IOP Conference Series: Earth and Environmental Science

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To cite this article: M Buchholz and T Lützkendorf 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1363** 012107

Building passports in their role as building information systems - background, framework, implications

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Abstract. Building-related information is essential for performing tasks and making decisions in the design, construction, and management of buildings as well as in transactions. This is increasingly recognized by actors of the real estate industry and by policy makers. As a result, there is a renewed interest in information management solutions and, in particular, building information systems (BISs) with an interface character for multiple tools, such as building passports (BPs) and digital building logbooks (DBLs). Gradually, a better understanding of their main goals and functionalities is evolving due to initiatives in politics, academia, and the real estate industry. However, for wider adoption, a sufficient level of common characteristics regarding the functions, covered data categories, and technical foundations is crucial. Therefore, an information system architecture (ISA) for BPs is proposed that builds upon basics of research on building-related information management and BISs. In addition, selected references are made to insights from business informatics, as this has only marginally been done in traditional approaches of the real estate industry. The ISA provides a holistic view on the relevant elements of a BP and thus serves as a basis for further developments, standardization, and harmonization. The findings are used to discuss practical implications not only for BP design, but also for their use. The authors conclude that the foundation is laid for BPs to become a very useful tool for the transformation of the building stock to support a sustainable development.

1. Introduction, research questions and research approach

Buildings are complex systems. One aspect, among others, that particularly stresses this realization is their environmental footprint which is constituted by the input of resources used for the production, construction, and use of buildings as well as the output in form of emissions and wastes. Globally, buildings are responsible for an estimated 34% of the global final energy consumption and 37% of global CO_2 emissions [1]. Thus, there is a consensus that the built environment plays a crucial role against the background of mitigating anthropogenic climate change and environmental pollution. In order to implement the necessary changes, actors from the real estate industry need to first understand the context of these developments and the implications of specific requirements on their actions, such as those induced by regulation. Capturing, assessing, and communicating the sustainable performance of buildings and their environmental performance as an important part of this performance becomes a critical task. This can only be supported and achieved through an intensive exchange and management of information throughout the entire life cycle of buildings.

While managing information has always been a challenging yet implicit task in the building life cycle, actors increasingly recognize its huge impact on the success of their strategic and operational actions leading to a higher allocation of resources for this task. This includes the intensified use of information management instruments and tools. Their main task it to systemize information and to assist actors in the creation, collection, processing, storing, sharing, analyzing, and securing of building-related data. One of these tools are building passports (BPs) [2], also known under the more recent term 'digital building logbook' (DBL) [3]. The idea of BPs is known for more than 40 years [4, 5], but never led to a widespread establishment. A new interest in BPs derives from the increased complexity of building-related information management and the potentials of digitization, automation, and technological advancements [5]. Therefore, a BP is increasingly interpreted as 'building information system' (BIS).

Despite the renewed interest in BPs, which is reflected in the increased number of publications [5], political reports, and business models, there are still open questions. A selection of those is raised as research questions:

1) What is the current state of knowledge on BISs and which role do they fulfill for information management in the building life cycle?
2) How does a suitable information system architecture (ISA) for BISs, such as BPs, look like that considers all the main resources, perspectives, and system boundaries?
3) How can the ISA proposed be used for the further development and implementation of BPs and which implications and recommendations can be derived for their successful use?

In this contribution, section 2 deals with research question 1) by providing a background on BISs. Section 3 contains explanations on the ISA, whereas section 4 answers question 3).

The research mainly builds on the discussion about BPs in the European context. While the background on BISs and the ISA for BPs mainly address the interest of researchers and potential BP developers, the implications and recommendations also address users and policymakers.

Real estate research is becoming more differentiated in order to react to trends, such as the ongoing digitalization, in connection with new requirements in the real estate industry. One consequence of this development is the adoption of knowledge from other domains. BISs are an object under consideration in interdisciplinary research at the interface between informatics and real estate. Since this area of research is still evolving and basics still have to be laid, a selection of topics relevant to the discussion about BPs is explained in chapter 2 for more context. The authors first derive a common understanding for the term 'building information system' based on underlying concepts and former definitions, then provide a background on how BISs are treated in research, before giving an overview of different BISs based on a cluster analysis. The contents in this chapter loosely build upon former work of the authors and other relevant literature that has been identified in a targeted literature review. The contents, specifically the clusters in section 2.3, do not rely upon an in-depth analysis of specific systems, but rather serve the goal to place BPs in the context of BISs.

2. Background on building information systems

2.1. What is a building information system?

According to definitions from business informatics, an information system is a socio-technical system, consisting of human-machine interrelated elements, that facilitates to collect, structure, process, store, disseminate, transform, and make usable data, information, and knowledge in order to support decision-making, coordination, control, analysis, visualization, and automation of processes [6, 7]. Information systems are regarded as open and dynamic systems that are artificially separated from their environment [8]. While several kinds of information systems have evolved over time, their original and most important function is generally to improve information management for their users. Business informatics traditionally investigates information systems based on their application and numerous use cases in business organizations [9]. Many of the theories and findings are applicable to other domains and objects of consideration too. Information systems within the real estate industry, including the architecture, engineering, construction, and operations (AECO) domain, can be referred to as BISs.

For capturing how BISs work, it is necessary to put the basic functions of information systems into the context of information management use cases throughout the building life cycle. Use cases can be derived as follows: Actors perceive occasions in which they actively want to engage with some kind of information throughout the entire life cycle of buildings and all tasks involved [10]. Typically, actors perceive an information demand at a specific point in time, whereas the need for an information management solution can also be the availability of suitable data storage or sharing options. BISs can step in at this point and, in theory, fulfill user requirements by facilitating data creation, collection, storage, distribution, analysis etc. The underlying logic is illustrated in **Figure 1** with a couple of concrete examples for occasions and tasks.

