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European building passports: developments, challenges and future roles

SYNTHESIS

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ABSTRACT

Throughout the life cycle of buildings, data are created, collected, processed, exchanged and used to support decision-making and operations. However, the construction and real estate actors often struggle with managing data successfully, mainly because existing data resources are scattered across a large number of changing building owners and stakeholders. The goal of adopting and using building information management tools (BIMTs) that store, exchange and manage building-related data is to overcome information silos and bring together data about a particular building. BIMTs, such as a building passport (BP), an electronic building file or a digital building logbook (DBL), follow a holistic approach by serving as data repositories. Although the underlying idea is not new, the topic recently gained wider attention at the interface of politics, academia and real estate industry. The current state of BIMTs, and in particular the role of BPs, is analysed to help understand the main driving forces, challenges and opportunities in BP development.

POLICY RELEVANCE

Mandatory introduction of Energy Performance Certificates (EPCs) in Europe can be seen as a role model for BPs. The aims were to improve transparency in the real estate market to encourage owners to modernise their buildings and to inform market participants about hidden characteristics. These tasks are now transferred to more complex BIMTs. The European Commission has introduced DBLs in the Energy Performance of Buildings Directive (EPBD) in 2021 as a data repository that is supposed to be linked to national databases on the energy performance of buildings. In addition, the European Commission is working on a European framework for DBLs and has the vision of establishing a network of national DBL databases. No legal obligation to use BPs/DBLs exists yet, but further proposals in European and national regulation are expected in the future.

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1. INTRODUCTION

Building-related data are essential for preparing and making decisions at different points in the building life cycle. Collecting, managing, exchanging, transferring and interpreting information has always been an implicit task of building owners and other stakeholders. The construction and real estate industries have developed and established various approaches to managing information during the design, construction and operation of a building. Today, practitioners are increasingly confronted with large amounts of building-related data that can be collected and increased requirements by stakeholders, such as the public sector, financial organisations, insurers, appraisers, *etc.* To meet the resulting information needs and support building owners and other stakeholders, building information management tools (BIMTs) are being developed. This is the result of several developments:

- New attributes are needed to describe the functional properties and characteristics of buildings against the background of current information demands. The construction and real estate industries are estimated to account for 34% of the global final energy consumption and 37% of global CO_2 emissions (GABC 2023). Governments and societies acknowledge that the built environment is a key area of action when it comes to defining and pursuing climate and environmental goals. This leads to great interest in the greenhouse gas emissions or material composition of a building. Standardised approaches to collecting, storing and disseminating the required data are needed.
- Actors in the construction and real estate industries seek to make the real estate market more transparent. BIMTs could contribute to more transparency about buildings and their characteristics by providing actors with the specific information they need. This applies to various occasions and tasks in the life cycle of a building, such as valuation, real estate transactions and maintenance planning.
- The public sector is looking for instruments to help steer its political objectives. Given the importance of buildings to economic, ecological and social development, the public sector welcomes solutions provided by BIMTs and has an interest in the respective data itself.
- The construction and real estate industries need a more extensive and intensive exchange of information to comply with the principles of sustainable development, as expressed in environmental, social and governance (ESG) guidelines, sustainability reporting, integration of sustainability aspects in risk analysis and portfolio management.

First suggestions of how BIMTs should be formally named, used and maintained/updated can be found in the literature. One option consists in building passports (BPs), which can be defined as follows:

> A [BP …] is a whole life cycle repository of building information. It covers a building's administrative documentation as well as data regarding its plot and location, its technical and functional characteristics, and its environmental, social and financial performance. In its fully digital realization, the [BP …] acts as a single point of input, access and visualization of all the information associated with a building. It is a living document, containing a mix of traceable static 'as built' and continuous dynamic record-keeping of performance data and information.
>
> (Hartenberger *et al.* 2021: 14)

The idea behind the concept is to dynamically collect, store and provide relevant building-related data throughout the design, construction and operation of buildings (Dourlens-Quaranta *et al.* 2020). As a result, BPs are assumed to offer benefits to the actors of the construction and real estate industry. For example, they can standardise the documentation of constructed assets, help monitor building performance, increase transparency in real estate transactions, and facilitate communication between building owners and stakeholders (Hartenberger *et al.* 2021; Signorini *et al.* 2021).

Although BPs create many potential benefits, they are not yet well-established despite a 40-year history. While the discussion and the tool itself benefit from the newly gained attention, there are still misconceptions about the functionality and ways to overcome existing barriers for further developments.

The aim of this paper is to improve the understanding of BPs by considering the following main questions:

- How do BPs fit into the overall landscape of BIMTs?
- Why is it important first to define the main functions of tools such as a BP or digital building logbook (DBL) in the context of information management?
- What are the milestones that led to the current understanding of BPs?
- Which challenges exist in the development of BPs according to the literature?
- How do different initiatives deal with the concept?
- Where are similarities and differences compared with other BIMTs, and which implications as well as recommendations can be derived for the further development of BPs?

The paper is structured as follows. Section 2 deals with the first research question by classifying BPs in the context of information management for buildings. Section 3 explains the method of the analysis that is based on a systematic literature review. The results are presented in Section 4 together with current development challenges. Section 5 contains conclusions, limitations and recommendations for further action.

2. INFORMATION MANAGEMENT TOOLS

2.1 TYPOLOGY OF TOOLS

This section introduces different types of BIMTs and their main functions to improve the understanding of how BPs fit into a broader context. The development and implementation of different types of BIMTs mainly result from specific needs of actors, such as building owners, constructors, facility managers, surveyors or public authorities. To support their information management throughout the construction, design and operation of buildings, these actors use tools to collect, store and analyse data. In past years, special attention was given to tools that were specifically designed to support the management and exchange of data in the life cycle of buildings. BIMTs can be classified according to their main function (Table 1).

