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Linking digital product passports and digital building logbooks: Socio-Technical challenges and a pathways for integration

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ABSTRACT

This study identifies socio-technical challenges and enablers in integrating Digital Product Passports (DPPs) into Digital Building Logbooks (DBLs) and develops a guiding framework. While both instruments advance with overlapping sustainability objectives at the policy level, their effective integration remains unresolved. Adopting a qualitative multiple-case study, we investigated four European DBL initiatives from Germany, the UK, France and Belgium through semi-structured interviews triangulated with secondary sources. Findings show that integration barriers are less technical, but more procedural, and organizational. Key challenges include absent ontologies and unstructured data, unclear responsibilities and weak incentives, and digital fatigue, low awareness, and role ambiguity. Enabling factors highlight regulatory support, market incentives, and user-centered design. We propose that DBLs should function as Systems of Systems, with four interdependent enablers, namely, regulation, standardization, interoperability, and simplicity as prerequisites for scalable, effective DPP–DBL integration. The framework informs policy, industry, and researchers and supports sustainability transitions in the built environment.

1. Introduction

The European building industry is undergoing major transitions, including energy transition, circular transition, and digital transformation. These shifts are driven by the urgent necessity to address global environmental and economic challenges, particularly given the industry's substantial resource consumption and environmental footprint (European Energy Agency, 2024). Amid this evolving landscape, digitalization has become an important aspect to manage life cycle information more efficiently, improve transparency, and create new market opportunities. Driven by commitments like the Paris Agreement, United Nations' Sustainable Development Goals and the European Union's (EU) Green Deal, there has been a significant rise in digital solutions and policy instruments over recent years, particularly for circular economy implementation (Çetin et al., 2021; van Capelleveen et al., 2023) and energy renovation for the European building stock (Hwang et al., 2025).

The building industry operates typically in a data-rich environment; however, due to the fragmented nature of sector and the slow adoption of digital innovations, much of this valuable information remains underutilized (Honic et al., 2019; Wijewickrama et al., 2021). This creates structural holes in the flow of information along the buildings' value chain (Wijewickrama et al., 2021), leading to limited accessibility and unreliable quality of information for circular and decarbonization interventions (European Commission, 2020b). To overcome these challenges, various digital solutions and policy instruments have emerged in recent years, including material passports, building renovation passports, digital building logbooks (DBLs) or building passports (BPs), and digital product passports (DPPs). These passport initiatives aim to enhance data accessibility and clarity, facilitate more effective communication between stakeholders and lead to informed decisions across the entire lifecycle of buildings.

Among these initiatives, DBLs and DPPs have progressively gained prominence within the EU's policy agenda concerning the Twin Transition. The European Commission initiated a series of technical studies in 2020 aimed at developing an EU-wide DBL framework (European Commission, 2020c). These studies systematically analyzed existing DBL and BP tools already operational in the market, identified core components required for establishing a harmonized framework, and examined potential implementation challenges as well as success factors across member states. Furthermore, the DBL concept has been explicitly

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Abbreviations

BIM	Building Information Modelling
BP	Building Passport
CPR	Construction Products Declarations
DBL:	Digital Building Logbook
DPP	Digital Product Passport
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificates
EPD	Environmental Product Declaration
ESPR	Ecodesign for Sustainable Products Regulation
MP	Material Passport
SoS	System of Systems

highlighted in key EU policy documents, such as the Renovation Wave and the recast of the Energy Performance of Buildings Directive (EPBD), underscoring its role as a critical enabler of data transparency and interoperability for energy renovation processes (Hwang et al., 2025; Malinovec Puček et al., 2023). Additionally, several Horizon 2020-funded projects, such as ALDREN and iBRoad, have been initiated to further advance the creation of structured and easily accessible building profiles across the lifecycle, thereby facilitating informed decision-making processes for various building types and stakeholders (Signorini et al., 2025)

In parallel, a new regulation has been enforced starting in 2024, mandating the implementation of DPPs as part of the Ecodesign for Sustainable Products Regulation (ESPR) to accelerate the circular transition of industries and enhance transparency in product data (European Union, 2024a). The ESPR requires that all products sold within the EU, including construction materials, be accompanied by DPPs containing detailed information on their origin, composition, environmental impact, and end-of-life handling. Building on this, the Construction Products Regulation (CPR), aligned with the ESPR's objectives, is expected to come into force by the end of 2025, making DPPs mandatory for construction products (European Union, 2024b). These regulatory developments will significantly impact how building industry stakeholders manage product data in both new construction and renovation projects.

While research on a similar stream, namely, material passports has been growing in the built environment (see, e.g., Honic et al. (2024)), our understanding of the implications of DPPs for the industry still remains limited, especially from a socio-technical transitions perspective. Most existing studies focus on technical functionalities, traceability, and circular design potentials of material passports (Çetin et al., 2023; Munaro and Tavares, 2021), yet they fall short in engaging with the institutional and systemic challenges posed by the upcoming regulatory frameworks.

Under the new ESPR and CPR, DPPs will become mandatory for critical construction products and is expected to reshape how product data is generated, managed, and shared across the industry (European Union, 2024b). The new CPR mandates the development of a dedicated construction DPP system that is interoperable with the broader EU framework, aligned with BIM, and responsive to the sector's specific needs (Mêda, Calvetti, et al., 2024). To ensure machine readability and integration with digital tools such as BIM, DBLs, and product registries, the regulation also calls for a harmonized EU-level data dictionary for construction products (European Union, 2024b). Given the parallel development of DBLs as tools for managing building-level data, there is a pressing need to investigate how DPPs and DBLs can be effectively integrated. Despite overlapping goals, current literature offers limited insight into their alignment (Mêda et al., 2021). A sociotechnical approach is essential in addressing this gap, as technologies like DPPs and DBLs do not operate in isolation but within a broader ecosystem of people, processes, and institutional structures. Without considering the social, organizational, and procedural dimensions, technical integration risks being ineffective, fragmented, or met with stakeholder resistance (Sony and Naik, 2020). Therefore, we deploy a qualitative multiple case study of four European DBLs to address the following research question:

> RQ: What are the socio-technical challenges influencing the integration of digital product passports (DPPs) into digital building logbooks (DBLs) and how can these challenges be addressed?

The structure of the paper is as follows. Section 2 provides a brief overview of the research background, outlining key digital and policy developments at the European level. Section 3 introduces the methodology, including the case studies and data collection methods. Section 4 presents the findings and offers a discussion of the results and Section 5 concludes the study.