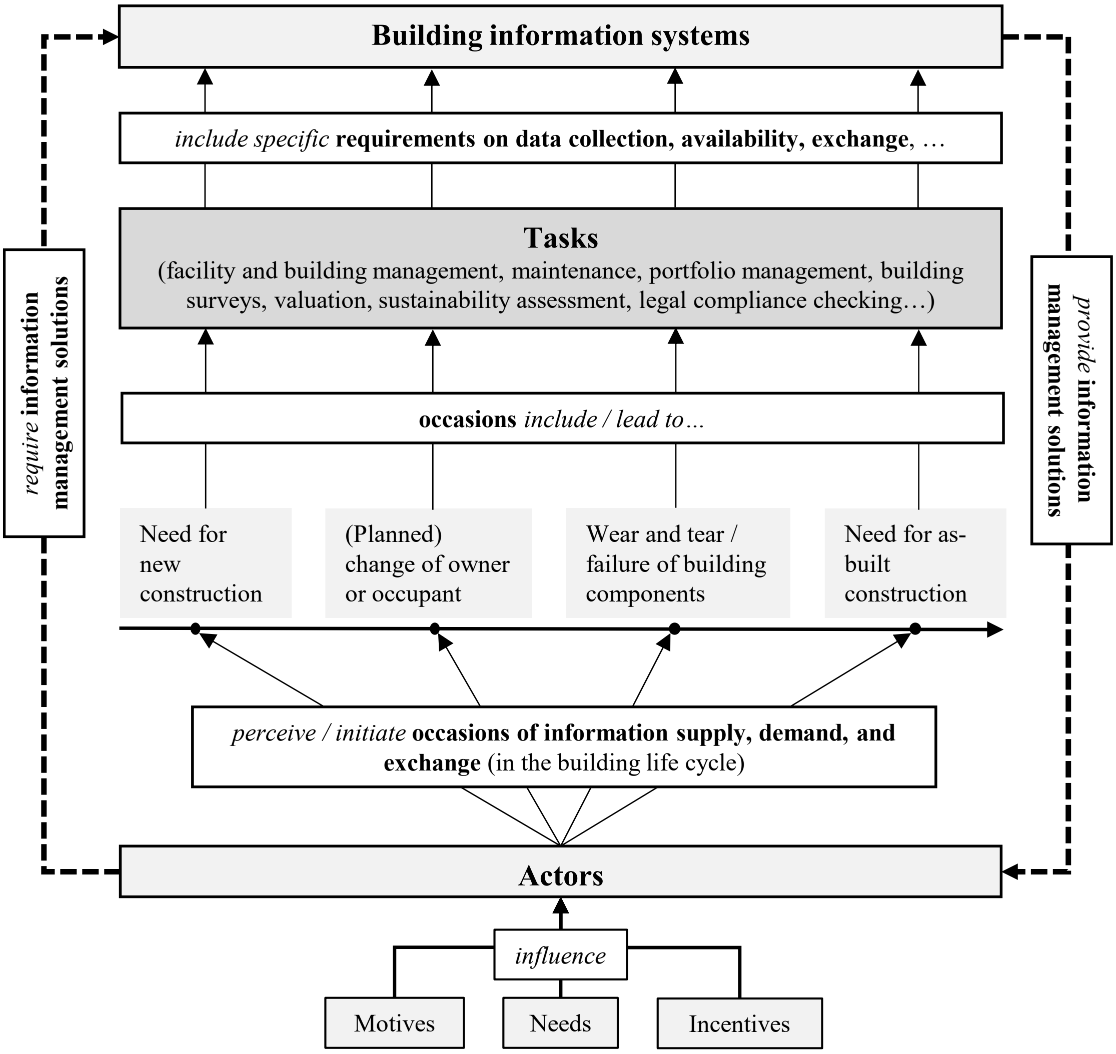

Figure 1. Role of BISs in the context of building-related information management

The literature shows that 'building information system' is not a new term and that it has been used long before in a similar context [11]. Several researchers gave more or less meaningful definitions which are listed in **Appendix 1**. It becomes evident that there is no consensus regarding the term 'building information system'. This is another indication that the logic of information systems has not been actively transferred to the real estate industry. So far, the usage of the term has been rather informal and was interpreted according to the contextual needs of authors. For a more consistent approach, it is proposed to take the meaning of the underlying concepts, namely a 'building' and an 'information system', more into consideration. Hence, from the authors' point of view, a BIS should be interpreted as a human-machine-interrelated system that supports building owners and other actors involved in managing information throughout the life cycle of a building by facilitating the collection, storage, distribution, and use of building-related data.

2.2. Building information systems as a research domain
Research on BISs in the context of information management is an interdisciplinary field that, despite a couple of outstanding publications in the past [10, 12–18], is still evolving under the branch of building-related research. The reasons for the rather slow advancements are manifold. The real estate industry has traditionally been a slow adopter of new technologies, trends, methods etc. This reflects in the academic landscape which is fragmented due to the variety of topics, focal points, and expert domains. In the context of BISs, researchers selectively focus on…

- specific use cases (occasions, tasks, processes) in the building life cycle, such as construction management, portfolio management, or sustainability assessments,
- the implementation of information and communication technologies (ICTs) while neglecting the underlying premises of information management,
- building use types or building components, such as office buildings or building materials, and
- other objects of consideration, such as companies or projects.

As of late, several trends are responsible for the increased interest in BISs from a more general perspective [19]. In particular, BIS research investigates ways to transition to a more structured way of capturing and storing building-related data by leveraging the potentials of digitization and automation in connection with specific technologies, such as building information modeling (BIM), digital twins, sensor technology, 3D scanning, artificial intelligence (AI), cloud computing, semantic web, and many more. Another reason for the grown interest in BISs are changing information needs of real estate actors and the pressure induced on these actors to satisfy the resulting information demands in an effective and efficient way [5]. Institutional real estate companies, investors, the construction industry, banks, state institutions, but also private building owners need new and increased amounts of building-related data to assess the sustainable quality and performance of buildings. The pressure to act does not only result from environmental requirements, but also from economic and social motives [20].

