBL data structure definition under the EUB SuperHub project, focused on energy performance, sustainability, and smartness.	Journal	Malinovec Puček et al. (2023)	Yes, datasets
Libro del Edificio Electrónico (LdE-e): Advancing towards a Comprehensive Tool for the Management and Renovation of Multifamily Buildings in Spain	Framework for a tool for Spain incorporating an energy led DBL and a renovation passport. Holistic, cloud-based and blockchain supported.	Journal	Espinoza-Zambrano et al. (2023)	Yes, datasets
European building passports: developments, challenges and future roles	Awareness of building passports focusing on main functions, milestones, information management, and relation with other concepts and initiatives.	Journal	Buchholz and Lützkendorf (2023)	No
Digital Twins as Enabler for Long Term Data Management Using Building Logbooks	Enabling DBL and Digital Twins using a multi-model-container (MMC) approach - building inspections as use case.	Conference	Al-Sadoon et al. (2023)	Yes, in general
Applicability of the European Union's Building Renovation Assessment Framework in Spain	Assessment of the Measurable Progress Indicators (MPI) for decarbonisation set under EU Recommendation 2019/786 in Spain, evidencing the DBL role.	Journal	Arbulu et al. (2023)	No
The Digital Building Logbook as a gateway linked to existing national data sources: The cases of Spain and Italy	Identification of the mutual connections to existing data sources and propose a general dataflow structure for the DBL in Spain and Italy.	Journal	Gómez-Gil et al. (2022)	No
Contribution of New Digital Technologies to the Digital Building Logbook	Identification of new technologies for digital data acquisition and analysis, focusing on circularity and energy efficiency. How DBL gathers data providing indicators.	Journal	Gómez-Gil et al. (2022a)	No
Review and Analysis of Models for a European Digital Building Logbook	Review of EU DBL models to summarise and compare available information.	Journal	Gómez-Gil et al. (2022b)	No
Circular Economy and Digital Twins in the Construction Sector	Identification of concepts surrounding twin transition and how they align with each other.	Conference	Alonso et al. (2022)	No
A process-based framework for digital building logbooks	Business model process notation for DBL, evidencing the links, data sources and interactions through the life-cycle.	Conference	Mêda et al. (2022)	Yes, process
Digital Twin application on next-generation Building Energy Performance Certification scheme	Exploring potential developments in digital technologies under the D^2EPC project, where DBL is a relevant element to set the EPC next-generation scheme.	Conference	Koltsios et al. (2022)	No
Boosting Research for a Smart and Carbon Neutral Built Environment with Digital Twins (SmartWins)	Simulation and assessment of sustainable energy for the built environment using BIM and Digital Twin - SmartWins project.	Conference	Fokaides et al. (2022)	No
Digital Twin solutions to historical building stock maintenance cycles	Challenges and benefits in digitalising historical buildings. Energy aspects using DBL.	Conference	Rosa (2022)	No
Trusted DBL: A Blockchain-based Digital Twin for Sustainable and Interoperable Building Performance Evaluation	Proposing the trusted DBL concept, explaining data flows and architecture using blockchain.	Conference	Niavis et al. (2022)	No
Incremental digital twin conceptualisations targeting data-driven circular construction	Framework to implement Digital Twin at the building level, exploring steps and key concepts, where Data Templates and Digital Building Logbooks are central.	Journal	Mêda et al. (2021)	No
Potentials of Blockchain Technology for Construction Management	Blockchain implementation for construction management and associated concepts where DBL is one of them.	Journal	Turk and Klinc (2017)	No

to data sources and functionalities, digital technologies, or event contributions to progress indicators associated with the environment. Despite the wide range of discussed aspects, the DBL is broader and, as a result, also its challenges. This wide range of aspects makes it very difficult for many stakeholders to understand the benefits, namely when they are out of their scope of action; Gap #2. This issue is, in fact, critical because it demands a clear vision and maturity of the concept and all its details to provide awareness and training on the benefits realisation at different levels.

Starting with the purposes, it should be unquestionable that the DBL concept has its roots in energy efficiency, gaining relevance as an instrument glued to the EPC and being meaningful during the design phase. However, many others cross the way for this accomplishment, concluding that DBL cannot orbit around the EPC but the other way around. As observed, several research works identify DBL as a Digital Twin enabler surpassing many energy efficiency boundaries. The latest studies open the way for a clearer but not exhaustive vision of the DBL purposes. Regarding scope, it is critical to understand the link with the built object life-cycle. In this sense, it originates with the idea of building the object. It will end when the deconstruction of the object is over. A built object, even before the construction starts, has a place where it will stand; this is a land portion or cadastral parcel and is the first information to become part of the DBL. This information is needed for energy efficiency analysis and other purposes, such as permitting. From this, Gap #3 (Inconsistency around the scope and purpose of DBL) has started to be bridged. The previous reflection is relevant for working out Gap #6 (Challenges linked with the interoperability offered by the repository). From the start, DBL will need to consider the links with databases associated with land registry and finance and databases associated with public authorities and EPC emission, among others. In addition, DBL needs to be structured to ensure interoperability between two different realities, GIS and BIM. Of course, this gap has many issues to solve, and not all will be worked on under the DBL.

Albeit, DBL implementation will need to follow up and, eventually, provide insights regarding its specific needs. It is interesting to observe that Gap #2 (DBL benefits not transparent to all the stakeholders) applies to these two realities as stakeholders involved in BIM and GIS will need to see things beyond their boundaries. In this respect, and as mentioned, the awareness of the relationship between DBL and DBP supports bridging this gap. These issues are especially relevant when considering Gap #5 (Barriers to updating the DBL). Continuous updates of DBL will occur during the different phases of the built object, and these will occur with dataflows from other databases using interoperability protocols. Although some research works approach this from a very high level, this constitutes a vast field for research. Considering some existing outcomes and just as an example, there is the need to make

clear the positioning and relationship of DBL with digital product passports (DPPs) and material passports (MPs), as well as the further evaluation of the role of DBL in the use phase of the building, how it should relate or assume a role on the digital twin environment. In the Transition Pathway, Papadaki identified the action "Improve data availability on buildings' safety through a regulatory proposal for digital building logbooks" (action 6.4) (Papadaki et al., 2023). The DBL deals with data defined under several regulations and EU Directives. The ability to have a joint agreement on these diplomas goes beyond the DBL, but that needs to be considered when preparing the implementation. It is relevant to remember that updating the EU Directive on Safety and Health must be straightforward. All deliverables should somehow relate to or become part of the DBL.

Notwithstanding, the vision on Gap #8 is that besides all these concerns, there is the need to set a specific legal framework to govern the DBL framework, scope, and purposes, as well as requirements from other databases and regulations to link and harmonise with it. Although this seems a closed circle where all gaps are related and requires the accomplishment of the others to be solved, this is an iterative process where use cases need to be set to identify what can be a quick win and what is a constraint that will need the alignment of several stakeholders to be solved. On top of this, understanding the criticalities is vital. Guiding principles and actions are fundamental outcomes to be produced at the EU and member-states level.