2. Research background

In Europe, the built environment is a major contributor to environmental footprint, accounting for approximately 40% of total energy consumption, primarily from building operations, material production, and construction activities (European Construction Sector Observatory, 2018). It is also responsible for around 50% of all extracted materials and generates more than 35% of the EU's total waste (European Commission, 2022; Eurostat, 2020), much of which is not adequately recovered or reused. As the EU pushes for a climate-neutral and resource-efficient economy through initiatives like the European Green Deal, the Circular Economy Action Plan, and the Renovation Wave Strategy, reducing the environmental footprint of buildings has become a policy priority. In the meantime, digitalization has become increasingly a priority strategy for the European economy and several policy initiatives have been launched in recent years, such as Shaping Europe's digital future, A European Strategy for Data, and the Digital Europe Programme (European Commission, 2025). Therefore, Europe is underway towards a twin transition, combining green and digital transitions, to achieve climate goals.

Digitalization for circular building practices and energy efficiency interventions has been widely studied, with new passport tools emerging from both research and industry to support the twin transition. Some tools focus on the design stage, combining BIM with material passports to increase recyclability of building materials (Honic et al., 2019), while others address broader data requirements for material passports for existing building stock (Çetin et al., 2023). A recent study by Hwang et al., (2025) analyzed 31 EU policy documents and identified nine key digital instruments driving the energy transition of the existing building stock, highlighting DBLs and Building Renovation Passports as essential for informed decision-making for renovating the existing building stock. Similarly, Gómez-Gil et al. (2022) conceptualized DBLs as centralized lifecycle data repositories that enhance data accessibility and support key stakeholders. As illustrated by these examples, the digital passport landscape is diverse and evolving. In the following subsections, we briefly introduce some of the key tools shaping the digital and sustainable transition of the European building sector.

2.1. Material passports (MPs) and material inventories

The term *Material Passports* (MPs) commonly refers to digital datasets that specify the materials used in building components, along with their technical and chemical properties, to support informed end-of-use decisions such as reuse, recycling, or recovery (Çetin et al., 2023). The first conceptualization of this idea can be traced back to the "Nutrition Certificates" proposed by Hansen et al. (2013), which aimed to enhance the value of building materials by documenting their characteristics to enable continuous reuse instead of disposal. With the introduction of the Circular Economy Action Plan and several EU-funded projects, most notably Buildings as Material Banks (BAMB), the concept evolved further. The BAMB project developed a prototype material passport that tracked the residual value of building products along the supply chain, linking components to data carriers such as QR codes (BAMB, 2019). One of the earliest commercial implementations is the Madaster platform, an online database that provides detailed insights into the materials and products used in buildings, including their carbon footprint and economic value (Madaster Platform, 2023).

Due to the evolving nature of the MP concept, they are applied for various purposes across research and practice. The core function of an MP is to facilitate value recovery from building products through reuse and recycling (see, e.g. (Göswein et al., 2022; Munaro and Tavares, 2021),). Beyond this, commercial applications also assess the circularity level of entire buildings and calculate environmental impacts based on the materials they contain (Heisel and Rau-Oberhuber, 2020). Some researchers have developed BIM-based tools that integrate Life Cycle Assessment methods to support design optimization, aiming to improve recyclability performance at the end-of-life stage (Honic et al., 2019). Although the term "material passport" implies a material- or product-level focus, MPs can be developed at various levels of aggregation from individual components to entire buildings.

In terms of lifecycle stages, MPs can be created during the design phase or updated during the operational stage; however, their most critical use occurs when a building reaches the end of its functional life (Çetin et al., 2023). Empirical studies also highlight the use of simplified versions of these tools in practice, commonly referred to as *Material Inventories*. These inventories can be seen as a basic output of the waste audit, listing the type and quantity of materials from donor buildings and serve as practical data sources for stakeholders to reuse materials and elements (European Commission, 2018). Typically, they include basic information about reclaimed components, such as dimensions, condition, and location, and may be supported by photographs and digital tags to facilitate identification and reuse (Buchholz and Lützkendorf, 2022; van den Berg, 2024).

2.2. Digital product passports (DPPs)

The Digital Product Passport (DPP) concept was first and briefly introduced in the EU legal framework under the Batteries Regulation, alongside the battery passport, a specific concept set for this type of product (European Union, 2019). In this diploma, the DPP is presented as the cross-industry concept to which the battery passport must be compliant in relation to technical, semantic and organizational aspects (Jansen et al., 2023). In this, it is also mentioned that the DPP is governed by a framework law applicable to a multiplicity of products, the ESPR. The new ESPR updates and expands requirements for making sustainability a norm for a wide range of products, where construction products are included.

Focusing on this specific industry, it is relevant to highlight that the DPP comes as a natural evolution, as since the first Construction Products Directive, published in 1989, the aim was to establish, via a common technical language, harmonized conditions for the free trade of products inside the EU market (Eurpean Communities, 1988). At that time, the focus was on the standardization of the performance requirements and the assessment methods. Since then, there has been one change leading to the publication of the Regulation EU N° 305/2011, the CPR (Eurpean Union, 2011). This diploma updated requirements and introduced environmental concerns by presenting the EPDs. Yet, these were set as non-mandatory.

Following these developments, there were activities seeking the development of a smart CE mark and the digitalization of product data (Aragón and Alberti, 2024). These initiatives were already anticipating and targeting compliance with the product information needs in BIM (Mêda et al., 2023). The wide understanding and adoption of the CE mark and affiliated declarations by worldwide manufacturers, together with the recognition of the added-value and expansion possibilities, have contributed to the international relevance of the DPP in the construction industry.

A similar and parallel situation has happened with other products, in requirements such as the energy performance and declaration of use of substances of high concern. Presently, the discussions around DPP development and implementation surpass the EU, involving the United Nations and International Standards Organization, just to name a few entities. Several bodies are joining efforts to develop frameworks compliant with the requirements for the DPP to serve a wide range of sectors.

In brief, the DPP is nowadays defined in general terms in the EU Ecodesign regulation, being complemented for specific industries or types of products by delegated acts, where the new CRP is the legal diploma for the construction products (European Union, 2024c). The DPP aims to cover the product's life cycle from manufacturing to elimination. In the construction industry, it is worth highlighting that a product life cycle can cover several building life cycles (Mêda, Hjelseth, et al., 2024).