Table 1: Selected types of building information management tools (BIMTs) and their main functions

TYPE OF BIMT	MAIN FUNCTION	EXAMPLE
Action plan	Approach that goes beyond an operating manual, describing concepts for future activities and providing bases for their implementation (including retrofitting, modernisation, conversion, expansion, deconstruction)	Renovation roadmaps
Data and document repository	Approach to collection and management of building-related data and documents of all kinds throughout the life cycle, usually based on a documentation of as-built information	Building passport, logbook or file
Green building rating and sustainability assessment system	Approach to describing and evaluating essential characteristics and properties of a building such as the technical and functional quality.	Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), Deutsche Gesellschaft für Nachhaltiges Bauen e.V. (DGNB)

(Contd.)

TYPE OF BIMT	MAIN FUNCTION	EXAMPLE
Quality assurance system	Approach in the sense of a checklist that first formulates the requirements and then documents the qualities achieved in planning and execution	Building documentation according to regulations
User manual	Approach to describing the way in which a building is used and operated	Building user guide
Virtual representation	Approach to creating and maintaining a digital copy of the building in conjunction with building information modelling (BIM)	Digital twins

Generally, the boundaries between the different BIMTs are blurred, as the main functions of one type can be combined in new, more complex tools. For actors in the real estate industry, it is often difficult to immediately identify the original function of an instrument due to the lack of transparency and the abundance of existing approaches. This leads first to criticism of the current situation. New initiatives and additional BIMTs without any further explanation of their main functions may increase confusion among the actors. From the perspective of the authors, an explanation of the main functions of BIMTs would be a very important step for their successful implementation.

While some tools are regulated by public authorities and legally binding, others are still unregulated. The following categories show examples of the degree of legal obligation:

- Publicly regulated, *e.g.* Energy Performance Certificates (EPCs) in European Union (EU) member states
- Standardised at the international (International Organization for Standardization—ISO) or supranational (European Standards—EN) levels
- Other (public) documentation requirements according to funding programmes or green building rating systems
- 'Industry standard' based on agreements between actors of an industry
- Privately regulated, such as documentation requirements based on green building rating systems from private organisations
- Unregulated: individual offerings and business models

There is no universal convention on how to classify BIMTs. Given the high interest in tools such as BPs by the public sector (the European Commission (EC) and national governments), some form of standardisation or regulation is expected in the future. First developments in this direction have started: the EC is working on the development of conventions for DBLs (Dourlens-Quaranta *et al.* 2020; EC 2023).

2.2 PROBLEMS AND CHALLENGES

Managing information throughout the building life cycle has always been challenging. Buildings are complex assets with a long service life. This fact alone makes it difficult to keep track of all the details involved in a building. In addition, a larger number of actors is involved directly or indirectly in the design, construction, operation and usage of a building. When moving from one life cycle stage to the next or during transactions, there is a risk of data loss due to insufficient data transfer between actors. The handover process between construction and operation of a building is particularly critical. Due to the temporally limited phase of interaction, project delivery teams and operators need to clearly specify their requirements and make use of integrated data management solutions for better coordination (Whyte *et al.* 2016).

Since every actor supplies and demands specific information against in line with specific motives there is not necessarily an economic or other incentive to exchange valuable information with other actors (Hartenberger *et al.* 2021). However, some current instruments contribute to overcoming this problem, at least partly. For example, the EU taxonomy leads to regulatory pressure on real estate investors to record and disclose sustainability-related aspects (EY 2023).

Information management throughout the life cycle of a building has become more complex recently due to dynamic, overlapping developments. These include the following:

- A shift from to a more sustainable approach that also considers environmental and social aspects in decision-making
- New legal requirements and stricter requirements in the EU and its member states regarding the environmental performance of buildings, which partly also results in additional and extensive legal certificates and disclosures for the respective actors (*e.g.* in the form of EPCs)
- An increased number and diversity of actors involved in the life cycle of a building with specific information demands due to new business models or technical solutions, which also leads to competitive pressure in markets
- New opportunities through developments in information and communication technology (ICT), especially based on the use of data by artificial intelligence (AI), data-mining or computer vision applications

These developments lead to an increased demand of building-related data. Actors require accuracy about the past, present, and future states and performances of a building. This raises questions about the appropriate structuring of such technical, administrative and economic data, and about the granularity in terms of construction work, building component and installed building elements. However, the construction and real estate actors often lack the expertise and the resources to effectively and efficiently collect, store, analyse and share data. 'Expertise' refers to knowledge about the relevance of data collection, the incentives and motives to exchange data, or the management of data processing. 'Resources' covers human, technical or financial resources, for example.

3. METHODS

A systematic literature review was carried out to identify, analyse and interpret the relevant scientific literature. The methodology is loosely based on explanations by Snyder (2019) and von Gernler (2023). The bibliographic databases Scopus and Web of Science were used to identify relevant literature since they cover a large amount of multidisciplinary references and conveniently enable the export of metadata.

Initial research identified relevant search strings for the review. It became evident that a single focus on BPs and on more general terms in the context of BIMTs is not sufficient to reach a high level of sensitivity. For this reason and since many terms have been used without specifying all functions of a concept, similar passport approaches, such as material passports or renovation passports, are considered as well. Due to the dynamic developments in the research field and the lack of standardised terms, the precision of the literature search is rather low (reduction from 131 to 56 in the second iteration) (Figure 1). This, in combination with the unknown level of sensitivity, gave rise to the idea to complement the systematic search by a targeted search. As a result, it was possible to identify literature that has no publication index, but still is very relevant to the topic, such as technical reports from the EC. In order to receive the final sample size and to ensure a sufficient level of publication quality, several selection criteria were applied. This resulted in 108 papers included in the literature review.