2.3. Overview of relevant building information systems
Against the more general definition of BISs and the numerous options for specialization in the building life cycle, a wide range of BISs exists. Especially practical implementation variations from the real estate industry are hard to grasp due to the heterogeneity of BISs. In order to derive a reasonable overview on specific types of BISs, the focus within this contribution specifically lies on BISs with a severe potential to improve information management throughout the building life cycle and with sufficient attention and evidence in the scientific literature.

A hierarchical clustering method [21] is applied to classify BISs on the basis of their similarity to other BISs. For this, a selection of criteria was applied. This included aspects, such as the origin of a concept, terminology, functions for information management, functions for building-related tasks, data covered, ICTs integrated, users intended and their level of expertise, proximity to buildings and decision-makers etc. The criteria were applied to frequently mentioned BISs in practice and theory, resulting in the clusters listed in **Appendix 2**.

The clusters cover a wide range of existing BISs, while many BISs that were not explicitly mentioned can be assigned to one of them. They primarily serve to give an overview on the landscape of BISs, as illustrated in **Figure 2**. While it is not within the scope of this paper to analyze the individual functionalities in detail or to draw a strict line between different clusters, the potential interface role of BPs can be highlighted. For this reason, BPs/DBLs are also perceived as a 'gateway' [22].

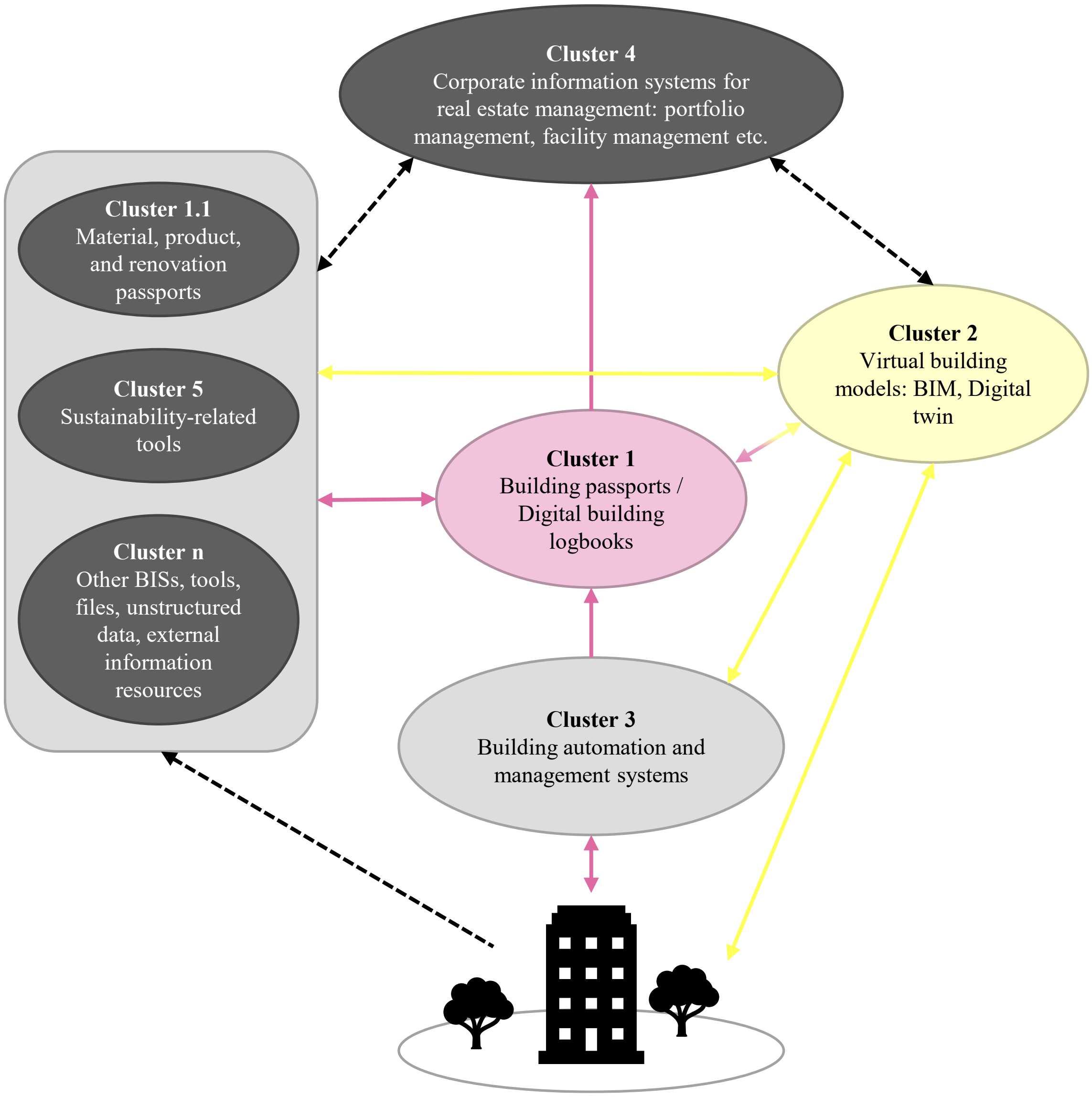

Figure 2. Interrelations between different clusters of building information systems

The use of a central system, such as BPs, has the potential to simplify information flows and data sharing in the real estate industry. In order to do so, one of the primary requirements on BPs is the facilitation of interoperability between different BISs and data sources [23], which is simultaneously one of the biggest barriers in alternative information pathways (dashed black lines in **Figure 2**). In comparison to virtual building models, BPs can become an important tool also to non-experts.

3. Proposal of an information system architecture for building passports as main outcome

The basic structure of an information system can be displayed by an information system architecture (ISA). The goal of an ISA is to break down an information system into its fundamental elements to reduce the overall complexity [24]. This enables an abstract view that can be modeled in an architectural model [25]. Additional advantages of an ISA lie in the possibility to develop, manage, and analyze specific elements of an information system largely independent from other elements. An ISA can function as a conceptual framework throughout the entire lifespan of an information system including its design, implementation, and management. In the following, the concept will be applied to BPs that represent cluster 1 from the typology of BISs.