2.3. Building renovation passports

The emergence of research and policy interest in enabling staged deep renovations within the European Union is a relatively recent development (Fawcett and Topouzi, 2019), with the first drive initiated by the Renovation Wave Strategy (European Commission, 2020a). One notable policy instrument that has emerged in this context is the *Building Renovation Passport* (Buchholz and Lützkendorf, 2023; Spillemaeckers et al., 2021; Villarejo et al., 2021). Central to this tool is a renovation roadmap, which provides a tailored, step-by-step plan to improve a building's energy performance over time by breaking down deep renovation into manageable phases. In doing so, it aims to mitigate common barriers to uptake, particularly those associated with the high upfront costs, technical complexity, and disruptions inherent in deep renovations (Maia and Kranzl, 2019).

Furthermore, scholars recommend expanding building renovation passport content to include energy demand profiles, renovation records, proposed measures, certification schemes, and financial data such as subsidies. Integration with Energy Performance Certificates (EPCs) is also gaining attention, as EPCs offer baseline data and help estimate post-renovation performance (Maia and Kranzl, 2021; Mellwig et al., 2022; Mpouzianas et al., 2024; Sesana et al., 2019). Building on this, Hwang et al., 2025 highlight the central role of the DBL as a foundational data infrastructure for delivering accurate and effective building renovation passports. The 2024 revision of the EPBD further reinforces this direction by setting long-term objectives. By December 2026, all EU Member States are required to establish national renovation plans that outline decarbonization roadmaps, with intermediate targets for 2030 and 2040, and include complementary strategies such as financing schemes and supportive policies (Hwang et al., 2025).

2.4. Digital building logbooks (DBLs) or building passports (BPs)

The concepts of DBLs and BPs have emerged in response to growing demands for comprehensive and interoperable building-related data management throughout the life cycle of buildings (European Commission, 2020b). Historically, the idea of a BP was introduced in national contexts in Germany and Belgium as early as the 1990s, motivated by the need to improve the transparency, traceability and building performance documentation (Buchholz and Lützkendorf, 2023). These early passports primarily functioned as static repositories, capturing essential building attributes, legal records, and performance metrics at specific points in time. Over the past two decades, digitalization in the built environment, together with policy initiatives such as the EU's *Renovation Wave* and *EPBD*, has accelerated the evolution from traditional building passports to more dynamic and interconnected DBLs. The DBL was formally introduced in the 2021 EPBD recast and is now being positioned as a cornerstone of the European strategy to support decarbonization, circularity, and digital integration across the building sector (Alonso et al., 2023; Gómez-Gil et al., 2023).

Although the terms *DBL* and *BP* are often used interchangeably in academic and policy discourses, studies confirm they are conceptually aligned as life cycle-oriented, building-specific data repositories (Buchholz and Lützkendorf, 2023; Signorini et al., 2025). Both aim to centralize building data in a single digital interface for use by diverse stakeholders, with differences largely tied to national or institutional preferences (Buchholz and Lützkendorf, 2023). However, the European Commission's *Technical Guidelines for Digital Building Logbooks* (DG Grow, 2023) introduce a key distinction: while BPs offer a static snapshot, DBLs are designed for dynamic, time-based tracking as they log ongoing changes, such as ownership transfers, system upgrades, and real-time performance data (DG Grow, 2023; Mêda, Fauth, et al., 2024). To unlock the full potential of DBLs, a harmonized European framework is essential, one that ensures semantic and technical interoperability while allowing for decentralized implementation responsive to national contexts (DG Grow, 2023).

2.5. Research focus

Fig. 1 presents an overview of key passport initiatives currently being developed and deployed across Europe to support sustainability transitions in the built environment. While MPs and DPPs share overlapping goals, stakeholders, and data requirements, their regulatory status and scope vary significantly (Honic et al., 2024). Notably, DPPs are being formalized through EU legislation and are set to become mandatory instruments for promoting transparency, traceability, and circularity at the product level (European Union, 2024a). In contrast, MPs remain voluntary and fragmented in their application, supporting data management at the product and building levels, and is mostly driven for the economy of resources (Çetin et al., 2023). Similarly, while BPs and DBLs often refer to similar concepts (Buchholz and Lützkendorf, 2023), recent EU policy direction has increasingly emphasized the DBL as the preferred terminology and framework for managing comprehensive, life cycle-oriented building data (European Commission, 2020b).

Given this policy momentum, we argue that integrating DPPs into DBLs is not only logical but necessary (Mêda, Hjelseth, et al., 2024). Both are driven by EU regulatory frameworks and share the objective of creating interoperable, data-rich systems to support circular and sustainable building practices. DBLs, as centralized repositories of building-level information, and DPPs, as standardized sources of product-level data, must be aligned to ensure seamless data exchange, reduce duplication, and enable more effective decision-making throughout a building's life cycle. Therefore, this study focuses on the technical, procedural, and socio-organizational challenges and opportunities associated with this integration.

3. Materials and methods

3.1. Multiple-case study

In this study, we adopted a qualitative multiple-case study approach, following the methodological guidelines of Yin (2018), to explore the adjustments required in social and technical aspects by DBL owners to effectively integrate DPPs into their tools. The analysis is conducted from a socio-technical systems perspective (Sony and Naik, 2020), enabling a comprehensive assessment of processes, people, technological aspects (Schlarman, 2001), as well as the barriers and facilitating factors involved in linking these two instruments. We selected a socio-technical lens because it acknowledges the interdependent relationship between social elements (e.g., stakeholders and their interactions) and technical elements (e.g., technologies and systems). This perspective allows us to more effectively identify complexities, interdependencies, and dynamics within the case studies, providing a holistic understanding of the DPP-DBL integration challenges and opportunities.

The multiple-case study methodology was chosen for its strength in providing detailed insights into each individual scenario, while also supporting comparative analysis across different cases (Eisenhardt, 1989). This approach identifies both commonalities and distinctions among cases, generates fresh insights from empirical evidence (Eisenhardt, 1989), and enhances the accuracy, dependability, and credibility of the study findings (Yin, 2018). Ultimately, the goal of this research is to create a guiding framework linking DPPs with DBLs informed by real life cases and furthermore address identified challenges by recommending enablers to DBL owners and policymakers to accelerate the sustainable transition of the building industry.