3.6. Common reflections in DBP and DBL – Intuition

DBP can assume a wide range of processes that are always regulation-driven. Notwithstanding, all constitute key milestones for the construction process as imply compliance checks. Despite the differences, the permitting process requires structured data. It will produce outcomes that must be recorded and kept for future life-cycle phases.

The DBL aims to collect all building-relevant information, meaning data on characteristics and records of relevant events. It also aims to link existing databases containing metadata or documents for specific purposes. The DBL must be deployed before the start of the design phase and will remain through the buildings or infrastructure life-cycle. This makes the DBL a massive information repository with features for interaction/exchange with other tools or platforms throughout the construction life-cycle.

According to Noardo, the building permit process digitalisation is part of the broader framework of digitalisation in the construction sector, starting with the need to provide digital information about the city context and the related planning regulations and ending in the digital building logbook and digital assets and facility management tools (Noardo and Wu, 2022a). This understanding is, as seen, shared by stakeholders implementing DBP or DBL-related platforms. However, with exception to this reference, research and practice evidence a gap in the understanding and alignment of the potential relationships between both concepts. Considering all aspects mentioned comes the intuition on the relationships and questions regarding to what extent DBP can or should use data/elements from the DBL to streamline compliance checks and to what extent DBP outcomes should become part of the DBL. Fig. 4 presents a conceptual vision translating the initial intuition. The diagram comprises four main phases: Promotion/Feasibility, Design/-Procurement, Construction, and Operation. Each phase is depicted as a separate section for both the permit and the logbook processes, highlighting their interconnectedness and the continuous flow of information.

The integration of DBP and DBL within a common framework seems crucial for achieving the efficiency and sustainability goals, for example, set by the EU Green Deal. By ensuring that all relevant data is stored, organised, and accessible throughout the building's life-cycle, the construction industry can significantly enhance regulatory compliance, operational efficiency, and overall sustainability. This holistic approach not only addresses current gaps but also paves the way for a more resilient and adaptive construction sector in the future.

4. Action - FOCUS group

The focus group involved several quantitative and qualitative activities to verify intuition and collect insights to accomplish the objectives. As mentioned, these were presented at the beginning of the session, together with the agenda and the moderators' presentation.

4.1. Context understanding

The first survey was established as a warm-up instrument for the discussion part. It aimed to identify attendees' professional backgrounds and experience and collect unbiased data regarding the knowledge level on DBP and DBL, as well as initial insights on potential alignment/links. In terms of professional background, the group had different origins, from architecture (27.7%) and engineering (22.2%) practices to academia (27.7%) or geospatial sciences (11.1%). Regarding

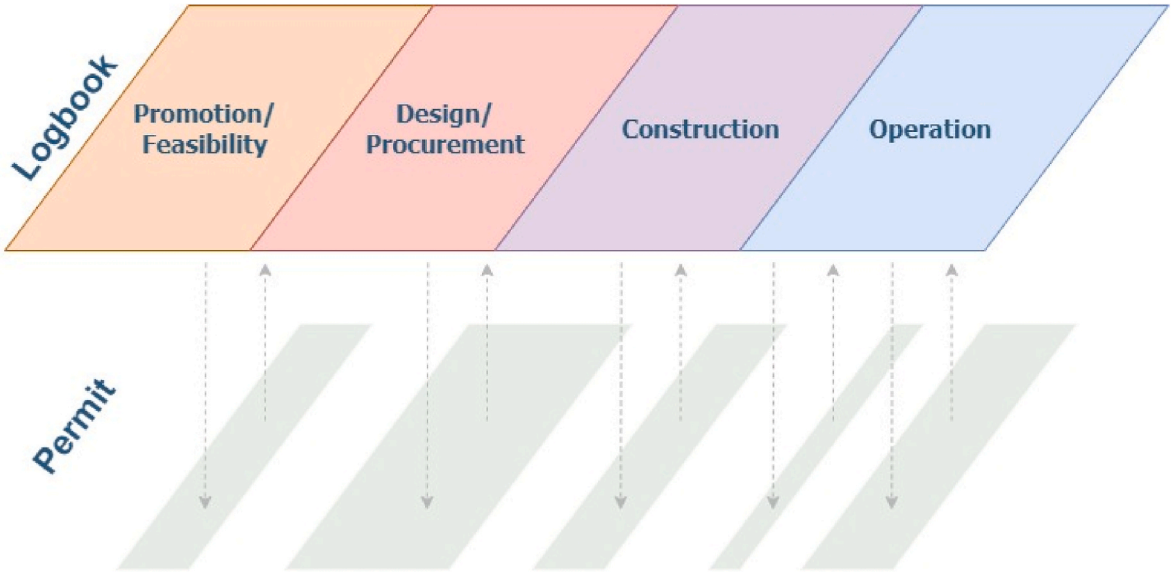

Fig. 4. Conceptual vision of the intuitions regarding DBL and DBP relationships.

professional experience, 22.2% had work experience between 15 and 20 years and 77.8% had more than 20 years. Concerning the concept level of knowledge, a six-level scale was set ranging from "I do not know anything about it" to "I work with it or part every day, either in real practice or research". Higher maturity was observed for DBP, with 50% answering that they work with the concept daily; this is the sixth level. It is also important to highlight that a large majority placed their answers on the fourth and fifth levels, 25% "I have a good knowledge of specific parts" and 16.7% "I have a good knowledge of many parts", respectively.

Regarding DBL, 38.5% of the respondents answered, "I have some knowledge about it", the third level, followed by 30.8% of answers with the fourth level, "I have a good knowledge of specific parts". These results were not unexpected considering the criteria for choosing the focus group, as the mailing list of individuals engaged in DBP projects and research was more extensive. Anticipating this fact, the initial phase of the workshop had a moment to share open notes regarding DBL. The open notes shared reflect personal experiences and concerns associated with ambiguities and implementation strategies. It was possible to group the thoughts into three clusters, expressing DBL visions, Technological issues, and Data requirements, as follows:

DBL visions – *"DBL as the central database enabling Digital Twin at building scale, highlighting the link between permitting and life-cycle construction process phases". "Mandatory building operation and management registries are already a reality in some countries, and DBL will expand the purpose and functionalities where permit(s) are essential".*

Technological issues – *"Bottlenecks deriving from granularity issues and the adoption of differing phasing for the construction process life-cycle, for example, design-driven vs. operation-driven phasing". "Definition of a network of databases and tools collecting data for DBL"? "Compatibility issues, relationship with existing systems and databases, how to tackle the overlaps"? "DBL data ownership, privacy audit, and communication channels to be established" raises* issues that deserve meaningful discussions.

