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Building-as-a-Service: Theoretical Foundations and Conceptual Framework

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Abstract: The provision of data with information management are a significant challenge for the digital developing construction industry. The utilisation of data from a built asset's planning, design, and construction phases to the operations phase core and to the facility management function of building and integration in supporting core business and support services is frequently limited due to technical obstacles in information management. The paper presents the second of three stages of design science research to propose a conceptual approach for the implementation of the "as-a-service" method for the construction industry, namely "Building-as-a-Service" (BaaS). BaaS involves a shift in the concept of services: users become recipients of services generated by the building, not only services provided in the building. The paper shows the interdependencies between these various concepts and suggests a possible framework for the inclusion of these "as-a-Service" approaches for enabling a Digital Twin based on Building Information Modelling, which is becoming mandatory in several European states. The study gathered the foundational theoretical constructs through a literature review and elucidated them to make the proposed framework feasible. The theoretical foundations comprise Building Information Modelling (BIM), the Digital Twin (DT), the interconnecting technology of smart applications and the practical application in projects. The approach of "Building-as-a-Service" in combination with smart applications can be an approach to making the use of buildings available in a resource-saving way to clients, building owners and users.

Keywords: Building-as-a-Service; Building Information Modelling; Digital Twin; facility management; information management; construction management

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1. Introduction

The construction industry is sufficiently known to have a diminutive digital affinity with a tendency towards digital ignorance, as has already been shown in many studies [1–3]. So far, construction is still mainly associated with classical Taylorism [4]; construction tasks and necessary associated changes to the asset are precisely specified in terms of form, performance, and time to perform a given task. Furthermore, the construction production environment is confined. It lacks flexibility due to the unique characteristics of finished products (i.e., assets) in the built environment, which include immobility, complexity, durability, costliness, and high demand for social responsibility [5]. The construction industry's performance measures are significant cost against budget, with less integration to core service outputs than cross-industry, owing to the difficulty in using data from the planning, design, and construction phases, which is not or only partially transferred to the operations phase and thus can only develop limited effectiveness there [6]. Principally, however, proven concepts from other industries should be critically scrutinized, optimized for use in the construction industry and introduced.

Facility management (FM) is a management function in supporting core businesses delivering core services by integrating people, place, and process [7]. Facility management is hinged on information. Information management application in the built environment is progressively based on Building Information Modelling (BIM) [5]. BIM is commonly applied in capital delivery: planning, design and construction phases, but is not used effectively [8] over the whole lifecycle, especially in the operations phase where the Facility Management (FM) falls. Data is not only incompletely available or inaccurate; thus, it is not beneficial [9] in achieving core business service outcomes as there is no comprehensive alignment of information between the built asset integrating the facility, people and core processes [10]. Although international standardisation exists for structuring, providing, and processing construction data, a lack of data alignment may be one factor for the construction industry's low efficiency and effectiveness compared to other industries. However, this has been a well-known fact for decades, as [11] already described in 2004: "Unfortunately, the construction industry has not yet used information technologies as effectively to integrate its design, construction, and operational processes". The mechanical engineering sector may be considered a leader due to its heavy emphasis on data-driven procedures and technologies. However, it faced a similar quandary to the construction industry today in the 2010s, suffering from the breakdown of data to create long-term value for stakeholders [12].

According to the UK BIM framework [13], BIM in operations should integrate with organisational enterprise systems in delivering built asset performance aligned to core business strategy. The fundamental change of the conventional supply chain-based industry into a data-based business can be summed up as information system integration [14]. This has prompted a "call to action" in academia for broad integration of information management across the lifecycle by all professions, particularly in FM [15,16]. This research investigates the approach of "as-a-service", which is based on information management. "As-a-service" would provide an overarching opportunity to view buildings as a locus for service delivery based on available data from the building, making it possible to achieve the UN Sustainable Development Goals (SDG). However, little thought has been given to applying these service approaches to the construction industry yet [17].

2. Methods

The study employs design science research as a practical research strategy for BIM research [18]. Design science is a knowledge-creating activity like prescriptive research. The distinction is that design science focuses on improving aspects of the built environment to achieve continuous improvement [19]. A cyclical, sequential development process is adopted and evaluated at each level, with corrective action taken as needed. First, consider a specific problem, such as the ongoing and frictionless usage of data throughout the life cycle, as outlined in this context. Then, corresponding solutions are identified and evaluated to determine if they are appropriate for solving the problem. The goal is to use iterative development procedures to generate solutions that can be implemented efficiently, especially in a rapidly evolving domain like BIM [18,20–22].