3.2. Case selection

When selecting cases, we deployed Yin's (2018) replication logic, which is different from sampling logic commonly used in surveys. While sampling logic typically requires selecting a subset of respondents statistically representative of a larger population, replication logic aims to select specific cases based on theoretical propositions. This approach does not attempt to statistically represent a broader population. Instead, it seeks to gain insights that replicate or contrast across selected cases to yield robust analytical results. As listed in Table 1, we selected four cases from different European countries based on the following criteria:

	Material Inventories	Material Passports	Digital Product Passports	Building Renovation Passports	Digital Building Logbooks
Scale	Material, Product, Element	Area, Complex, Building, Element, Product, Material, Raw material	Product, Element	Building	Building
Industry	Built environment	Built environment	Cross-industry	Built environment	Built environment
Lifecycle stage*	End-of-use	End-of-use	Whole lifecycle	Operation/ use	Whole lifecycle
Policy or regulation**	CE Action Plan Waste Framework Directive	CE Action Plan Waste Framework Directive	EU Ecodesign Directive, ESPR, CPR	EPBD, Renovation Wave	EU-wide Framework for a DBL, Renovation Wave, EPBD

Fig. 1. Overview of the key digital passport initiatives for sustainable buildings in Europe. DPPs and DBLs are highlighted with dotted lines as their integration is the focus of this study.

Table 1
Overview of selected cases.

Name DBL	Active regions	Primary data	Secondary data
DBL 1	Germany, Scotland, the Netherlands, Italy	Managing director (interview) Project manager (interview)	Company website, presentations, EU project reports, white papers
DBL 2	The UK	Chief operating officer (interview)	
DBL 3	France	General director (interview) Project manager (interview)	
DBL 4	Belgium	Project manager (interview)	

Table 2
Details of the selected cases.

Case study	Active regions	Passport type	Market focus	Functionalities
DBL 1	Germany, Scotland, the Netherlands, Italy	BP	Homeowners, real estate companies, housing associations	User-friendly data collection, energy balance, decarbonization strategies
DBL 2	The UK	DBL	Homeowners	Classic property logbook for building related data, user-centric renovation advice
DBL 3	France	DBL	Homeowners, property professionals	Centralized data repository, maintenance and renovation advice
DBL 4	Belgium (Flanders)	BP	Homeowners	Official data repository for building data, API connection with other databases, renovation guidance

- Tools operate currently within the European building industry,
- Tools identify themselves as a BP or DBL,
- Tools implicitly or explicitly support sustainability transitions strategies, such as energy renovation, circular construction, or carbon reduction,
- Tools that primarily label themselves as an MP or a material inventory were excluded due to conceptual overlaps with DPPs (see, Sections 2.1 and 2.5).

3.3. Data collection and analysis

Data collection for the selected cases involved both primary and secondary sources. For primary data, semi-structured interviews were conducted with DBL owners or relevant employees to explore their experiences, practices, and perceptions regarding DPP–DBL integration. Interviews were held online via Microsoft Teams, recorded, and transcribed verbatim. Interview questions can be found in Appendix A. In total, six professionals participated, with sessions ranging from 40 to 90 min. These sessions were held between April 2025 to August 2025. Secondary data included company websites, professional reports, online presentations, and both academic and grey literature related to each case, providing contextual background and supporting triangulation of the findings.

The collected data were first analyzed on a case-by-case basis and subsequently compared across cases using thematic coding based on the People, Process, and Technology (PPT) framework developed by Schlarman (2001). This approach enabled a systematic classification of the barriers and enablers identified in the interviews, thereby directly addressing the research question. Further, building on this, both individual and cross-case insights were synthesized to develop a framework that gives a pathway for future integration of two technologies.

4. Findings and discussion

This section presents the findings from four case studies focused on the current challenges and potential enablers of integrating DPPs into DBLs. The results are organized under the socio-technical dimensions of technology, process, and people, reflecting both the structural and behavioral factors (See Fig. 2). Furthermore, building on case study findings and literature review, we present a framework to address identified challenges (Section 4.5).

4.1. Overview of the cases

The first case, DBL 1 (Germany) is a BP tool developed to support building owners, housing associations, and asset managers in collecting and managing structured building data. The platform operates on both a smartphone app and a cloud-based database. The main functionality of DBL 1 is enabling non-expert users to collect robust, visible building data, such as structural elements, systems, and photos for contextual analysis. These data are visualized in a simplified 3D model of a building. The platform calculates the energy balance and operational energy consumption and provides whole life carbon assessments, covering both operational and embodied emissions. DBL 1 further offers tailored decarbonization strategies, including retrofit and renewable energy options. In terms of circularity, DBL 1 supports layering materials in their data models and is currently running a project with a material supplier to apply unique material identifiers to be able to quickly identify and reuse certain materials from the buildings registered in their system. See in (Table 2).

The second case, DBL 2, is a UK-based digital property logbook designed for homeowners to manage data and records related to their residential property. It enables users to store and track information such as property transactions, building work, certifications, and maintenance activities. DBL 2 logbooks are connected to permanent data sources like the land registry, local authorities, and certification bodies, while also supporting temporary links to estate agents, conveyancers, and other professionals. The platform is homeowner-focused and prioritize user access and control over all data related to their property. To improve sustainability services, DBL 2 is currently developing a user-centric automated renovation advice for their users. In addition, in the coming months, a test connection is to be made with a DPP software through API.

The third case, DBL 3 is a DBL, currently deployed across 50,000 dwellings in France, including multifamily and single-family homes. Designed for both residents and property professionals, DBL 3 offers a centralized digital space accessible via web and mobile app, allowing users to manage and access key information about their property, including general dwelling data, equipment, regulatory documents (e.g., diagnostics, warranties), and energy consumption. The platform also features real-time energy monitoring, maintenance tracking, and a communication module for updates and alerts. Furthermore, DBL 3 provides advice to their clients on maintenance of the equipment to prolong lifetime of products as well as promote energy efficiency through a new functionality for renovation advice.