Data requirements – *"How far will it be required to go in terms of data granularity? For example, building a carbon footprint from life-cycle assessment of all products"? "Is DBL* supporting *community management, risks register (H&S), energy, and flexibility paths? There is a need to work further on the definition regarding the purposes/answers to be provided".*

4.2. Observation and analysis

Two questions were repeated in both surveys. The objective was to understand the perception evolutions regarding DBP and DBL during the workshop. One question focused on aligning the two concepts. The other aimed at defining each concept in a word or sentence. Fig. 5 presents the results from the first question. The dark colours represent the results from the first survey and the light ones from the second.

There are two main aspects worth mentioning. The first is that the observed uncertainties (a significant percentage) regarding the links between DBP and DBL were clarified during the event. The second is that, initially, 50% of the individuals considered the links going through the entire construction process phases. By the end of the session, the amount had raised to 80%.

4.3. Moderators led-discussion

The moderators delivered a brief presentation on DBP and DBL using a summary of the elements described in the diagnosis sub-sections. The objective was to present the latest literature supporting the concepts and provide up-to-date insights. Following this moment, 5-min time frames were set to discuss "Information Requirements", "Technological Requirements", "Common Processes", and "Regulatory Framework" regarding DBP and DBL. From the discussion, "Stakeholders" was considered an additional topic.

Most attendees shared concerns regarding the definition of the framework relating to information requirements. During the last few years, investment and effort have been made to establish standards to frame this topic, meaning these should be used. They also mentioned that DBP requirements are mostly regulations-driven, while DBL seems more open. A minimal information requirement defined by the legal framework should be established for both situations, where additional requirements could be identified depending on specific needs, national frameworks, and business opportunities, among others. An example shows the City of Vienna, which issued a document describing the information requirements for their openBIM permit process and that even in the new standard information delivery specification (IDS) from buildingSMART International (Urban et al., 2024).

Regarding "Technological Requirements", the thoughts and the discussion were centred on existing tools and systems and how these should be improved or expanded to meet the needs of DBP and DBL. The issues involving the data handover between stakeholders, the use of open standards and protocols to foster interoperability and the means to ensure data ownership and privacy were among the more referenced aspects. It was also evident during the discussion that new tools are needed for information validation or to perform tasks not yet completely covered by existing software. However, these developments should be grounded on prior agreements considering all aspects mentioned previously. At this point, some overlaps started to occur between topics. This was somehow expected and an intended contribution to the discussion. When debating the "Common Processes", there was a general agreement that a link with GIS is needed and that General Protection Data Regulation (GDPR) and sensitive data will be held in permitting and logbook systems. Despite the wide range of permitting processes,

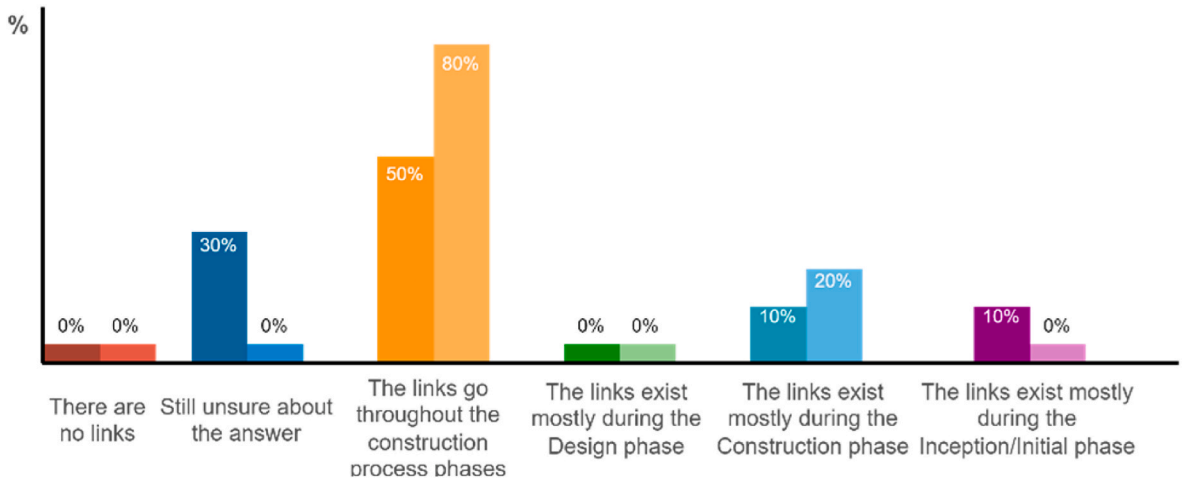

Fig. 5. First and second survey answers to the relationship between DBP and DBL.

some shared a vision of a complete link where "DBP itself can be an integrated part of the DBL process". The discussion centred on the "Stakeholders'" requirements for some minutes, focusing on awareness, training, and competencies to understand, proficiently apply, and operate the technologies and processes surrounding DBP and DBL.

Regarding the "Regulatory Framework", the contributions focused first on the observed trends. For example, what has been done by the EU regarding the EPC? Based on that example, thoughts were shared that the EU should push to establish a minimal framework from which national regulations could elaborate further. This type of initiative would also focus on the main objectives, setting the links with other relevant EU regulations. Aligned with this comes the terminology issue. Considering previous situations, it was recognised that regulation is needed, defining all main concepts and terminology to establish a common technical language. Finally, whether the same legislation should cover the two concepts was debated, resulting in a mix of opinions without a clear trend.

4.4. Exploration of perceptions

Considering the participants' profiles and awareness levels, observing the workshop's contributions to improved knowledge and perception of DBP and DBL, individually or as connected concepts, was very interesting. Positive comments were collected regarding the session. Several perceptions can be explored using data collected from the surveys and the discussion period. Starting with the results from the second repeated question in both surveys, Fig. 6 systematises the main aspects characterising the concepts at the workshop's beginning and end.

Most issues raised during the discussion derived from thoughts shared during the initial part of the workshop. The time frame to discuss each topic upheld detailed insights on the most pertinent ideas or concerns. It also allowed an understanding of the overlaps in the predefined areas. Table 3 summarises the cluster analysis of all contributions and how they relate to the topics set for discussion.

The analysis of the perceptions points to interesting headings, which will be further discussed. Notwithstanding, some can be already summarised, namely how the vision of the attendees shifted during the workshop from a characteristics-driven approach to a more background/main concerns and developments approach, pointing steps to future action. Table 3 shows how the different groups of issues overlap with the defined topics, providing insights into priority actions, concerns to be tackled first, and event contents to be safeguarded in legal documents and guidelines.

4.5. Open thoughts

In addition to all the discussion, there was some time for sharing open thoughts that could touch on topics not identified or worked during the focus group. Many attendees shared or left comments about the implementation costs and the business models supporting the ownership and maintenance of the datasets, information, and tools. One other comment had to do with user-friendliness. It is recognised that most stakeholders will need specific training. Nevertheless, due to the technical content and processes, it is vital to prepare interfaces and functionalities to encourage stakeholder engagement. Most comments, however, suggest priority aspects to be considered in roadmaps approaching the concepts together or individually. Emphasis is placed on the standardisation of the data to be used and the definition of datasets. Associated with this aspect is the definition of the accessibility layers, starting with public and private data and, within the private data, the different accesses depending on the stakeholder's profile. The definition of starting points for each concept is assumed to be a priority, as from this, it will be possible to start trialling use cases for each concept and its connections.