3.1. Overview

For a comprehensive ISA of BPs, two relevant aspects must be determined. First, the necessary elements, which can also be interpreted as building blocks [25], modules [25], or perspectives/views [26], must be identified. They should cover all the essential entities of an information system and, at the same time, be limited to a reasonable number that allows a good overview. Second, the relationships between the elements must be placed. Only if the elements work together, they can constitute a well-functioning information system. For BPs the following key elements are proposed against the background of the state of knowledge on BPs and information systems:

- Users: One of the key features of information systems is that they consist of both machine and human elements. In this case, the term 'users' stands for all actors that are actively involved in a BP.
- Functions: Functions refer to the tasks that a BP offers to users.
- Data: Data, especially building-related data, are an essential resource in a BP.
- Technology: Considering the ICT in a separate element allows to clarify other elements more from a semantic standpoint.
- Processes: Processes can be interpreted as the engine or control unit of an information system. They connect internal resources and manage interactions with the environment of a system.

Most of the existing research on BPs focuses on selected aspects only. Even publications that try to take a more comprehensive view mostly fail in terms of giving an overview on necessary elements and their relations [2, 3, 27].

For the elements proposed, the question remains how they interrelate. It is proposed to establish the process element as the single element that connects all elements (**Figure 3**). Thus, the other elements can be modeled statically which makes it easier to understand their content. Similar approaches of creating an ISA, such as the reference ISA by Scheer [24, 26], which makes proposals for modeling functions, data, and processes, have proven fruitful in business informatics. Instead of users and ICT, Scheer models organizational aspects and service-related aspects. This difference can be explained by the business-oriented context of his proposal. In comparison, BPs are regarded as a BIS with multiple users that all have their own motives.

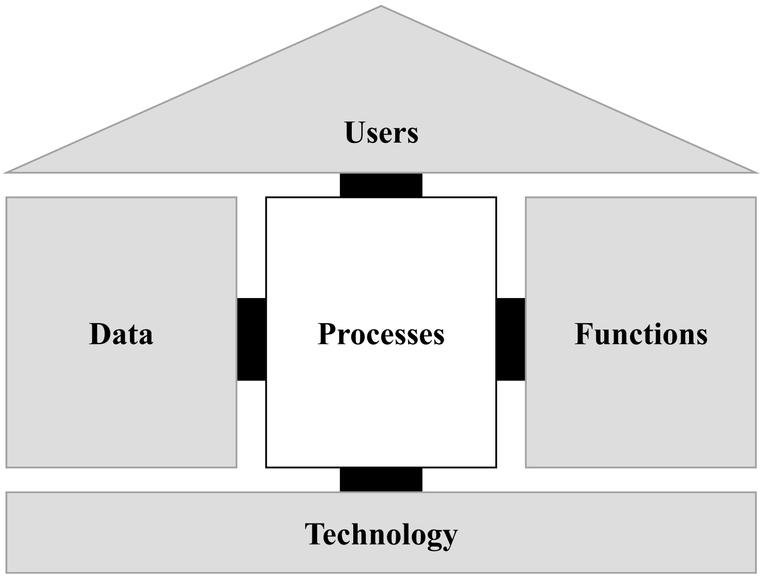

Figure 3. Information system architecture for building passports

In the following sections, the different views (elements) of the ISA will be explained in more detail. In addition to own proposals, the explanations will explicitly consider insights from existing research on BPs and put them into a new and more holistic context.

3.2. Point of view: User

Since nearly all actors of the real estate industry have a severe need for building-related data, the variety of BP users is expected to be large [2]. These potential users are all highly individual persons or institutions. In order to get a better picture of their operations, motives, needs, and other characteristics, it is a common practice in the real estate industry to classify actors into groups of different roles [28]. Building owners fulfill roles as self-users and landlords, while stakeholders take in all kinds of roles throughout the building life cycle. Within BISs, these task-related roles can form the basis for a characterization of users. Among other things, they can serve the initial assignment of roles for a role-based access control (RBAC) strategy [29]. However, reducing a user to its role in the real estate industry does not provide sufficient information that is required for a successful functioning of a BP. Therefore, it is proposed to represent the user element in the ISA by a user model which can serve for identity and access management (IAM) and overall user management. Basic information to consider in a user model are shown in **Figure 4**.

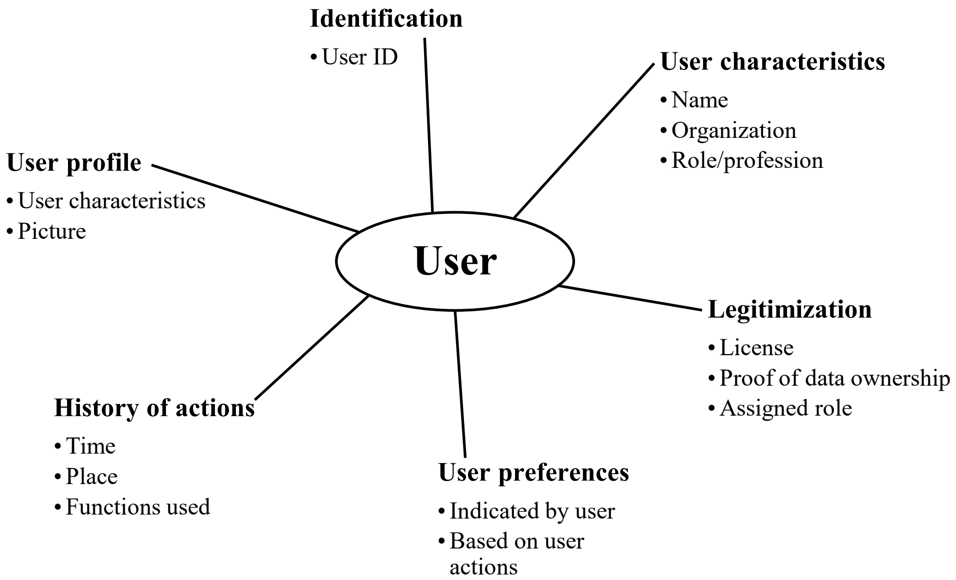

Figure 4. Information to consider in a user model for BPs

By taking users into account, the ISA follows the basic definition of information systems as human-machine-interrelated systems. It is noteworthy to say that actors involved in the building life cycle are not permanently involved in a BP, provided that a BP exists for a specific building. They are only temporarily an active part of the system when they enter it.