Finally, the fourth case, DBL 4 is a BP platform developed by the Flemish Government for residential dwellings in Flanders in Belgium. It serves as a centralized and user-friendly repository containing verified information about a building, its plot, and surroundings. The platform includes various data such as energy performance (e.g., EPC label, renovation roadmap, actual energy use), installations, and soil

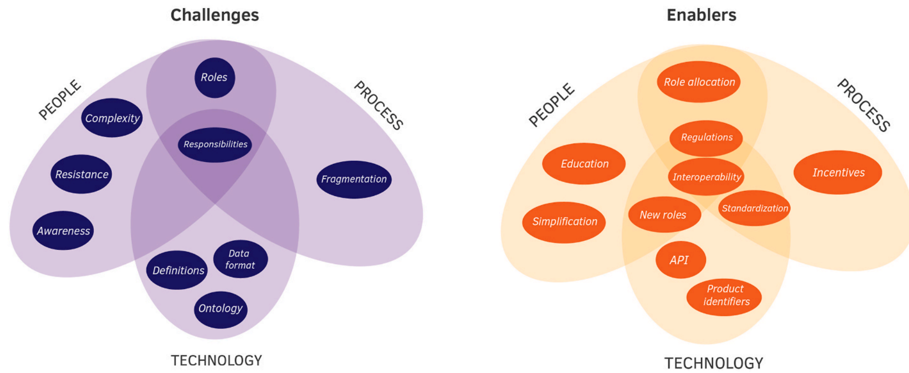

Fig. 2. Main challenges and enablers clustered at People, Process and Technology dimensions (based on Meda et al., 2024).

composition. DBL 4 integrates data from various government sources through automated API connections, ensuring real-time updates and accuracy. The platform also supports data sharing with third parties and professionals via secure access. Aimed at individual building units (e.g., single-family homes or units in multifamily buildings), DBL 4 enables owners with transparent, official data and guidance for sustainable renovation and long-term property management. DBL 4, in collaboration with other organizations, is developing a new module for circularity and inventory of materials.

Overall, all selected case studies function primarily as central data repositories for buildings or individual building units, providing guidance on enhancing energy performance. Currently, circularity and DPPs are not core priorities for these tools. Nevertheless, all cases acknowledge the growing importance of integrating DPPs, driven partly by policy developments, although circularity and DPP implementation are not yet mandated by regulation. The subsequent subsections will explore the key challenges and enabling factors associated with this integration and propose a guiding framework to advance this agenda.

4.2. Technological challenges and enablers

Although most interviewees considered their technical infrastructure and digital capabilities to be relatively advanced, they highlighted ongoing challenges related to the semantic and systemic alignment between DPP and DBL data. These challenges primarily stem from issues of interoperability, standardization, and data architecture rather than technological limitations. Interviewees further noted that integrating DPPs into their existing DBLs would not present significant technological obstacles, as their current workflows already involve regular updates and adjustments to software operations.

A recurring challenge across all cases is the absence of common definitions and ontologies for building components and construction products. This makes it difficult to ensure consistent and automated mapping between DPPs and the digital records within DBLs. The interviewee from *DBL 2* pointed out, *"The tech is simple … The real problem is: what is a product? Is a window a product, or is it five products?"* This problem is exacerbated in complex building assemblies, where multiple layers of materials may or may not each carry their own DPP. Such ambiguity may introduce noise into the data model and hinder both usability and traceability. All four cases emphasized that technological integration is entirely feasible, provided that a set of shared technical and semantic standards are adopted. As the interviewee from *DBL 2* underscored: *"Once the industry agrees on what the data schema looks like, we're ready. The hard part isn't tech, it's getting people to agree."* Especially, DPP integration through APIs is mentioned to be an enabler.

Furthermore, *DBLs* continue to rely on unstructured data formats, including PDFs, scanned invoices, and unverified documents. As noted by the *DBL 3* interviewee: *"Most of the information is contained in PDF documents … it's not very useful if you want to exploit the information."* This reliance on static, often incomplete documentation obstructs automated data processing and might undermine the verification of DPP attributes like recyclability, emissions data, and material origin. Additionally, lack of object-level identifiers within building records prevents DPPs from being linked systematically to their corresponding physical assets in a DBL, a problem explicitly raised by *DBL 1, DBL 3 and DBL 4. DBL 1* has already piloted the integration of material tracking systems (QR-tagged products) automatically linked to the logbook, reducing human error and administrative effort: *"We are in a project with a material supplier … where we track concrete from the old building and prove it is reused as insulation in the new one."* This proof-of-concept demonstrates that when upstream product information is structured and digitalized, integration with DBLs becomes both possible and impactful.

4.3. Process related challenges and enablers

Beyond technological considerations, institutional and procedural issues may also complicate the integration of DPPs into DBLs. Across all four case studies, the workflows for embedding DPP data within DBLs are either unclear or voluntary, resulting in limited adoption. A significant challenge lies in ambiguity regarding roles and responsibilities. For example, in the DBL 3 case, although legislation assigns responsibility for DBL data entry to building owners, this top-down directive has proven ineffective in practice. The platform coordinator highlighted this problem, stating, *"Who is going to fill in, and who is going to pay for it? If it's a professional, they will ask who is going to pay for the time spent entering accurate information into the customer's record."* This illustrates a misalignment between assigned data responsibilities and actual user capabilities. Homeowners are legally obligated to document information that they neither fully understand nor prioritize, whereas stakeholders who possess the necessary data, such as builders, suppliers and auditors have no binding legal or financial incentive to contribute. Similarly, DBL 2 experienced challenges when attempting to involve contractors in the documentation process due to the added complexity: *"If you ask a contractor to create an account just to enter one document for one job, you will lose them at the login screen."* Additionally, DBL 1 highlighted limited enthusiasm even among environmentally aware clients, emphasizing, *"Even if there are 80 clients, only one will typically go that far."* These observations indicate broader structural barriers that must be addressed to facilitate meaningful integration of DPP and DBL workflows.

These findings indicate a lack of effective incentives and standardized procedural triggers for capturing DPP data during critical lifecycle events, such as construction, renovation, and maintenance. DBL 1, for instance, illustrated how market-driven incentives such as public tenders and certification schemes can effectively stimulate integration. In one Swiss project, the capability to track secondary materials via the DBL directly contributed to enhanced environmental certification, providing a tangible competitive advantage: *"You suddenly get a market advantage by making that effort … but you need to prove it."* At the procedural level, successful integration is significantly more probable when it aligns closely with existing regulatory frameworks and established operational workflows. A DBL 2 interviewee emphasized the necessity of regulatory support, stating: *"None of this will happen unless the industry regulators make it happen."* Additionally, automation of data collection through API integration and intelligent document processing was highlighted as an enabling measure. These examples collectively suggest that integration efforts are most effective when data requirements coincide with existing incentives and regulatory processes, such as permitting procedures, subsidy allocation, or sustainability certification schemes. Finally, simplifying user interactions was repeatedly emphasized as essential. Rather than adding complexity through additional tools, DBL 2 and DBL 4 adopted hybrid solutions, leveraging familiar communication channels (e.g., email or pop-up messages) to streamline data collection and encourage user compliance.