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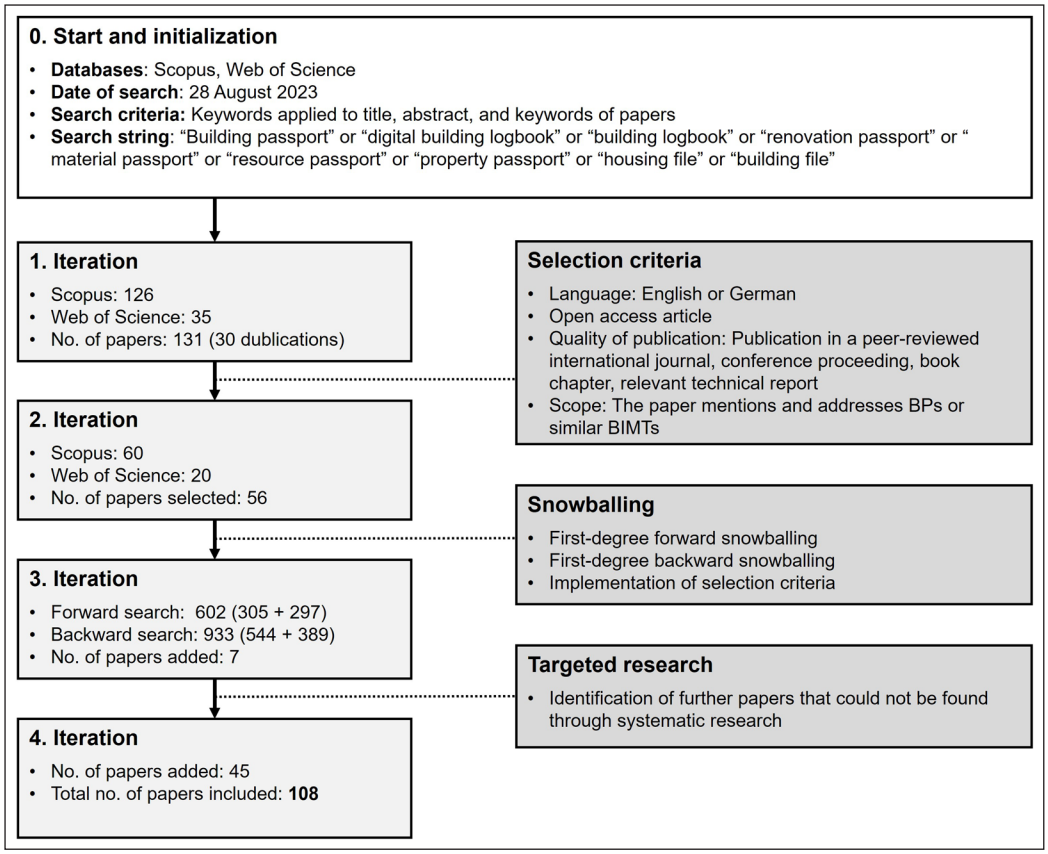

Figure 1: Approach to the identification of the relevant literature.

4. BUILDING PASSPORTS

4.1 MILESTONES IN BP DEVELOPMENT AND RESEARCH

According to the identified literature, the term 'building passport' was first mentioned in the early 1980s by Eichstädt (1982), who described a building passport (BP) as a tool to assist building owners in maintenance planning. A more specific concept was published by Eichstädt *et al.* (1983). A BP was recommended to evaluate the costs of building surveys, maintenance works or major as-built measures for all types of buildings in the former East Germany. Hence, a BP was supposed to work as a data container that carries building-related information according to minimum requirements (Eichstädt *et al.* 1983). For a long time there was no further evidence in the literature until the German government intended to introduce a BP scheme in 1997 for the first time (Blum 2009). Shortly afterwards, a national commission on sustainable development identified BPs as one of the key actions and as a tool for standardised collection and exchange of building-related information. BPs were to contain all relevant information from the construction stage, including, for example, documentation of construction work, specifications on structural safety, fire protection or installed materials. Furthermore, they were supposed to make suggestions for the use stage (German Parliament 1998). The proposal was implemented as a BP document published by the German Ministry of Transport, Building and Housing (2001) three years later. In 2004, this document became part of the so-called housing file ('Hausakte'), a concept that combined general information on a property and documents such as EPC predecessors or the BP (Ministry of Transport, Building and Housing 2004). Simultaneously, first private initiatives emerged in Germany such as the 'ImmoPass' (Dekra 2001).

In other countries, the introduction of similar concepts occurred the early 2000s. In the UK, the use of building logbooks was proposed by the national building regulation for the first time in 2002. The goal was to better inform building owners and occupiers on the structural and functional details of their building with a focus on energy performance (UK Government 2002). There was also the wish to better inform the actors involved in real estate transactions. As a result, the Home Information Pack (HIP) became a legally binding instrument in 2007. As a set of relevant documents such

as a Property Information Questionnaire, an EPC and Land Registry documents, its aim was to provide the buyer of a domestic property with the most relevant information supplied by the seller. The HIP was repealed again in 2010 after criticism relating to additional costs for selling homes (House of Commons Library 2010). To date, a variety of other initiatives has been launched in European countries. For an overview and analysis of these initiatives, see Carbonari *et al.* (2020), Hartenberger *et al.* (2021) and EC (2022).