As stated above, a user model can be applied for IAM. While outsourcing the management of user authorization to expert services is recommended [30], still, a strategy is needed how to grant access to specific functions. For a long time, RBAC strategies were the most favorable option for a wide range of information systems [29]. Typical roles in BPs could be administrator, owner, auditors, planner, solution provider, user, visitor etc. [31]. The advantage of this approach is that access rights can be managed for these predefined roles only and not for every single user. However, using RBAC alone still does not offer a high level of granularity and flexibility. Further policies, rules, and constraints are needed in times, when people access information systems anytime, from anywhere, using all kinds of devices. Thus, it is proposed to either complement or fully replace an RBAC strategy by an attribute-based access control (ABAC) strategy [29]. In ABAC, access is granted situationally based on specific attributes and their values. The respective policies must be implemented in the process view (section 3.6), where the access of users on specific functions is modeled.

3.3. Point of view: Functions
The function element of a BP should provide a clear picture of the most important functions that a BP can offer to the user and how these functions are connected. Within the last few years, several publications mentioned potential functions of BPs (and DBLs, which are identical tools) [2, 32, 33]: A BP, for example,…

- acts as a single point of input, access, and visualization of static and dynamic building-related information for single buildings throughout their life cycle.
- offers data sharing and data exchange possibilities via platforms that enable interaction and collaboration between actors.
- is an interactive system that actively engages with the user, e.g. through alerts and reminders.
- gives building owners full control over their building-related data.
- provides linkages to other BISs and information resources, such as BIM models.
- supports various tasks throughout the building life cycle, such as facility management and maintenance, valuation, portfolio and risk management, public policy making.

The commonality of these definitions is that they provide a specific context. Authors connect tasks to specific system boundaries/framework conditions (single building, building life cycle…), data aspects (static, dynamic, indicators…), technologies/technical solutions (platforms, BIM…), and use cases (building-related tasks). This helps bridging the gap between the information system and the needs of actors. However, this approach also makes it difficult to receive a holistic view on the functions in the sense of tasks. Thus, it is proposed to solely focus on functions within the function element and spare other aspects, such as data, technologies, use cases etc. for other elements of the ISA. This creates a more abstract and simpler view.

A suitable technique to model functions and their relations are function trees [26]. They use a hierarchical abstraction mechanism on the basis of suitable criteria for distinction. For BPs, a first distinction is proposed for inherent (built-in) and built-up functions (**Figure 5**). Inherent functions cover aspects that are necessary for a BP to work as an information system that fulfills requirements on its availability, security, user-friendliness etc. This includes management aspects concerning all elements within the system. Inherent functions are expected to be mostly fulfilled by manual or automated administration processes.

Built-up functions refer to functions that provide actual value for the addressed user groups of BPs. It is proposed to follow a structure that orientates on the processes of information management including data collection, sharing, analytics mechanisms, and interaction aspects. These functional bundles should then be further specified to clearly emphasize the tasks that a BP fulfills.