5. Findings

Based on the focus group, Fig. 7 illustrates the interconnected aspects of implementing DBP and DBL through a comprehensive Venn diagram. Each diagram component represents one of the critical levels: Data, Technology, Stakeholders, Processes, and Legal Framework. The overlaps between the circles highlight where the levels intersect, underscoring their interdependencies and combined influence on the digital transformation of permits and logbooks.

Data is a foundational element, intersecting with several other components. Where Data overlaps with Processes, the focus is on records maintenance and curation, emphasising the importance of managing and preserving information throughout the construction life-cycle. The intersection with Technology highlights concerns regarding data security and accessibility and the use of existing databases. Ensuring that data is both secure and readily accessible is crucial for the efficiency and reliability of DBP and DBL. Concerning Stakeholders, the interaction with Data underscores the importance of related services that assist in accessing the information. The overlap with the Legal Framework points to the necessity of a well-defined data framework, ensuring data handling complies with regulatory requirements.

Technology is the enabler for digital transformation and intersects broadly. The intersection with Data involves securing and accessing data and utilising existing databases to enhance efficiency. Overlapping with Processes, Technology focuses on governance, regulatory standards, and the financial aspects of technology implementation. About Stakeholders,

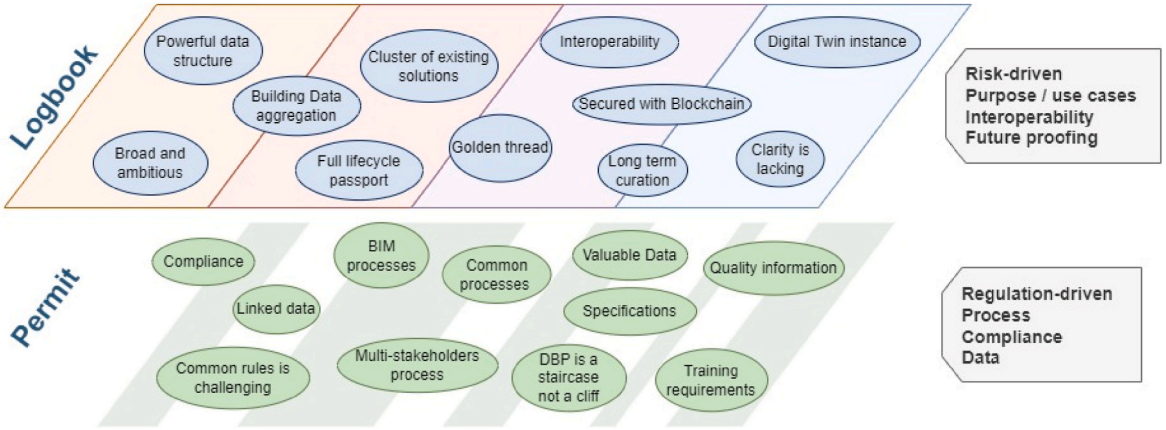

Fig. 6. Summary of the aspects characterising DBP and DBL.

Table 3
Cluster analysis contributions relating the topics with the discussion levels.

Topic	Technology	Data	Legal Framework	Stakeholders	Processes
Data security and accessibility	X			X	X
Records maintenance/curation	X		X		X
Data framework		X	X		
Terminology		X	X	X	
DBL and DBP relationship		X	X	X	X
Information reliability	X	X	X		
Awareness, training, knowledge	X	X	X	X	X
Exist. Databases (connecting dots)	X			X	X
Implementation costs	X			X	X
Governance	X		X	X	X
Relation to BIM	X	X	X	X	X
Related Services		X		X	X

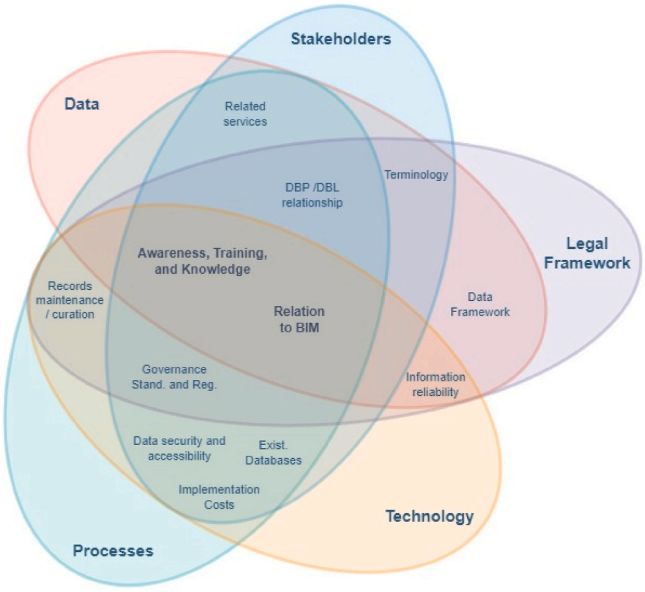

Fig. 7. Venn diagram summarising focus group inputs and discussion.

Technology emphasises the importance of raising awareness, providing training, and enhancing knowledge about digital systems. The interaction with the Legal Framework aims to ensure that the technological solutions are set to provide reliable information, adhering to legal and regulatory requirements.

Stakeholders are vital, and their intersections with other components are significant. When intersecting with Technology, the focus shifts to awareness, training, and knowledge, highlighting the need for stakeholders to be educated and well-informed about the technological aspects and benefits of DBP and DBL. The interaction with Data underlines the necessity for services directly related to stakeholder needs and responsibilities. The overlap with the Legal Framework involves consistent terminology, ensuring that all parties have a clear and shared understanding of the terms used.

Processes form the operational backbone and intersect with several areas. The overlap with Data highlights the critical role of maintaining and curating records, ensuring that all procedural data is systematically managed. In conjunction with Technology, Processes emphasise governance, standards, and regulations, ensuring that the technological implementations align with established procedural norms. It also addresses implementation costs, reflecting the financial considerations of integrating new technologies.

Legal Framework ensures regulatory compliance and intersects with various elements. The intersection with Data establishes a data framework to ensure that all data management practices comply with legal standards. Overlapping with Stakeholders focuses on standardising terminology to avoid misunderstandings and ensure clarity in communications and documentation. The interaction with Technology centres on information reliability, emphasising the importance of having accurate and dependable data and technological processes.

At the centre of these intersections are key aspects.