Apart from first attempts of governmental bodies to raise awareness of BPs, little attention occurred in the scientific literature until the mid-2010s. Thus, many questions remained open about the functions, use cases and features of BPs. At the same time, other tools, such as EPCs or green building rating systems, gained popularity. For studies that still considered BPs in their work during this period, see, for example, Blum (2001, 2002, 2009), Lützkendorf (2000), Rohde *et al.* (2011), Virta *et al.* (2012) and Reisinger *et al.* (2014).

Publication density increased from 2016 onwards (Figure 2). This is associated with the efforts of the EC to improve the energy performance and the overall information density of the European building stock. Several research projects were funded under the European Horizon 2020 funding programme with the goal to investigate tools, such as renovation passports or EPC evolutions to foster more energy renovations in the EU (Table 2). Within these projects, the necessity of a tool that contains all the information needed for decisions regarding the energy performance became evident. For this reason, all projects suggested BPs and DBLs. For the results, see, for example, Fabbri (2017), Libóríο *et al.* (2018), Sesana & Salvalai (2018), Sousa Monteiro *et al.* (2018), Sesana *et al.* (2019, 2020, 2021), Zirngibl *et al.* (2019) and Signorini *et al.* (2021).

Table 2: Overview of European Union-funded research projects with reference to building passports

PROJECT NAME	OBJECT OF CONSIDERATION AND REFERENCE TO BP	SOURCE
ALDREN	Foster renovations of non-residential buildings using building renovation passports	Sesana *et al.* (2020)
BIM4EEB	Building information modelling (BIM)-based solutions for planning renovations in residential buildings	Signorini *et al.* (2021)
iBRoad	Renovations of single-family houses using individual building renovation roadmaps and enhanced Energy Performance Certificates (EPCs)	Sousa Monteiro *et al.* (2018)
X-tendo	Development of a new generation of EPCs	Volt *et al.* (2020b)

Gómez-Gil *et al.* (2022b) studied the proposals of ALDREN, iBRoad and X-tendo in terms of the references they used as a starting point for their passport/logbook definition, the stakeholders involved, the potential user needs, the proposed data structure, the data resources included, the potential functionalities, and their operation and use. They found that the specific proposals differ across all categories, but there seems to be a consensus on key features. As a conclusion, none of the proposed BPs or DBLs combines all the characteristics of a holistic approach, so that the results should be incorporated in further research activities (Gómez-Gil *et al.* 2022b).

An important milestone in research on BPs and DBLs was reached through the technical reports published by the EC (Carbonari *et al.* 2020; Dourlens-Quaranta *et al.* 2020; Volt *et al.* 2020a). In connection with the practical guidelines on BPs from the Global Alliance for Buildings and Construction (GABC) (Hartenberger *et al.* 2021), these lay important foundations for further research by establishing a common understanding of the concept. Among other things, the EC consulted industry representatives and evaluated the current maturity of DBL initiatives in the EU (Dourlens-Quaranta *et al.* 2020). Since the EC is working on a variety of issues relating to a more digital and sustainable building industry, the proposal of DBLs is part of a bigger picture of its efforts. For example, future use of DBLs was formally proposed by the current version of the European Energy Performance of Buildings Directive (EPBD) (European Union 2021).

Since the above reports have been published, several researchers, including Buchholz & Lützkendorf (2022), Mêda Magalhães *et al.* (2022), Gómez-Gil *et al.* (2022a, 2022b, 2022c, 2023) and Malinovec Puček *et al.* (2023), have focused, for example, on functionality, technical features or data categories covered by BPs.

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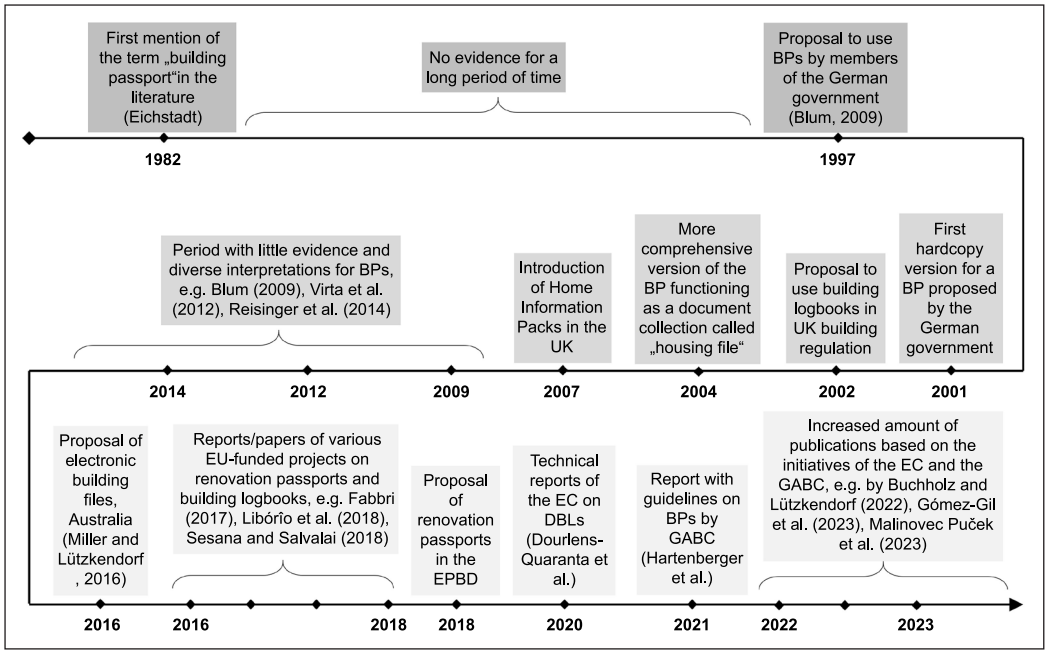

Figure 2: Important milestones of building passport (BP) development in the literature.