4.4. People related challenges and enablers

Among all four cases, barriers related to people emerged as the most widespread and challenging. These barriers include resistance to adopting digital tools, limited awareness of DPPs, and confusion about roles and responsibilities within project teams (issues that also negatively affect workflows). Interviewees frequently noted digital fatigue among construction professionals. For instance, a DBL 3 representative explained: *"They don't like administrative tasks at all, especially having to sit in front of a computer just to enter details about windows or materials."* Often, stakeholders struggle to see the value or purpose of DPPs. According to DBL 2: *"We're creating a complicated web of digital tools, DBLs, building renovation passports, materials passports, product passports, that don't make sense to the average person."* This overload of information, combined with industry jargon, duplication of effort, and fragmented responsibilities, discourages engagement across the entire value chain.

To overcome these challenges, interviewees highlighted the importance of human-centered design, simplicity, capacity building, and clearly defined roles. Education and targeted training were consistently emphasized as crucial for effective DPP–DBL integration, especially for professionals directly involved in data entry. DBL 1 specifically called for clarity in role allocation, noting: *"If we DBL 3rly state that it's the contractor's responsibility to upload product data, then they become accountable. Right now, nobody is clearly assigned that job."* Additionally, user-friendly design emerged as a key factor. As a DBL 1 interviewee succinctly stated: *"Entering product data should be as easy as ordering a hamburger."* Participants frequently recommended intuitive tools, automated data entry, and pre-filled forms as practical ways to overcome resistance.

Even among more institutional actors, such as regional governments, there is confusion around roles. Interviewee from DBL 4 openly acknowledged that although they have started exploring circularity, their understanding of DPPs remains limited: *"We do not yet address circularity or material impacts … but we are eager to integrate these aspects in the future. The process of creating a DBL caused hesitation because it demands extensive information from users."* Furthermore, none of the case studies had DBL 3rly assigned roles focused on data stewardship. As the interviewee from DBL 2 pointed out: "*When we talk to developers, no one knows who we should approach about data, such a role doesn't even exist."* This lack of clear accountability represents an organizational gap. Even if platforms are technically prepared to handle DPP data, there is often no responsible person to ensure timely, accurate, and complete data entry. Finally, interviewees emphasized that regulatory support and market incentives are critical to changing behaviors and attitudes, as these external pressures motivate stakeholders to actively implement DPPs.

4.5. Towards a DBL as systems of systems

Building upon the empirical insights gained from our multiple-case analysis and the literature presented in Section 2, this section discusses the future role of DBLs and introduces a guiding framework aimed at overcoming the identified socio-technical challenges with the enablers emerged from case study analysis, especially those related to interoperability, standardization, simplification and regulation.

According to the European Commission's 2020 DBL study report (European Commission, 2020b), a DBL is defined as *"a common repository for all relevant building data. It facilitates transparency, trust, informed decision-making, and information sharing within the construction sector, among building owners and occupants, financial institutions, and public authorities … As such, it can include administrative documents, plans, descriptions of the land, building and surroundings, technical systems, traceability and characteristics of construction materials, performance data such as operational energy use, indoor environmental quality, smart building potential, lifecycle emissions, as well as links to building ratings and certificates …"* Following this definition, DBLs are envisioned as central digital platforms managing building-related data throughout all lifecycle stages of buildings.

However, as discussed in Section 2, the extensive range of existing digital tools reflects the complexity inherent in managing building data. Although these tools are developed to serve specific purposes, overlapping functionalities and inconsistent terminologies frequently lead to confusion. Reflecting on lessons learned from previous BIM research on BIM implementation barriers (Ahmed, 2018) (e.g., social and habitual resistance to change, lack of sufficient information sharing and lack of standardization), it has become clear that no single system can comprehensively address all requirements. Instead, effective digital transformation in construction relies heavily on integrating multiple specialized systems (Farghaly et al., 2024).

In this context, the concept of a System of Systems (SoS) emerges as particularly relevant. An SoS refers to a collaborative, interactive ecosystem where multiple independently managed systems operate collectively to achieve shared objectives (Sadeghi et al., 2024). Typically, an SoS exhibits three core characteristics: first, it is open at the top, meaning new applications can be integrated dynamically. Second, it is open at the bottom, allowing functional rather than rigidly specified definitions of system components. And, third, it is continuously evolving, balancing stability with adaptability to accommodate changing needs (Klein and Van Vliet, 2013).

We argue that DBLs should be designed and function as an SoS, as envisioned by the European Commission, to effectively address interoperability and data standardization challenges. As illustrated in Fig. 3, four distinct clusters have been identified, with the DBL positioned as a central hub that integrates these clusters, streamlining diverse streams of building data into a cohesive and interoperable framework.

This SoS approach provides a robust response to the interconnected challenges of integrating DPPs and DBLs, including semantic misalignment, reliance on unstructured data, unclear role definitions, and limited stakeholder engagement. Addressing these issues requires a holistic perspective that acknowledges interdependencies across technical, procedural, and organizational dimensions. Sustainability itself is a complex, systemic problem that demands systems thinking (Voulvoulis et al., 2022), where effective solutions account not only for technological considerations but also for governance structures, workflows, and human behavior.

Regulations play a particularly critical enabling role and must be both clear and enforceable. Systems thinking frames regulations as systems in their own right, composed of interconnected rules, incentives, procedures, and data flows. An SoS perspective facilitates the alignment of regulatory frameworks with the technical systems they govern, thereby reducing ambiguity in data requirements and ensuring legal expectations correspond to actual information flows. As demonstrated in the case studies, vague or voluntary responsibilities hinder effective implementation. Regulatory instruments should therefore be precise, mandatory where appropriate, and complemented by incentives that reflect the capacities and roles of relevant actors.