- **Awareness, Training, and Knowledge**: These are crucial across aspects, ensuring that all participants are informed, educated, and competent in understanding and using DBP and DBL,
- **Relation to BIM**: BIM comprises several parts common to the DBP and DBL requirements, such as information containers, Level of Information Need (LOIN), and interoperability. These are central to the integration, highlighting its importance in connecting various data points and processes within the digital framework, and
- **DBP/DBL relationship:** Emphasises the interconnectedness between DBP and DBL, ensuring that both systems work cohesively to enhance the overall efficiency and effectiveness of the construction process and building life cycle management.

This analysis underscores the complexity and interrelated nature of managing DBP and DBL, highlighting the need for a coordinated approach that addresses data management, stakeholder involvement, legal compliance, procedural integrity, and technological innovation.

Fig. 8 provides a detailed overview of the interconnected activities between DBP and DBL throughout the various phases of a building's lifecycle on a process level, extending the initial framework based only on intuition, previously presented in Fig. 4. Each phase outlines specific activities related to the permitting process and the logbook updates, highlighting key milestones and their interdependencies.

During the Promotion/Feasibility phase, the groundwork for the project is established. Activities in the logbook at this stage include cadastre registration and pre-consultation processes, ensuring that all preliminary data and consultations are documented.

In the Design/Procurement phase, the focus shifts to refining project plans and securing necessary resources. The logbook continues to be updated with relevant details as design modifications and procurement decisions are made. Concurrently, the permitting process involves several critical steps: submission of initial plans, administrative checks, assessments, and the gathering of comments. This phase also includes the participation of other agencies and the public to gather comprehensive input. Once these steps are completed, conditional permits can be issued, leading to the first significant milestone: starting clearance. This clearance marks the transition to the next phase, confirming that initial conditions are met, and the project can proceed to detailed design and procurement.

The Construction phase is where the physical building work takes place. During this phase, the logbook is continuously updated with records of construction progress, products entering on-site, modifications to the original plans, and results from various inspections. The permitting process remains active through ongoing inspections to verify that

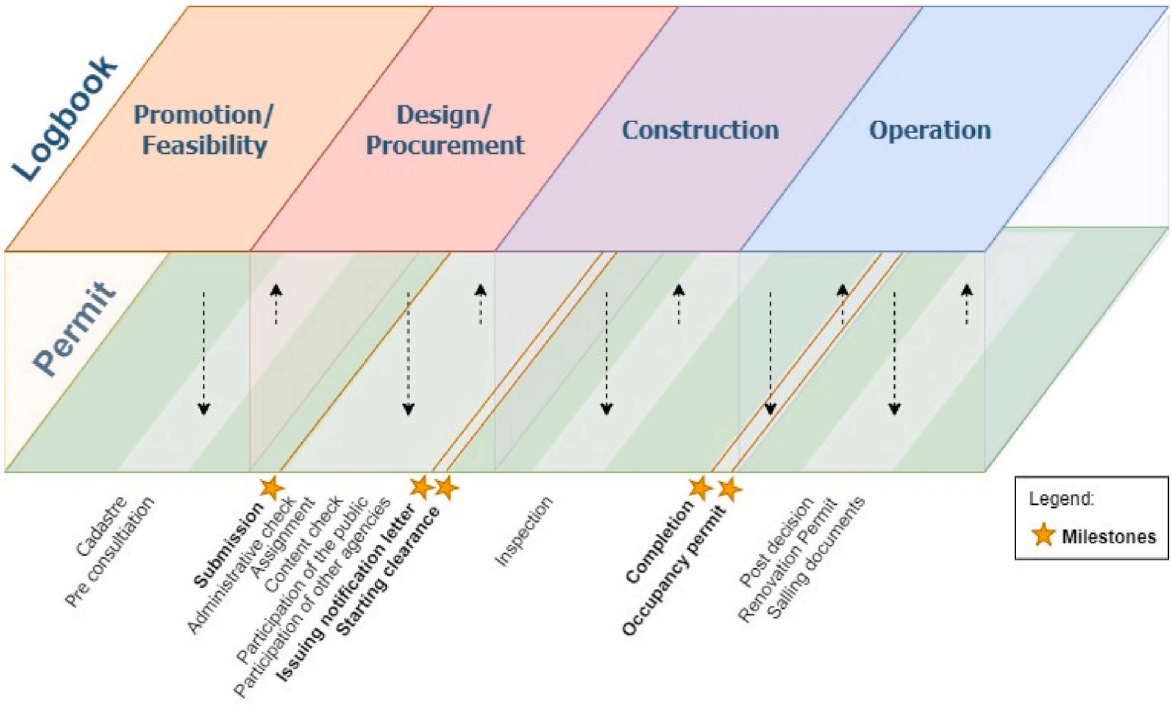

Fig. 8. Process level connections between DBP and DBL.

construction adheres to the approved plans and regulations. These inspections are crucial for maintaining compliance and ensuring the project's integrity throughout the build process.

The final phase, Operation, begins once construction is complete. The logbook now serves as a repository for post-decision updates, renovation permits, and sailing documents. These records ensure that the building's operational history is well-documented and accessible for future reference. The permitting process during this phase includes two significant milestones: the completion milestone, signifying the end of construction activities, and the occupancy permit milestone, authorising the building's use by occupants. Additionally, post-decision activities include further updates and renewals based on operational needs, ensuring ongoing compliance and accurate documentation. Fig. 8 highlights several key milestones marking significant transitions in the process.

- **Starting Clearance**: Marks the transition from the feasibility phase to the design phase after conditional permit approval,
- **Completion**: Signifies the end of construction activities and readiness for final inspections, and
- **Occupancy Permit**: Granted upon completing all inspections, allowing the building to be occupied.

Fig. 8 also illustrates the flow of information between the DBP and DBL through vertical and horizontal arrows. Vertical arrows represent the continuous exchange of updates between the permit process and the logbook, ensuring that all relevant data is captured and maintained. Horizontal arrows denote the progression through the different phases, highlighting the interconnected nature of DBP and DBL activities.

6. Discussion and conclusions

With the present research, it is possible to state that DBP and DBL are related concepts with several mutual data/information exchanges and multiple interconnections throughout the construction process and building life-cycle. However, this alignment is still not obvious, even within communities of experts. The study captured the dynamic relationship between DBP and DBL, identifying at multiple levels the importance of continuous updates and data sharing across all phases of the construction process and building life-cycle, ensuring regulatory compliance, efficient project management, and comprehensive record-keeping from project inception to operation. This holistic approach facilitates a more resilient and adaptive construction process, aligning with modern requirements for transparency and efficiency in building management. While DBP comprises packages of processes on a more time-framed scale, DBL is continuous. This means that there are no time lags. The DBL should be deployed before any permit process and will continue after the last one.

DBP and DBL can be set as independent systems. However, considering the overlaps in their scope and for the sake of digital sobriety (Péréa et al., 2023), it is relevant to consider a shared landscape for terminology and datasets. This aspect should encompass other systems and concepts. Additionally, it is worth highlighting that the efficiency and complete accomplishment of the objectives of both concepts might be disturbed if there is the need to feed each one manually with data from the other.