Figure 2 clearly shows that the idea of BPs has a long history in national legislation and in the scientific literature.

4.2 CURRENT CHALLENGES

4.2.1 Overview

Several aspects led to the low rate of diffusion of BPs. Some of the existing barriers and challenges were mentioned and analysed in the literature. They can be classified into several categories (Table 3).

BARRIERS AND CHALLENGES	SPECIFICATION
Legal challenges	• Administrative burden • Unclear legislation • Fragmented regional approach • Uncertainty of data ownership and access rights
Economic challenges	• Lack of sound business models • Costs too high
Technical challenges	• Lack of synergies with other tools and technologies • Accessibility of information
Personal barriers of potential users	• Lack of motivation to update contents • Lack of trust • Issues of data privacy and data protection • Lack of understanding main functionalities • Benefits not clearly defined • Unfamiliarity with digital tools
Barriers connected to the tool	• Data quality issues such as accuracy, availability, consistency or interoperability • Unclear object of consideration and system boundaries

Table 3: Existing barriers and challenges for the diffusion of building passports

Sources: Carbonari *et al.* (2020); Hartenberger *et al.* (2021).

Some barriers refer to the (further) development of BPs, others rather refer to the problems during use. While many of the barriers are closely related to each other, the majority of them reveal that there still is considerable uncertainty regarding the tool.

4.2.2 Lack of a standardised definition

Even though a common understanding of BPs has been promoted by some of the latest publications, no standardised term has been defined yet. In order to obtain a better picture, relevant definitions are compared against frequently mentioned features of BPs and DBLs (Table 4).

Table 4: Comparison of different building passport (BP) and digital building logbook (DBL) definitions

	DOURLENS-QUARANTA *ET AL.* (2020)	**HARTENBERGER *ET AL.* (2021)**	**MAIA *ET AL.* (2021)**	**SOUSA MONTEIRO *ET AL.* (2018)**	**GERMAN PARLIAMENT (1998)**
Used term: Passport (BP)		×			×
Used term: Logbook (DBL)	×		×	×	
Main function as dynamic data repository	×	×	×	×	×
Whole life cycle focus	×	×	×		
Single-building focus	×	×	×	×	×
Single point of access	×	×	×	×	
Coverage of all relevant building data	×				
Facilitate decision-making and information exchange	×	×		×	×

According to the literature, a BP or a DBL is a life cycle-oriented data repository for single buildings. The goal is to cover a wide range of building-related data and make these data available via a single point of access in order to facilitate decision-making and information exchange among building owners and other actors. Despite using different terms, the given definitions share very similar views on the main features. Some of these essential features have already been proposed in early definitions, such as that from the German Parliament (1998). It becomes evident that BPs and DBLs are one and the same tool. The introduction of a standardised definition could help resolve misconceptions originating from the different terms. The EC (2023) explains its choice for the term 'logbook' in one of its latest publications by the aspect to 'log' data into a repository over time. The present study mainly uses the term 'building passport' (BP) based on its long-term application and the association of signalling information via a passport. However, the choice of exact term is not essential in comparison with the clarity of functions.

4.2.3 Uncertainty about functions and use cases

The goal of BPs is to make relevant building-related data available to the actors of need throughout the building life cycle and thus fulfil their information demands. Thus, BPs potentially serve as a BIMT with numerous use cases (see Section 2.1). In order to achieve that, conventions must be found for the information supply during relevant occasions in the life cycle (Hartenberger *et al.* 2021). In some instances, it may be necessary not only to supply new data but also to update existing data. This results in three basic operations that schematically illustrate the functions of BPs in their role as data repository:

- 'Write': based on collection, creation or linkage, building-related data are added to a BP (Figure 3)
- 'Read': users can access data from a BP according to their information demands and use it for their purposes
- 'Edit': users can read and edit data. In addition, new data can be added to a BP when the accessed data are used for additional analyses, assessments or simulations

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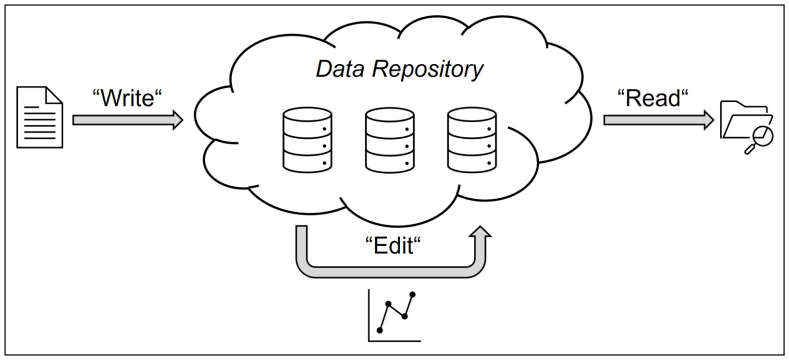

Figure 3: Basic operations performed on a data repository.

The basic functions of a BP shown in Figure 3 must be operationalised in the context of specific situations so that they become tangible for BP users. There are typical tasks in the building life cycle in which BP data are collected, retrieved or altered (Table 5). It must be analysed and determined how an effortless and efficient entry and retrieval of data can be facilitated for authorised actors in these situations (EC 2023).