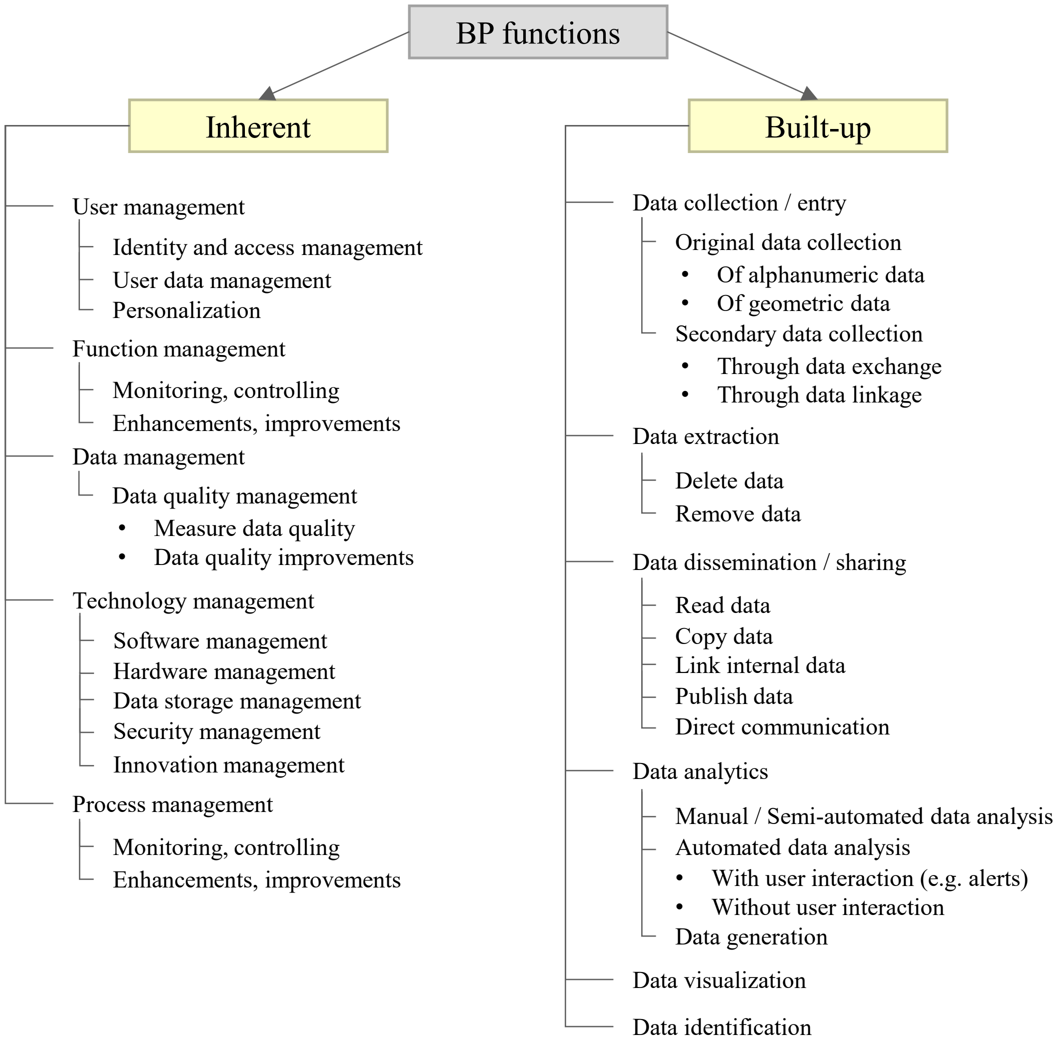

Figure 5. Function tree for building passports

The function tree presented in **Figure 5** demonstrates the broad capabilities of a BP. In comparison to design tools, certification systems, building automation and management systems (BAMSs) etc., a BP is not restricted to a specific combination of functions with other elements (data, users, ICTs), but rather focuses the storage and management of data in the long term.

3.4. Point of view: Data

The data element of the ISA, also called data architecture, should provide a structure that covers and specifies all relevant data points and their relationships for a BP. In this regard, 'covering' means that requirements on the data content are met while 'specifying' refers to the fulfillment of additional requirements on data quality, such as availability, security, interoperability etc [19].

The data content of a BP should orientate on the information (management) needs of actors from the real estate industry and on the object of consideration, primarily single buildings of various use types [2]. Several studies tried to investigate and display the data content of BPs [2, 3, 5, 34, 35]. Partly, the demand side has been taken into consideration through expert surveys [32] and the analysis of existing initiatives [36]. In other cases, the possibilities of describing a building through different perspectives were taken as a basis [2]. Most of the time, the result was a collection of building-related data in a typology of different abstract categories. Typical categories mentioned are general, structural-related, economic, legal, dynamic, and aggregated/performance-based data. A crucial aspect lies in the definition of the right level of detail in the data so that they are comprehensible for a wide range of non-expert users of BPs [5]. In addition, the data content should be coordinated in respect to other BISs to avoid severe redundancies in their functionality (section 2.3).

For a clear picture, data points and their relationships should be specified in an integrative approach. This requires a suitable conceptual data modeling approach. Data can be modeled on different levels according to their proximity between real world entities and their technical implementation. One distinguishes between semantic, logic, and physical data models [37]. While logic and physical data models are more or less interrelated with the underlying technology how data is stored, semantic data models can be developed vastly independent from that. Thus, the focus in the data element is placed on a semantic data model for the data architecture.

A typical and traditional modeling language that has proved a successful option for the development of meaningful semantic data models is the entity-relationship modeling (ERM) language. Since its first proposal [38], the language has been implemented frequently and enhanced. ERM is particularly suited for cases in which all potential elements and relationships are already known in advance, as it is often the case for corporate information systems of a single organization. Another approach, that is rather new in the context of the real estate industry, is data modeling based on ontologies in connection with linked data/semantic web technology and the logic of Resource Description Framework (RDF) (**Table 1**).

Table 1. Important terms for ontology-based data modelling in the semantic web context

Term	Definition
Ontology	"Specification of a conceptualization" [39] to formally represent entities, their relations, and potentials to enhance them
Resource Description Framework (RDF)	Approach and language to model real world aspects in triples consisting of subject, predicate, and object; used for linked data and semantic web technology [40]
Linked (open) data	Idea to link structured data via the internet/web; enables location-independent access to data as a basis for data sharing [41]
Semantic web	Approach as an evolution to the traditional web 2.0 ('web of documents') that enables an integration of data so that it is more granularly available ('web of data') [42]

Advantages of semantic modeling on the basis of RDF in combination with linked (open) data lie in the high semantic and technical interoperability, meaning that data fulfills the FAIR ('findable', 'accessible', 'interoperable', 'reusable') principle among other requirements [43]. Therefore, this approach is particularly suited for use cases in which not all potential entities and relationships are known in advance and where data is rather heterogenous and multi-structured. For instance, single data can be linked as well as complete files. A respective data ontology can be enhanced and react to future requirements on information management. This gave rise to implement this approach in a research project initiated by the European Commission (EC) that investigated DBLs in the context of managing information on the European building stock [23]. An ontology was proposed to define important entities and relationships for building-related data. In addition, a data dictionary was developed that defines the terminology used in the ontology. Within their reports, the authors explain the underlying logic and technologies of their approach, including all elements of a data architecture. Further specifications can be found in the respective technical reports [23, 35].

From the authors' point of view, the approach from the EC can serve as a good basis for further development and practical implementation of BPs. In specific, the opportunity to establish a common framework that can facilitate a sufficient level of harmonization in the data content should be exploited. This is a relevant step to reduce interoperability problems in the industry where more and more BP services and products as well as other BISs and data-driven solutions will evolve in the future. The approach of the EC joins the uptake of initiatives to establish a common data model/standard in the real estate industry, as pursued with the International Building Performance & Data Initiative (IBPDI) [44], the Brick Consortium [45], or the data standard by the Royal Institution of Chartered Surveyors (RICS) [46]. From the perspective of the EC and national policymakers, it can be an option to use the ontology proposed to specify minimum requirements on the scope and quality of data in BPs. Similar requirements can also be defined by industry initiatives that want to apply BPs in building stocks.