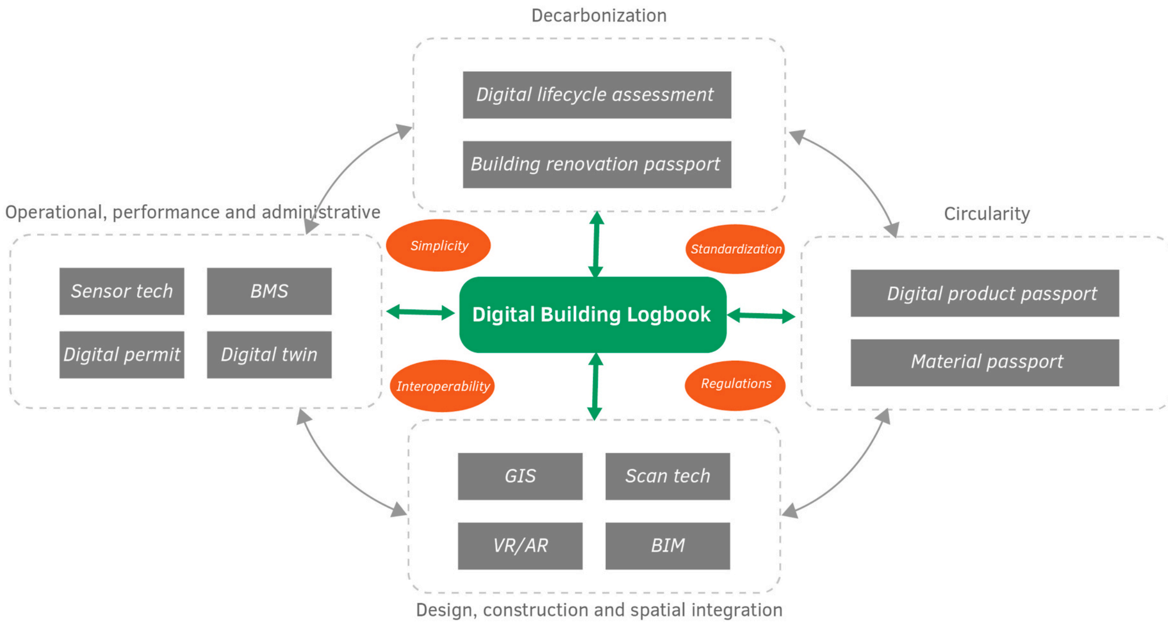

Fig. 3. Digital building logbooks as System of Systems (SoS). Built on previous research (Farghaly and Jones, 2023).

Second, standardization is essential for aligning information requirements, data structures, and data exchanges. An SoS perspective supports this process by enabling the harmonization of ontologies, terminologies, and metadata across systems. Numerous initiatives are already underway to define core datasets and minimum information requirements (see, e.g., the Dutch construction industry's efforts to standardize circularity data (Çetin et al., 2023; Platform CB'23, 2020)); however, many of these emerge through bottom-up processes, which can constrain their scalability and interoperability. A coordinated SoS framework can bridge bottom-up initiatives with top-down governance, a balance that is crucial for achieving effective and widely applicable standardization. Once data requirements are clearly defined and standardized, system integration becomes significantly more feasible.

Third, interoperability, both semantic and syntactic, is inherently supported by the SoS approach. Semantic interoperability, defined as the consistent interpretation and use of data, relies on shared ontologies and metadata, which become more feasible to develop and adopt once standardization and regulatory clarity are established. Building on this foundation, syntactic interoperability, the ability to exchange data through consistent formats and protocols, can follow. This enables system-to-system integration via open, verified APIs grounded in agreed vocabularies. Within the context of building information systems, the DBL can serve as the overarching SoS, coordinating and regulating data flows across subsystems through standardized vocabularies and APIs.

Finally, simplicity emerges as a cumulative outcome of the other enablers. When users clearly understand which data to provide, how to structure it, and why it is required, the burden of compliance is reduced, and engagement improves. An SoS perspective facilitates streamlined data entry and interface design by ensuring that only relevant information is requested and that data can be submitted through familiar, accessible channels. This user-centered orientation is crucial for reducing digital fatigue and overcoming resistance to adoption. In conclusion, the SoS approach offers a scalable and coherent means of coordinating diverse initiatives, systems, and stakeholders. By addressing regulation, standardization, interoperability, and simplicity in an integrated manner, SoS can underpin the effective and sustainable implementation of DPP–DBL integration.

4.6. *Policy recommendations*

To support seamless DPP-DBL integration, the EU should accelerate efforts to develop and enforce a harmonized EU-level data dictionary and ontology for construction products and building components. As case findings indicate, inconsistent terminology and lack of object-level identifiers significantly hinder interoperability. The creation of standardized data schemas, aligned with BIM and existing EU databases, could enable more automated and accurate data exchanges across platforms.

Policymakers should embed DPP data collection and integration into key life cycle procedures such as permitting, subsidies, certification schemes, and public procurement. Evidence from the cases shows that integration is more likely when linked to financial or regulatory incentives. Procedural triggers, such as requirements during renovation subsidies can institutionalize DPP workflows and accelerate adoption.

The rollout of DPP and DBL integration must be supported by widespread awareness campaigns and targeted capacity-building efforts. National and EU-wide digitalization strategies and vocational training programmes should include modules on circularity data, DPPs, and data interoperability. Particular attention should be paid to onboarding construction professionals, architects, product and material manufacturers, and legal actors, who are essential to effective implementation.

To avoid fragmented implementation, the EU should coordinate the rollout of the important policies such as ESPR, CPR, EPBD, and Circular Economy Action Plan with a common vision for digitalizing building data. This action must be coordinated with the intentions of setting a common European data space for the construction/built environment. An EU-wide digital governance body could help align the objectives, timelines, and technical requirements of related initiatives, ensuring that DPP and DBL (and other digital instruments such as permits and renovation passports) developments reinforce and integrate rather than duplicate each other. Alternatively, new task forces could be formed across policy initiatives to align digital goals and technical requirements.

While there is a history of harmonization for the elements that constitute the basis for the DPP, as evidenced, a similar effort is needed for the DBL, starting with the aspects that are already common across the EU regarding building characteristics and information. In this respect, the data collected for statistical purposes and the GIS metadata standardization initiatives play a key role in streamlining achievements.

4.7. Future research and limitations

This study presents a multiple case study and a guiding framework to address the socio-technical challenges and enablers of integrating DPPs into DBLs within the European building sector. However, several limitations should be acknowledged, which also offer directions for future research.

First, while the qualitative insights derived from exploratory multiple-case study approach provide an in-depth exploration of real-world practices across diverse European countries, namely, Belgium, France, Germany and the UK, our findings are inherently context-specific and may not be generalizable to other countries, contexts and EU-level understanding. Future research could enhance our findings with broader studies such as surveys to examine patterns across a wider sample of DBL initiatives. Given the limited number of cases, theoretical saturation cannot be fully ensured. Future studies could consider other case selection criteria such as development stage of each DBL, duration of use for more saturated results. Also, comparative multiple-case studies are recommended to investigate country specific integration and standardization issues that eventually could help developing a harmonized EU-level ontology for DPPs.