Table 5: Relation between building-related tasks and the main operations on a building passport

OCCASION/TASK IN THE BUILDING LIFE CYCLE	DATA COLLECTION (WRITE)	DATA RETRIEVAL (READ)	DATA USE AND ALTERATION (EDIT)
Building design documentation	☒	☐	☐
Construction documentation	☒	☐	☐
Proof of compliance with regulations	☐	☒	☒
Financing and valuation	☐	☒	☒
Finance-oriented real estate management	☐	☒	☐
Technical building management including maintenance management	☒	☒	☒
Refurbishment or renovation	☐	☒	☒
Sustainability/building performance assessment	☐	☒	☒
Deconstruction planning	☐	☒	☐
Change of owner	☐	☒	☒
Statistical surveying	☐	☒	☐

Many functions result from the information supplied by the BP for a certain task (Table 5). The literature mentions several functions:

- Building diagnosis: based on continuous monitoring of a building and enabling of building performance assessments
- Alerts and reminders: to indicate maintenance and refurbishment needs or to raise attention to exceptional measuring values
- Benchmarking: linking a BP with other buildings
- Linkage of users to external databases: to provide them with valuable information, *e.g.* real estate cadasters
- Integration of other BIMTs: to further assist building owners in decision-making, *e.g.* renovation roadmaps (Sousa Monteiro *et al.* 2018; Dourlens-Quaranta *et al.* 2020; Hartenberger *et al.* 2021)

In addition, BPs have the potential to become an important platform for the involved actors to interact (Sousa Monteiro *et al.* 2018; Volt *et al.* 2020a). Building owners can be connected to relevant stakeholders such as building authorities, real estate agents and facility managers, for example.

BPs can offer benefits for the users (Volt *et al.* 2020a). General benefits, such as cost savings, efficiency improvements, greater transparency or risk mitigation in information management, can be distinguished from specific benefits associated with specific users and their operations (Hartenberger *et al.* 2021). Based on the analysis of existing European initiatives for BPs and similar tools, Carbonari *et al.* (2020) identified success factors for their implementation, such as a clear scope, a clear legal framework, regular updates, ease of use and the alignment with other initiatives.

Volt *et al.* (2020a) pay attention to the difference between functions and the related benefits. This difference remains unclear in most of the existing literature. From the authors' point of view, the focus on benefits rather than on functionalities makes it more difficult to understand the original function of BPs.

4.2.4 Defining the object and related data structure

One of the first steps in the development of BPs should be the determination of system boundaries. Definitions are needed for the object of consideration, the target group, the addressed operations in the building life cycle and the data to be covered.

These questions may have been addressed, but they have not yet been fully explored. According to Malinovec Puček *et al.* (2023), the concept of a BP should be applicable to all types of buildings. However, the specific framework conditions for different types of buildings must be considered in the development and implementation of BPs. For example, the level of detail of information demand and the financial resources might be higher in office buildings than in single-family houses. Dourlens-Quaranta *et al.* (2020) found that most initiatives already in place are designed for individual houses, but several also applied to multi-apartment, office, industrial and public buildings.

The debate about BPs is based on the assumption that the tool is attached to one specific building. This allows for a modular approach to bring together information from the object level and aggregate it on higher levels to enable decision support for institutional building stocks, national building stocks or the building stock in the EU, for example. The EC (2023) is working on a proposal on how this aggregation can be implemented technically.

For buildings with multiple owners, the scope and the reference area must be defined. Hartenberger *et al.* (2021) suggest that every unit of a multi-owner building should have a separate BP with specific data for the building unit. Common characteristics of the building can be integrated into several BPs in this case (Hartenberger *et al.* 2021).

Another important aspect concerns the question of when a BP should be implemented in the building life cycle. Mêda Magalhães *et al.* (2022) developed a process model that illustrates the necessary steps to set up a DBL from scratch. They define three interrelated processes for strategic definition, data collection during design and construction, and continuous updating during the use stage. However, no explicit explanation has been given for setting up the tool for existing buildings. Finding solutions for the existing building stock is key to a successful diffusion of the tool. Hartenberger *et al.* (2021) identify different starting points for BPs. Synergy effects and cost reductions might be achieved if BPs are introduced after property transactions or a renovation.

The timing of when to implement a BP in the building life cycle can influence the question of data categories. A framework for a BP data model must consider the specific features of an existing building compared with a newly constructed building as well as the requirements for different building use types. Thus, Malinovec Puček *et al.* (2023) propose a classification of building-related data that are applicable to all buildings in various states of their life cycle. Specific features are considered in a module of administrative information, while other categories remain universal.

For the use of BPs during the use stage, it is crucial to update information on a consistent basis. Several researchers have tried to identify the necessary data for BPs based on expert interviews or information management requirements, for example. The suggestions generally differ, but there is a consensus in terms of important categories (Table 6).

Table 6: Selection of the main data categories in a building passport

Sources: Dourlens-Quaranta *et al.* (2020); Hartenberger *et al.* (2021); Libórîo *et al.* (2018); Maia *et al.* (2021); Böhms *et al.* (2023); Malinovec Puček *et al.* (2023).