3.5. Point of view: Information and communication technology

The technological element specifies all the ICT resources used for a BP including respective methods, software, modeling and programming languages, hardware, and infrastructure. The goal is to establish a standalone view on ICT that allows to manage it successfully and to integrate it into specific processes. In order to classify ICT, orientation towards the function element is a suitable option (**Table 2**). Specific technologies and functions often go hand in hand, since the development of technologies historically followed the needs of information management. However, there might be overlaps on an abstract level because some technologies are increasingly relevant on a broader scale, such as artificial intelligence, and because there are new and hybrid forms of technologies. Authors that dealt with technologies for BPs/DBLs to date focused on selective aspects for data collection [22], data dissemination [23], or data storage and security management [47].

Table 2. Selection of technologies for building passports

Function bundle	Information and communication technology
Data collection	Sensor technology, internet of things (IoT) networks, computer vision technologies (cameras, lasers, radars), natural language processing (NLP), information retrieval
Data dissemination	Data exchange formats, linked data and semantic web technology, web platforms
Data analytics	Data mining techniques, artificial intelligence (AI), machine learning (ML) algorithms, visual analytics
Data storage management	Database technology, cloud computing
User and security management	Authentication mechanisms, cryptography, protocolling, blockchain

Apparently, the classification illustrated only provides a conceptual overview on relevant ICT. Not all of the mentioned technologies are necessarily an integral part of a BP. In order to further specify ICT elements as much as possible, ICT needs to be considered in the context of specific functions and data to see where they match for unique solutions that cannot be considered independently. The combination of the different elements of the ISA is an explicit part of the process element. For example, specific ML techniques, such as artificial neural networks (ANNs) or convolutional neural networks (CNNs), can be applied to enable analytics on condition data of building components to serve predictive maintenance [48]. The extent to which such aspects are integrated into a BP depends on the scope and availability of the technologies, functions, and data and must be determined carefully in relation to other BISs.

3.6. Point of view: Processes

The purpose of the process element is to connect all other elements in an integrated approach to dynamically represent how a BP functions. For a systematic approach, it is proposed to first bring together pairs of different elements. This leads to new essential sub-elements (**Table 3**) that can also be used to enhance the ISA. Here, these aspects are seen as part of the process element.

Table 3. Binary connections of elements for building passports and their meaning

	Function	Data	Technology
User	Specification of rules for the chosen access policy Requires an evaluation of user requirements and occasions of BP use	Complex many-to-many relation and therefore only implicitly connected via the user-function relation	Indirect connection through functions as an intermediary element
Function		Complex many-to-many relation on an abstract level that needs to be specified on a more detailed level	Specification of which technologies are needed/beneficial for which functions
Data			Specification of data storage technology for specific data

The insights from examining the binary relations between elements can serve as basis for developing an overall process model in addition to the single elements. Processes can be divided into three basic stages:

- Initiation stage: Processes are initiated by various external and internal triggers. External triggers refer to entities, primarily users, that enter the system with specific needs or intentions (e.g. occasions of information demand). Internal triggers address functions implemented for automation. Usually, these functions are based on specific rules to act either frequently or based on conditions (e.g. alerts when outlier values were detected).
- Execution stage: Specific tasks are performed based on defined procedures and in cooperation with entities from all the main elements in the system. These procedures can be modelled with the help of a process modelling language, such as business process modeling language (BPMN), enhanced event-driven process chains (eEPC), or UML activity diagrams [49].
- Final stage: The end of a process is reached when all steps included have been performed successfully and, in the best case, if the requirements of the user are met. Usually, a process leads to changes in the data content and user information. Administrative processes can also involve changes on ICT or on functions (and thus on processes).

Since a comprehensive process model for BPs becomes highly complex and extensive, it is useful to break it down into smaller parts based on specific criteria. Mêda Magalhães et al. [50], for example, propose a process model based on BPMN that is split into four parts in reference to the life cycle of the information system and the life cycle of a building. Even though the model incorporates a selection of user, data, ICT, and function elements, it stays on a rather abstract level which underlines the complexity of the process view. For further research and development of BPs, it is proposed to start process modeling approaches by specifying the elements incorporated. The ISA from this paper can serve as a basis. After that, selected processes should be modeled first in the context of specific BP use cases before gradually enhancing the process model.

4. Implications and recommendations

4.1. Perceiving building passports as building information systems
One reason for the low diffusion of BPs and the alternating interest in the tool is how its character is perceived in connection with how it is implemented. The character of BPs stayed more or less the same since early proposals. BPs are supposed be a tool to store, manage, and make available building-related data more consistently throughout the building life cycle. Especially basic, non-altered, and easy to interpret data are addressed. The aspect that changed over the years is the form of implementation based on new technological solutions and connected user requirements. This led to an evolution of file collections and hardcopy documents to more complex BISs. For future developments, it is crucial to first understand the character of BPs, as it has been proposed for a long time, but second perceive the new form as information systems. For the latter, more cross-disciplinary collaboration, especially between (business) informatics and real estate experts can be fruitful.

4.2. Recognizing the interface character
Some of existing BISs have received more attention than BPs in theory and practice over the years. This has various reasons, such as higher potentials for automation, more promising business cases, and more specific use cases in the short run. However, the need for more wholesome support of information management especially in the form of a more consistent storage of building-related data becomes clear in many types of BISs including BIM applications, BAMSs, and renovation passports. Instead of creating more confusion when various BISs move into the direction of data repositories, BPs could step in as an interoperable interface for other BISs (**Figure 2**). That way other BISs could stick to their original function, such as collecting, analyzing, or visualizing data. This shows that the idea behind BPs is not to replace existing BISs, but to facilitate a better information exchange/sharing between BISs and ultimately between actors.

4.3. Using a systematic design approach
The newly gained recognition of the usefulness of BPs led to a growth of studies and political interest. However, despite relevant proposals concerning single aspects, such as functions, data, or technologies, there is a lack of a systematic design approach that transfers to developments in the industry. The ISA proposed can step in at this point, since it covers all relevant elements and their relations for BPs in a single framework. Professionals can use this framework for the conceptual development of BP products on a semantic level.