From a strategic viewpoint, there can be several benefits from the synergies, proper links, and data sharing between DBP and DBL. The implementation challenges will be higher due to the coordination needs from a systems architecture perspective. However, several savings can be achieved in awareness, training, and getting the confidence of stakeholders for use. As discussed, several stakeholders' activities might overlap, meaning adoption can become more straightforward by working correctly with the overlaps.

At the EU level, the recently published updates on the common European Data Spaces state of play already address the need for a construction-related space (European Commission, 2024b). It also addresses several technical challenges associated with interoperability and security. Despite the construction singularities, these issues are being worked on at a higher level as part of the overall framework of data spaces. Understanding and following these developments is key to understanding the options and raising questions on to which extent the solutions apply or are sufficient to the construction requirements. This topic constitutes itself a vast field for future research.

This study's limitations are related to the defined scope and level of granularity. This intentionally sets the background for future and more in-depth research activities. This research focused on specific levels, setting the assumptions to work further on the articulation between DBP and DBL. As mentioned previously and following the concerns raised during the focus group, there are many challenges associated with existing databases and their integration, as well as security protocols to manage access to the information. The following testimonies from the focus group worth highlighting for future use:

"How the handover of information will be made from one owner to other? And how it will work for those renting a property (data ownership, data update, data accessibility)?"

"Who should hold the sensitive information? How and by whom the "level of sensitivity" will be defined?"

"It is important to understand exactly what the privacy concerns are – what are people comfortable to share publicly about their house/building? What are people worried about? Does this differ in different countries?"

The existing solutions, ongoing projects, and future research will help to better understand how these bottlenecks can be worked out and solved.

The present research delivers a solid background on the relationship between DBP and DBL. It opens fields for future investigation at different levels, such as Data, Technology, Stakeholders, and Processes. Each identified aspect in Fig. 7 is worthy of in-depth study. Similarly, the process framework presented in Fig. 8 should be worked further to identify the relevant data to be exchanged in each "arrow". Another dimension is related to the last research question, where almost everything is to be assessed and defined regarding potential alignments in strategic documentation and regulatory framework. Using as reference the 2024 Rolling Plan for ICT standardisation (European Commission, 2024a), future research activities will prioritise the data discovery, namely, to identify common data between DBP and DBL and where they are stored. This is found to be key to making a step forward towards the assessments in data usage and data sharing. The data governance seems to be, at this point, highly dependent on the forthcoming developments at the Common European Data Spaces level (European Commission, 2024c). However, the construction singularities must be presented as a relevant use case given the sector singularities, range and stakeholders' fragmentation.

Although the research has addressed chiefly the buildings, DBP and DBL apply and are meaningful to all built assets, namely infrastructures. DBL, although addressed in strategic documents today for buildings, the type of data they collect and manage is also very relevant for other construction entities such as civil engineering works, roads, and rail, among others.

The relationship and alignment between DBP and DBL will enable the golden thread of information forecasted by Hackitt (2020). In addition, DBP and DBL are also essential for the digital twin at the building/infrastructure scale because they provide a centralised and comprehensive digital repository of all building-related data from the initial design phase to operation. They benefit from the seamless data flow, enhancement of transparency and traceability, and support of regulatory compliance by documenting every process step. By facilitating process automation and real-time updates, DBP and DBL improve efficiency and decision-making, allowing for accurate and current digital representations of physical assets. Additionally, they enhance stakeholder collaboration and boost sustainable practices and life-cycle management, making them crucial for maintaining and optimising a twin-based mindset.

CRediT authorship contribution statement

Pedro Mêda: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Judith Fauth:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Christian Schranz:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Hipólito Sousa:** Writing – review & editing, Visualization, Supervision, Formal analysis. **Harald Urban:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

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Data availability

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

References

ACCORD consortium, 2023. Accord - automating the building permitting and compliance. https://accordproject.eu. (Accessed 2 March 2024).

Al-Sadoon, N., Fauth, J., Menzel, K., 2023. Digital twins as enabler for long term data management using building logbooks. In: IFIP Advances in Information and Communication Technology, pp. 673–686. https://doi.org/10.1007/978-3-031-42622-3_48.

Alonso, I.-N.C., et al., 2022. Circular economy and digital twins in the construction sector. In: Proceedings from the International Congress on Project Management and Engineering, pp. 444–456.

Alonso, R., et al., 2023. Towards the definition of a European digital building logbook: a survey. Heliyon 9 (9), e19285. https://doi.org/10.1016/j.heliyon.2023.e19285.

Amor, R., Dimyadi, J., 2021. The promise of automated compliance checking. Developments in the Built Environment 5 (October 2020), 100039. https://doi.org/10.1016/j.dibe.2020.100039.

Arbulu, M., et al., 2023. Applicability of the European Union's building renovation assessment framework in Spain. Environmental and Climate Technologies 27 (1), 391–406. https://doi.org/10.2478/rtuect-2023-0029.

Ataide, M., Braholli, O., Siegele, D., 2023. Digital transformation of building permits: current status, maturity, and future prospects. Buildings 13 (10). https://doi.org/10.3390/buildings13102554.

Bernstein, P., 2018. Architecture | Design | Data: Practice Competency in the Era of Computation. Birkhäuser, Berlin, Boston. https://doi.org/10.1515/9783035610444. Birkhäuser.

Bloch, T., Fauth, J., 2023. The unbalanced research on digitalization and automation of the building permitting process. Adv. Eng. Inf. 58 (June), 102188. https://doi.org/10.1016/j.aei.2023.102188.

Buchholz, M., Lützkendorf, T., 2023. European building passports: developments, challenges and future roles. Buildings and Cities 4 (1), 902–919. https://doi.org/10.5334/bc.355.

buildingSMART International, 2023. 'IFC to become a mandatory building permit document in Finland'. https://www.youtube.com/watch?v=tGtxU6FHH6c&t=2040s.

Cambridge University Press, n.d.a. Logbook. In Cambridge dictionary. https://dictionary.cambridge.org/dictionary/english/logbook (Accessed 17 April 2024).

Cambridge University Press, n.d.b. Permit. In Cambridge dictionary. https://dictionary.cambridge.org/dictionary/english/permit (Accessed 17 April 2024).

Capsa, 2024. Capsa - building passport. https://capsa-building.com/. (Accessed 12 March 2024).

Chek Consortium, 2023. Chek – change toolkit for digital building permit. https://chekdbp.eu. (Accessed 4 March 2024).

Chimni (n.d.). Residential Property Logbook. Available at: https://chimni.com/why-have-a-chimni-log/ (Accessed: 12 March 2024).

Christie, M., 1992. 'Using Action Research to Improve Teaching' (January).

Cirdax, 2024. Cirdax matterport. https://www.cirdax.com/. (Accessed 12 March 2024).

City of Vienna, 2023. Brise – the future of public administration. Available. (Accessed 4 March 2024).