DATA CATEGORY: INFORMATION ABOUT …	SPECIFICATION
Identification	ID for the building, building unit, cadastral parcel
Administration	General data about the building owner, involved actors, date of construction, *etc.*
Location and plot	Data that describe the specificity of the location and the plot, *e.g.* results from location analyses or climate data
Building structure	Data about the primary, secondary and tertiary physical structure of the building, as presented through design documents and digital building models
Technical and functional characteristics	Refer to structural stability, fire safety, thermal protection or flexibility of use
Built-in materials and systems	Material inventory, including type, quantity, quality of installed materials, risks to health and the environment, *etc.*
Use and operation	Data related to the use stage of a building, such as consumption data or maintenance aspects
Financial aspects	Include one-time and running costs and revenues
Financial, social and environmental building performance	Considers indicators and results from sustainability assessments, life cycle assessments (LCAs), cost–benefit analyses and other aggregated data
Documents	Additional attached documents and models such as licences, technical drawings, contracts, certificates, *etc.*

One of the main challenges in the development of BPs is to find the appropriate level of detail and format of the represented data. This aspect can be crucial for potential users to successfully find the information they need. The EC is therefore working on a semantic data model that aims to facilitate a common understanding of relevant terminology and which proposes a data architecture, including data sets. The proposal is based on the 'FAIR' principle that requires data to be findable, accessible, interoperable and reusable. The interoperability refers to documents as well as to single data in this case (Böhms *et al.* 2023).

For the further development of BPs in the near future, solutions are needed for digitising hardcopy documents. Thus, Hartenberger *et al.* (2021) propose a transition to a fully digitised version. Digitisation increasingly transfers data in more structured and machine-readable formats. The current scope of proposals for BPs includes both collections of structured documents (*e.g.* an EPC) or unstructured information as well as single data in a defined interchangeable format (*e.g.* the energy consumption value and/or energy performance class in an EPC). Another challenge is determining who owns the data in a BP. Current proposals see building owners as the primary data owners, but also include public authorities and other stakeholders to ensure sufficient data quality (Dourlens-Quaranta 2020; Hartenberger *et al.* 2021).

4.2.5 Differentiation from other tools

The difficulty of defining a clear scope for the function and use of BPs becomes even more complex when considering other types of BIMTs. This includes tools, such as product passports, material passports, resource passports, renovation passports, building information modelling (BIM) tools, digital twins, computer-aided facility management systems, and several more. First attempts have been made by the present authors to distinguish the concepts according to their focus in the building life cycle and the data categories they primarily cover (Figure 4).

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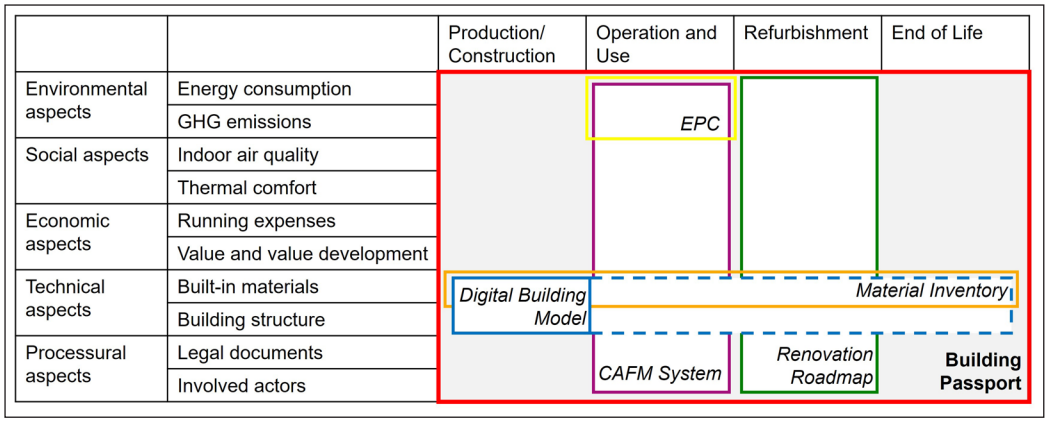

Figure 4: Scope of different building information management tools (BIMTs) including building passports (BPs).

Source: Buchholz & Lützkendorf (2022).

Buchholz & Lützkendorf (2022) propose to integrate several tools and their functions in a job-sharing approach with BPs at the forefront. This proposal goes along with findings on the functionality of renovation roadmaps, for example, which should be implemented alongside a BP/DBL (Fabbri *et al.* 2016). However, Figure 4 only gives a rough impression of potential differences between the tools and does not go into any detail. For a detailed comparison and for possibilities of job-sharing, the object under consideration, the main functions, system boundaries, as well as requirements on data quality, data interoperability and system architecture must be analysed.

Special attention has been raised to the relation between BPs and virtual building models, such as BIM models or digital twins. While BIM has mostly been used only for the design phase, it is increasingly considered as a tool for use cases in the whole building life cycle. A digital twin works as a digital model that enables a bidirectional information flow between the physical and the virtual entity. Both BIM models and digital twins are assumed to provide great benefits when used for building life cycle management (Kubler *et al.* 2016; Hosamo *et al.* 2022). Mêda *et al.* (2021) found that little is known about the relation between digital twins and DBLs. Other publications emphasised the following aspects for a differentiation of BIM and BPs/DBLs:

- BIM still mostly focuses on the building phase and on geometric data, while BPs also cover alphanumeric data and documents (Böhms *et al.* 2023)
- BIM models and digital twins contain more detailed data sets which are not adequate for the projected users of BPs (Hartenberger *et al.* 2021; Böhms *et al.* 2023)
- BPs combine a variety of data sources in comparison with BIM models and digital twins that collect data in direct conjunction with the building (Gómez-Gil *et al.* 2022a)

Based on the identified differences, several authors propose to regard BIM models and digital twins as an important data source that is linked to BPs (Dourlens-Quaranta *et al.* 2020; Hartenberger *et al.* 2021; Gómez-Gil *et al.* 2022a; Böhms *et al.* 2023). A BP does not have to represent the same level of detail and it may be sufficient to incorporate BIM models and digital twins on a meta-level through linkage. In this process, interoperability between different data formats must be ensured as one of the key principles in BP development (Böhms *et al.* 2023).