4.4. Leveraging potentials of digitization and automation
With the modern form of BPs as BISs, digitization and automation naturally come into play. Their application is not a purpose on its own but offers great potentials to increase the effectiveness and efficiency of how BPs can be maintained and used. They are present within all elements of a BP. Most of the time, this is the result of incorporating specific ICTs, ranging from hardware (infrastructure, computers etc.) to web technologies and AI. For BPs, it is proposed to especially concentrate on the following use cases:

- Gradually mature from hardcopy and file-based solutions to data-based solutions making data more granularly available and better machine-readable.
- Automate functions where technically and economically feasible to reduce manual labor; an example would be the automated generation of documents, such as an energy performance certificate (EPC), when necessary, on the basis of up-to-date data.
- Use automation to interact with the user; insights from data analytics can be used to assist users in decision-making; data analytics with the help of AI can also be of great use when analyzing data from multiple BPs, as applicable for housing companies for example.

4.5. Defining clear business use cases

The real estate industry has problems to determine the long-term value of building-related data, although it becomes increasingly evident, for example, through recurring costs for building surveys or through poor environmental ratings due to missing information. Business models should make use of the fact that not the continuous management of information is economically inefficient and risky, but the recurring need for data collection in times of increased data demands. It is proposed for business model development to orientate on the needs of different actors. This especially addresses:

- Builders and the construction industry: BP can be applied as a tool for a more standardized and comprehensive handover process. It is thus recommended to define the completion of construction (including new constructions and major as-built-constructions) as an appropriate point to initially set up a BP. Alternatively, other points in the building life cycle with increased collection of data (transactions, ratings, certifications…) can serve as well.
- Investors and building owners: A BP facilitates an improved provision with building-related data, gives owners more control over their data, and essentially enables operating a building more efficiently.
- Stakeholders: …receive a better and more standardized way to collect and access building-related data.

A more detailed list of benefits for individual actors can be found in Hartenberger et al. [2], for example.

4.6. Considering custom use cases

BPs should incorporate occasions in the building life cycle in which information management solutions are highly demanded. This is crucial so that they can fulfill an interface role for other BISs, which usually address more specific use cases. This also ensures that BPs speak to the right users. The specification of custom use cases goes hand in hand with the development of business models. The majority of use cases is expected for the use stage of buildings including renovations, maintenance works, transactions, or continuous monitoring.

5. Conclusion and outlook

The real estate industry strives for improved information management solutions. BPs are expected to play an outstanding role in this development, since they represent an instrument that is applicable for a wide range of building owners and stakeholders without expert knowledge. This contribution followed an interdisciplinary approach, with reference to the domain of business informatics, to represent the main elements of a BP. An ISA was presented that considers the users, functions, data, technologies, and their process integration. As a conceptual framework, it can contribute to a better understanding of how BPs function and provide significant assistance to (software) developers, system administrators, and all kinds of custom users. The framework and the modeling approaches can be transferred to other types of BISs too.

Even though the public sector and the research domain invest substantially into the investigation of user friendly and needs-based BISs, it lies in the hands of the real estate industry to make use of the proposals and the information resources. It is expected that the market for data-driven solutions and BISs will grow further. Business models including their respective products and services that consider the information management needs of actors will have competitive advantages over time. In the meantime, this contribution can serve as a basis for transferring the concept of ISAs into the practical implementation of BPs. One option to facilitate this lies in the collaboration of academics and representatives of the real estate industry in demonstration projects. Ideally, there can and will be legal requirements for the introduction of BPs. The public interest here is to improve data on regional and national building stocks. At a minimum, the state or standardization initiatives should lay the foundation for uniform content and exchange formats for data. In Europe, this process has already begun. Above that, further research is needed on the technical and economic implementation requirements for different types of actors.

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Appendix 1. Definitions for building information systems in the literature

Interpretation of a BIS as a(n)…
… inviolable, open, flexible, and automated system for building automation and security [51]
… advanced construction technology (ACT) system that sets the frame for information processing throughout the life cycle of buildings [52]
… system for collection, documentations, and evaluation of building information consisting of a data model, software, hardware, and systemic functions [11]
… knowledge base throughout the building life cycle to satisfy the information needs of different actors and to provide a basis for the assessment of object performance and quality [12]
…database for geometric information in conjunction with building information modeling [53]
… internet platform to merge geometric and other information throughout the life cycle of buildings and to visualizing of 3D models [54]
… dynamic collection of building-related data and documents throughout the building life cycle [10]
… distributed system based on a cloud architecture to enable building-related information management and to overcome deficiencies of BIM [55]

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Appendix 2. Clusters of building information systems

Cluster	Features	Terms
1	Focus on data storage and exchange Interface function High level of semantic and technical interoperability Raw (structured) data and aggregated (multi-structured) data Addresses primarily non-experts Coverage of entire life cycle with focus on use stage	Building passports, digital building logbooks
1.1	Focus on specific building components or specific data Partly connected to specific use cases (renovation) Elsewise similar features than cluster 1	Material passports, product passports, renovation passports
2	Focus on data creation, visualization, storage, analysis Modeling perspective Interface function Mostly raw and geometric data Addresses experts Focus on design and construction stage with applicability to entire life cycle	Virtual building models, such as BIM and digital twins
3	Focus on data collection and processing 'Close' to the building Raw, alphanumeric data Addresses experts High level of specification and technization Focus on use stage	Building automation and management systems (BAMSs)
4	Focus on data storage and analysis 'Further' from the building Mostly aggregated, alphanumeric data Specific addressees Focus on use stage	Corporate information systems for portfolio management, facility management, reporting, risk management etc.
5	Focus on data visualization and analysis Mostly aggregated, alphanumeric data Addresses experts and non-experts Focus on use stage	Platforms, systems, and tools for sustainability-related aspects