Cléa - Qualitel, 2023. Carnet d'Information du Logement. https://clea.qualitel.org/. (Accessed 12 March 2024).

DigiChecks consortium, 2023. DigiChecks. https://digichecks.eu. (Accessed 2 March 2024).
Dourlens, S., Carbonari, G., De Groote, M., Borragán, G., De Regel, S., Toth, Z., V, J., G, J., 2021. Study on the development of a European union framework for digital building logbook - final report. https://doi.org/10.2826/659006.
e-ehitus teemaveeb, 2020. A prototype of the BIM-based building permit procedure. In: https://eehitus.ee/timeline-post/bim-based-building-permit-procedure/. (Accessed 4 March 2024).
Eastman, C., et al., 2009. Automatic rule-based checking of building designs. Autom. ConStruct. 18 (8), 1011–1033. https://doi.org/10.1016/j.autcon.2009.07.002.
Espinoza-Zambrano, P., Marmolejo-Duarte, C., García-Hooghuis, A., 2023. Libro del Edificio Electrónico (LdE-e): Advancing towards a Comprehensive Tool for the Management and Renovation of Multifamily Buildings in Spain. Sustainability 15 (4). https://doi.org/10.3390/su15042957.
Estonian Ministry of Economic Affairs and Communication, 2018. Vision of e-construction platform. Talín. https://eehitus.ee/wp-content/uploads/2019/07/e-construction-platform-vision-ENG.pdf.
European Commission, 2019. The European Green Deal, COM(2019) 640 Final. Brussels.
European Commission, 2021. Proposal for a Directive of the European Parliament and of the Council on the Energy Performance of Buildings (Recast). COM(2021) 802. Official Journal of the European Union, Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0802&qid=1641802763889.
European Commission, 2024a. 2024 rolling plan for ICT standardisation. https://joinup.ec.europa.eu/collection/rolling-plan-ict-standardisation/rolling-plan-2024. (Accessed 3 February 2024).
European Commission, 2024b. Commission Staff Working Document - on Common European Data Spaces. Brussels.
European Commission, 2024c. Common European data spaces. https://digital-strategy.ec.europa.eu/en/policies/data-spaces. (Accessed 3 April 2024).
Eurostat, 1998. Classification of types of constructions. http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=CC_1998&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC. (Accessed 25 May 2017).
Fabbri, M., Groote, M. De, Rapf, O., 2016. Building Renovation Passports: customised roadmaps towards deep renovation and better homes. Buildings Performance Institute Europe.
Fauth, J., et al., 2024. Taxonomy for building permit system - organizing knowledge for building permit digitalization. Adv. Eng. Inf. 59 (May 2023), 21. https://doi.org/10.1016/j.aei.2023.102312.
Fauth, J., Bloch, T., Soibelman, L., 2023a. Process model for international building permit benchmarking and a validation example using the Israeli building permit process. Eng. Construct. Architect. Manag. 31 (13), 121–139. https://doi.org/10.1108/ECAM-06-2023-0593.
Fauth, J., Pasetti Monizza, G., Malacarne, G., 2023b. Understanding processes on digital building permits–a case study in South Tyrol. Build. Res. Inf. 51 (5), 518–532. https://doi.org/10.1080/09613218.2023.2178372.
Fauth, J., Seiß, S., 2023. Ontology for building permit authorities (OBPA) for advanced building permit processes. Adv. Eng. Inf. 58 (October). https://doi.org/10.1016/j.aei.2023.102216.
Fauth, J., Soibelman, L., 2022. Conceptual framework for building permit process modeling: lessons learned from a comparison between Germany and the United States regarding the as-is building permit processes. Buildings 12 (5). https://doi.org/10.3390/buildings12050638.
Fellows, R., Liu, A., 2022. Research Methods for Construction. Wiley-Blac, Oxford.
Fischer, S., et al., 2024. Generation of new BIM domain models from escape route analysis results. Developments in the Built Environment 19 (April), 100499. https://doi.org/10.1016/j.dibe.2024.100499.
Fokaides, P., Jurelionis, A., Spudys, P., 2022. Boosting research for a smart and carbon neutral built environment with digital twins (SmartWins). In: ISC2 2022 - 8th IEEE International Smart Cities Conference. https://doi.org/10.1109/ISC255366.2022.9922513.
GABC and UNEP, 2021. The Building Passport : a Tool for Capturing and Managing Whole Life Data and Information in Construction and Real Practical Estate. Nairobi.
Gómez-Gil, M., et al., 2022. The Digital Building Logbook as a gateway linked to existing national data sources: the cases of Spain and Italy. J. Build. Eng. 63 (August 2022). https://doi.org/10.1016/j.jobe.2022.105461.
Gómez-Gil, M., Espinosa-Fernández, A., López-Mesa, B., 2022a. Contribution of new digital technologies to the digital building logbook. Buildings 12 (December), 2129. https://doi.org/10.3390/buildings12122129.
Gómez-Gil, M., Espinosa-Fernández, A., López-Mesa, B., 2022b. Review and analysis of models for a European digital building logbook. Energies 15, 24. https://doi.org/10.3390/en15061994.
Grow, D., 2023. Technical Guidelines for Digital Building Logbooks - Guidelines to the Member States on Setting up and Operationalising Digital Building Logbooks under a Common EU Framework. Brussels.
Guler, D., Yomralioglu, T., 2021. A reformative framework for processes from building permit issuing to property ownership in Turkey. Land Use Pol. 101 (March 2020), 105115. https://doi.org/10.1016/j.landusepol.2020.105115.
Hackitt, J., 2020. The golden Th. https://www.goldenthread.co.uk/Golden-Thread-Review.pdf.
Hwang, S.A., 2024. Digital building logbooks and stakeholder mapping: a cross-sectoral approach to data collection and sharing. In: *Proceedings Of the European Conference On Computing In Construction*. Chania: EC3 - European Conference on Computing in Construction, pp. 594–601. https://doi.org/10.35490/EC3.2024.169.
International Standards Organization, 2018. ISO 19650-1 - Organization and Digitization of Information about Buildings and Civil Engineering Works , Including BIM - Information Management Using Building Information Modelling. Switzerland.
Jain, N., 2023. What is focus group research? Definition, types, methods, and examples. IDEAS. https://ideascale.com/blog/what-is-focus-group-research/#toc_What_is_Focus_Group_Research.
Koltsios, S., et al., 2022. Digital twin application on next-generation building energy performance certification scheme. In: ISC2 2022 - 8th IEEE International Smart Cities Conference. https://doi.org/10.1109/ISC255366.2022.9921821.
Kunz, J., Fischer, M., 2007. CIFE Research Questions and Methods, Stanford Digital Repository. Stanford.
Lee, H., et al., 2016. Translating building legislation into a computer-executable format for evaluating building permit requirements. Autom. ConStruct. 71, 49–61. https://doi.org/10.1016/j.autcon.2016.04.008.
Lewin, K., 1958. Group decision and social change. In: Maccoby, E.E., Newcomb, T.M., Hartley, E.L. (Eds.), Readings in Social Psychology. Rinehart, New York, pp. 197–211. http://web.mit.edu/curhan/www/docs/Articles/15341_Readings/Organizational_Learning_and_Change/Lewin_Group_Decision_&_Social_Change_Readings_Psych_pp197-211.pdf.
Malinovec Puček, M., et al., 2023. A data structure for digital building logbooks: achieving energy efficiency, sustainability, and smartness in buildings across the EU. Buildings 13 (4). https://doi.org/10.3390/buildings13041082.
Malsane, S., et al., 2015. Development of an object model for automated compliance checking. Autom. ConStruct. 49 (PA), 51–58. https://doi.org/10.1016/j.autcon.2014.10.004.
Mêda, P., et al., 2021. Incremental digital twin conceptualisations targeting data-driven circular construction. Buildings 11 (11), 554. https://doi.org/10.3390/buildings11110554.
Mêda, P., et al., 2022. A process-based framework for digital building logbooks. 2022 European Conference on Computing in Construction. Ixia EC3, 8. https://doi.org/10.35490/EC3.2022.183. EC3.
Mêda, P., Sousa, H., Calvetti, D., 2023. The anatomy of the digital building logbook embodied with health and safety data requirements. In: Emuze, F., Sherratt, F., Soeiro, A. (Eds.), Digital Transformation of Health and Safety in Construction (CIBW099W123): Book of Proceedings. FEUP edições, Porto, pp. 319–328. https://doi.org/10.24840/978-972-752-309-2.
Niavis, H., Laskari, M., Fergadiotou, I., 2022. Trusted DBL: a blockchain-based digital twin for sustainable and interoperable building performance evaluation. In: 2022 7th International Conference on Smart and Sustainable Technologies, SpliTech 2022. https://doi.org/10.23919/SpliTech55088.2022.9854287.
Nisbet, N., Wix, J., Conover, D., 2009. The future of virtual construction and regulation checking. Virtual Futures for Design, Construction & Procurement. https://doi.org/10.1002/9781444302349.ch17.
Noardo, F., Wu, T., et al., 2020. Geobim for digital building permit process: learning from a case study in Rotterdam. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences 6 (4/W1), 151–158. https://doi.org/10.5194/isprs-annals-VI-4-W1-2020-151-2020.
Noardo, F., Wu, T., et al., 2022a. IFC models for semi-automating common planning checks for building permits. Autom. ConStruct. 134 (March 2021), 104097. https://doi.org/10.1016/j.autcon.2021.104097.
Noardo, F., Guler, D., et al., 2022b. Unveiling the actual progress of Digital Building Permit: getting awareness through a critical state of the art review. Build. Environ. 213 (January), 108854. https://doi.org/10.1016/j.buildenv.2022.108854.
Noardo, F., Malacarne, G., 2020. Integrating eexpertises and ambitions for data-driven digital building permits – the EUNET4DBP. Int. Arch. Photogram. Rem. Sens. Spatial Inf. Sci. XLIV-4/W1, 103–110. https://doi.org/10.5194/isprs-archives-XLIV-4-W1-2020-103-2020.
Noardo, F., et al., 2020. Opportunities and challenges for GeoBIM in Europe: developing a building permits use-case to raise awareness and examine technical interoperability challenges. Spatial Sci. 65 (2), 209–233. https://doi.org/10.1080/14498596.2019.1627253.
Ozturk, G.B., 2020. Interoperability in building information modeling for AECO/FM industry. Autom. ConStruct. 113 (February), 103122. https://doi.org/10.1016/j.autcon.2020.103122.
Papadaki, I., et al., 2023. Transition pathway for construction, directorate H – ecosystems III: construction, machinery & standardisation. https://ec.europa.eu/docsroom/documents/53854.
Pärn, E.A., Raitviir, C., Zaki, M., 2022. E-construction: public innovation platform. In: University, T. (Ed.), *Public Innovation And Digital Transformation*. Tampere Un. Routledge - Taylor and Francis, pp. 129–153. https://doi.org/10.4324/9781003230854-8.
Péréa, C., Gérard, J., de Benedittis, J., 2023. Digital sobriety: from awareness of the negative impacts of IT usages to degrowth technology at work. Technol. Forecast. Soc. Change 194 (May). https://doi.org/10.1016/j.techfore.2023.122670.
Plazza, D., et al., 2019. BIM for public authorities: basic research for the standardized implementation of BIM in the building permit process. IOP Conf. Ser. Earth Environ. Sci. 323 (1). https://doi.org/10.1088/1755-1315/323/1/012102.
Preidel, C., Borrmann, A., Beetz, Jackob, 2021. Prüfung der Einhaltung von Normen und Richtlinien mittels BIM. In: Borrmann, A., et al. (Eds.), Building Information Modeling, VDI-Buch. Springer Vieweg, pp. 443–462. https://doi.org/10.1007/978-3-658-33361-4_23.
Romesburg, H.C., 1984. Cluster Analysis for Researchers. Lifetime Learning Publications United States, Belmont.
Rosa, F., 2022. Digital Twin solutions to historical building stock maintenance cycles. In: IOP Conference Series: Earth and Environmental Science. https://doi.org/10.1088/1755-1315/1073/1/012013.