4.2.6 ICT and user interface

The advancements in ICT enable the digitisation and automation of BIMTs, such as BPs. ICT assists the creators and users by digitising former analogue processes, reducing the manual workload, making them more efficient and, in some cases, partly enabling new solutions for existing tasks. Although BPs are mainly regarded as data repositories, the relevant ICT is not limited to storage solutions, but extends to the interfaces for data collection, dissemination and analysis.

The literature on BPs sees their digitisation as crucial to future applications. The main advantages of a digitised version are its dynamic character, the including of three-dimensional (3D) formats, and the possibilities of automation and scalability (Gómez-Gil *et al.* 2022a). Automation will play an important role in the realisation of specific BP functions, such as alert and reminder processes

or building diagnosis (see Section 4.2.3). Specific technologies that are assumed to gain relevance for BPs are, for example, blockchain technology (Ganter & Lützkendorf 2019), the Internet of Things (IoT), AI, BIM, 3D scanning and digital twins (Gómez-Gil *et al*. 2022a). From the authors' point of view, it is important to distinguish between the underlying technology including hardware, software, methods and specific tools that build upon this technology.

One of the main challenges in future BP development will be to ensure the technical interoperability so that information is easy to find and accessible for the user. For example, this includes the implementation of a suitable information system architecture, the selection of the underlying ICT to ensure secure, highly available and easy-to-maintain storage, transfer and visualisation of data, as well as a plan for maintaining the platform and infrastructure. While the EC (2023) investigates these issues for the connection between an EU-wide framework and national implementations, the authors highlight the necessity to test these aspects through prototyping and further studies. Another important challenge from the authors' point of view will be the compatibility of vendor-specific systems and data formats. This aspect is of high relevance as software product cycles are significantly shorter than the life cycle of buildings.

5. CONCLUSIONS

5.1 FINDINGS FROM THE LITERATURE REVIEW

The interest in building passports (BPs) increased significantly after the basic idea had been around for a very long time. This interest is a result of different developments. The detailed level of knowledge about BPs has increased and the topic has been investigated from different perspectives.

Several challenges should be addressed by future BP research and development:

- Definition of terms: a standardised definition as well as more transparency of the incorporated functions could help reduce misunderstandings
- Main functions: functions of BP are mostly based on the operations that are performed on the data repository. More specific functions can be built into a BP to generate specific benefits for the involved actors
- Scope of BPs: further analysis is needed to determine the appropriate level of detail in the covered data according to information needs that occur over the building life cycle
- BPs and other tools: building information modelling (BIM) models and digital twins are important data sources for BPs, but differ in scope and the level of detail of the underlying data
- Consideration of information and communication technology (ICT): several technologies should be considered in the development of BPs. For this, the technical interoperability and user friendliness must be ensured

These aspects should be addressed in further research as well as direct engagement with the industry and government actors involved in the life cycle of buildings.

5.2 RECOMMENDATIONS FOR ACTION

Based on the analysis of the literature review, several recommendations for action arise for addressing the identified challenges (Table 7).

5.3 LIMITATIONS AND OUTLOOK

This contribution provides only a brief overview. The literature review is a snapshot of the literature based on the dynamic developments with an increased publication density. Some relevant information from literature may be undetected due to the numerous terms and approaches to the topic.

ACTOR GROUP	RECOMMENDATIONS
Building passport (BP) developers	• Development of sound business models for BPs by creating and promoting benefits for the involved actors • Incorporate the existing knowledge on the functions of BPs and define a clear scope of the own product/service (*i.e.* definition of target groups, development of a modular approach for applied functions that can be enhanced over time, *etc.*) • Consider specifications and requirements from political institutions, academics and potential users
Researchers	• Consider the current state of knowledge on BPs to avoid (further) misunderstandings regarding key aspects • Further investigate existing barriers that hamper the diffusion of BPs • Analyse problems and provide solutions regarding the semantic and technical interoperability between BPs and other building information management tools (BIMTs)/technologies (examples from other tools/industries can be taken into account)
Policymakers	• Further develop existing proposals to use BPs as a tool for tasks of the public sector (*e.g.* monitoring of the national building stock) • Communicate current developments and provide guidance to building owners and other actors of the real estate industry • Integrate BPs into the landscape of existing BIMTs with relevance in regulation (*e.g.* Energy Performance Certificates (EPCs), renovation roadmaps, building information modelling (BIM), *etc.*) • Clarify formal issues (*e.g.* regarding property rights and data privacy) and provide a clear legal framework in the long run
BP users	• Articulate, signal, and communicate requirements on information management and on BIMTs to relevant stakeholders in order to implicate a demand-driven approach • Intensify the dialogue with other industry representatives to foster knowledge transfer, innovation and a common understanding of BPs (*e.g.* expressed through industry standards)

Table 7: Recommendations to actors based on the results

Only a selection of identified aspects could be considered in the present analysis. Aspects and challenges not covered in detail include issues of data ownership or information security, maturity levels of existing initiatives, awareness and perceived benefits/barriers of potential users, *etc.* This also includes detailed explanations of the underlying processes in BP use and of the different information sources for BPs.

Nonetheless, the current conditions are favourable for overcoming obstacles that have prevented the introduction and dissemination of BPs so far. This applies to both the demand for corresponding information and the political will to also use BPs for overriding goals, such as climate protection and resource conservation, as well as to the progress achieved in digitisation. It is important to see the cross-thematic/horizontal benefits. In Europe, it is therefore necessary to highlight the contribution that BPs can make to climate protection, the circular economy, strengthening consumer rights data-driven solutions, *etc.* BPs have the potential to become an important and useful tool.

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