Second, although the study adopted a socio-technical lens to capture the interplay between people, processes, and technologies, the analysis primarily focused on DBL owners and tool developers. As such, perspectives from other critical stakeholders, such as construction product manufacturers, contractors, public authorities, architects and end-users remain underexplored. Future research should engage with these actors to better understand how DPP-DBL integration affects different layers of the building ecosystem.

Third, this study captured a specific moment in the regulatory landscape shortly after the implementation of the ESPR and ahead of the full enforcement of the revised CPR. As policies evolve and DPPs become more widely implemented, longitudinal research will be valuable to track institutional adaptation, assess the effectiveness of integration efforts, and identify emergent best practices over time. We recommend follow up case studies with the same or forerunner DBL operators after a few years of DPPs becoming mandatory for construction products.

A fourth limitation of this study is that it does not include a systematic comparative analysis of national and EU-level policy documents and technical standards related to DBLs and DPPs. Given the uneven maturity and limited availability of such documentation across EU Member States, the present research primarily draws on stakeholder perspectives rather than formal regulatory frameworks. However, as national and EU policy frameworks continue to develop and become more established, future research will be increasingly able to conduct structured document analyses and cross-country comparisons to better explain how regulatory and standardization differences shape integration or fragmentation.

Finally, this study contributes to a growing body of knowledge on digitalization energy and circular economy transitions, thus twin transition. Further empirical and interdisciplinary research is essential to support the practical implementation of interoperable, human-centered, and policy-aligned digital systems for a sustainable built environment.

5. Conclusion

This study examined the socio-technical challenges and enablers of integrating Digital Product Passports (DPPs) into Digital Building Logbooks (DBLs) through a multiple-case study across four European initiatives. By adopting a socio-technical systems perspective, the study recognizes that integration challenges are not only technological, but also shaped by organizational, cultural, and regulatory conditions. This distinction is particularly important in a field that is often dominated by purely technical approaches. The research results revealed that technological barriers are less about digital capacity than about semantic misalignment, lack of standardized ontologies, and reliance on unstructured data. Equally important are procedural and organizational barriers, including unclear role allocation, insufficient incentives, and fragmented workflows. At the human level, digital fatigue, limited awareness, and ambiguous responsibilities hinder stakeholder engagement and adoption.

Drawing on empirical insights, the study proposes that DBLs should be designed and operated as Systems of Systems (SoS). Such an approach allows DBLs to act as integrative hubs that coordinate diverse tools, datasets, and stakeholders through four key enablers: regulation, standardization, interoperability, and simplicity. Clear and enforceable regulatory frameworks, harmonized ontologies and data schemas, semantic interoperability, and user-centered design are collectively essential to achieve scalable, effective, and sustainable DPP–DBL integration.

The findings underscore the importance of aligning bottom-up innovation with top-down governance to avoid fragmented implementation and ensure interoperability across the European building sector. As the EU moves forward with the ESPR, CPR, EPBD, and the Circular Economy Action Plan, harmonized governance structures, common technical standards, and targeted capacity-building efforts will be critical for accelerating adoption. Ultimately, the integration of DPPs into DBLs has the potential to transform the building sector by improving data transparency, supporting circularity, and facilitating the twin transition through digitalization. However, this transformation requires not only technological solutions, but also institutional reforms, human-centered design, and coordinated policy action.

Data statement

The interview transcripts generated and analyzed during this study are not publicly available due to confidentiality agreements with participating commercial companies. Sharing the full transcripts could reveal sensitive business information and potentially affect the competitive position of the organizations involved.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Open AI Chat GPT in order to improve readability of the manuscript. The tool is not used to create content. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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CRediT authorship contribution statement

Sultan Çetin: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. **Pedro Mêda:** Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing. **Karim Farghaly:** Conceptualization, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing. **Sun-Ah Hwang:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sultan Cetin reports financial support was provided by European Union. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Interview questions

Table A
Interview questions.

	Category	Interview questions	Related part in article
DBL Related Generic Questions	**Knowledge and Strategic Intentions**	Could you briefly describe the main functionalities and sustainability ambitions of your DBL tool? Does the concept of CE play a role in there? To what extent is your DBL tool designed to support circular strategies (such as reuse, recycling, design for disassembly)? Do you have specific goals or KPIs related to circularity and/or carbon reduction that your DBL helps address?	Section 4.1
	Knowledge and Implementation of DPPs	Are you familiar with the concept of Digital Product Passports? How would you describe your current understanding of DPPs and their relevance for the construction sector? Do you see potential added value in integrating DPP data into your DBL? Why or why not? Have you already taken any steps (pilot projects, consultations) towards exploring DPP implementation in your DBL?	
	Current Practices: Data Management and Integration	What types of data (e.g., material data, energy performance data, maintenance records) are currently collected and stored in your DBL How is product or component-level data currently handled within your DBL (if at all)? Are there existing integrations between your DBL and external databases, product catalogs, or renovation passports?	
Linking DPPs and DBLs	**Technology related challenges and enablers**	From a technical perspective, what adaptations would your DBL system need to integrate DPP data (e.g., database structure, APIs, metadata standards)? Are there current technological limitations in your DBL that might complicate DPP integration? What technical barriers or challenges do you foresee when integrating DPP data (e.g., interoperability, data quality, system updates)? What technical solutions, innovations, or standards (e.g., digital twins, blockchain, semantic ontologies) could act as enablers for linking DPPs with DBLs?	Section 4.2, 4.3, 4.4 & 4.5
	People related challenges and enablers	Which internal or external stakeholders would play a critical role in the integration of DPPs into your DBL? What additional human resources (e.g., new roles, skills, capacities) would be necessary to manage DPP information in your DBL? What people-related barriers and enablers do you anticipate (e.g., skills gaps, resistance to change, stakeholder misalignment)?	
	Process related challenges and enablers	Would the integration of DPPs require changes to your organizational workflows, data management processes, or business model? What process-related barriers could hinder the integration (e.g., lack of clear procedures, complexity of information flow, regulatory uncertainty)? What kinds of process improvements or methodologies could facilitate the DPP-DBL linkage (e.g., standardized data protocols, clear governance models)?	
	Future outlook	How do you envision the evolution of DBLs in the next 5–10 years in the context of digitalization and sustainability transitions? Do you foresee DBLs becoming part of a broader integrated system (e.g., connected to smart buildings, product supply chains, ESG reporting)? In an ideal world, what would a fully integrated DBL-DPP ecosystem look like from your perspective?	

Data availability

The data that has been used is confidential.

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