Samuelson, O., Stehn, L., 2023. Digital transformation in construction – a review. J. Inf. Technol. Construct. 28 (July), 385–404. https://doi.org/10.36680/j.itcon.2023.020.
Sesana, M.M., Salvalai, G., 2018. A review on Building Renovation Passport: potentialities and barriers on current initiatives. Energy Build. 173, 195–205. https://doi.org/10.1016/j.enbuild.2018.05.027.
Singapore BCA, 2022. Corenet X. https://www1.bca.gov.sg/regulatory-info/building-control/corenet-x (Accessed 4 March 2024).
Svetel, I., Kosić, T., 2022. Use of digital information in architecture, engineering, construction and operation: standardization efforts. Structural Integrity and Life 22 (2), 183–191.
Turk, Ž., Klinc, R., 2017. Potentials of blockchain technology for construction management. In: Procedia Engineering. Elsevier Ltd, pp. 638–645. https://doi.org/10.1016/j.proeng.2017.08.052.
Ullah, K., Witt, E., Lill, I., 2022. The BIM-based building permit process: factors affecting adoption. Buildings 12 (1), 45. https://doi.org/10.3390/BUILDINGS12010045.
Urban, H., Fischer, S., Schranz, C., 2024. Adapting to an OpenBIM building permit process: a case study using the example of the city of Vienna. Buildings 14 (4). https://doi.org/10.3390/buildings14041135.
De Wolf, C., et al., 2023. Whole life cycle environmental impact assessment of buildings: developing software tool and database support for the EU framework Level(s). Resour. Conserv. Recycl. 188 (December 2021), 106642. https://doi.org/10.1016/j.resconrec.2022.106642.