As in software development, the term "artefacts" refers to artificial objects created by people to solve actual problems. These artefacts can be "constructs, models, methods, or instantiations that add value in a specific context and whose utility can be rigorously shown and scientifically evaluated." [20]. Furthermore, these artefacts could be actual objects, drawings, guidelines, or ICT solutions [21]. Following this principle, a conceptual framework could be defined as an 'artefact' in design science research. The theory provides general constructs relevant to the problem; therefore, this study gathers theory constructs discussed in the next section to design the proposed conceptual framework through a literature review. This research presents the second of three stages of the design science process through a proposed conceptual approach for implementing the "Building-as-a-service" approach (BaaS). Future work evaluates and validates the proposed conceptual framework within the industry using case studies.

3. Theoretical Foundations and Terminology

Before discussing the context for the usability, applicability and possibilities of the BaaS approach, the necessary definitions of BIM, smart applications, the Digital Twin, BaaS and essential data to enable these services are explained.

3.1. Building-as-a-Service (BaaS)

The approach of BaaS is subject to scientific investigation; there are only a few holistic approaches to interpreting the term so far. Isolated approaches have linked this with energy efficiency [22] (p. 783). Energy efficiency forms the foundation of this definition, which, by contrast, focuses only to a limited extent on the basic and service functions of a building [23] (p. 92): "structures, systems, services, management and the interrelationship between them". As a result, the BaaS strategy focuses on the services generated **BY** a building rather than the service (s) supplied **IN** a building. As a result, the preceding definition must be expanded.

BaaS can be defined as "demand-oriented deployment of resources respectively assets. Costs for these resources arise mainly from their use (OPEX) [. . .] with usually no costs for their initial acquisition (CAPEX)" ([24] based on [25]). Within this context, the currently existing distribution of roles is shifting. Previously classically a long-term plannable, monetary resource, users of non-residential real estate are transforming into recipients of the building's services, which can be short- or medium-term and flexible. Construction companies are becoming full-service providers/intermediaries of real estate-related services, starting with assessing needs, financing, planning, and construction, and ending with the maintenance of the property [24]. Buildings become platforms for providers and consumers of information. The focus moves from service(s) in a building to view the building as a service-dominant, logic-based (SDL) asset [26]. The classic function of a building, such as protection, space for living or work, etc., is being supplemented by a data-based function due to this SDL. The use of this service-oriented philosophy as a "producer" of assets is underrepresented in the construction industry [27,28].

3.2. Building Information Modelling as Data Supplier

Given the prevalence of diversity in the construction industry, Building Information Modelling (BIM) has been generically standardized at the international level as the "use of a shared digital representation of an asset to facilitate design, construction and operation processes to form a reliable basis for decisions" [29]. However, this generic definition corresponds to the epitome of information management [17], merging data, processes, tools, and procedures to ensure the ability to decide. BIM allows "to link, store and reuse information in terms of attributes and properties to a specific building component in a three-dimensional computer-generated model enhancing cooperation, collaboration and coordination on- and offsite to improve productivity, effectiveness and efficiency" [30] (p. 136). BIM is a collaborative process supported by technology for information management. The most significant advancement over conventional construction procedures is that this digital model is stored in a database available to all participants rather than in a format [31,32]. A database for the use of BIM is a geometric representation of data, usually referred to as a building model [33] and contains data for planning and constructing an asset. This set of data is mostly static, as it is primarily a documentation of building conditions. Dynamic data are not included but are used for evaluating these building conditions using, e.g., simulations.

The use of information management methods such as BIM and the subsequent use of data science, data structuring, and information databases provides the opportunity to improve current performance, establish a new data baseline with more relevant and current data, and maintain data over a longer time span, thus; ensuring a seamless digital data flow, which would save significant resources in the construction process [34]. Successful implementation of BIM could lead to substantial cost savings in all life cycle phases of a building [35]. BIM can be used to provide services that require not only capital-linked investments (capital expenditures CAPEX) but also operational expenditures (OPEX). Furthermore, public clients have demanded a comprehensive value-added strategy for data creation and distribution [36] in CAPEX delivery and OPEX functions. Still, they lack the corresponding digital ordering and digital data management skills [37], respectively. On the contrary, research also reveals some complications in integrating BIM in lifecycle information management; for example, the current market practice of BIM works only to a limited extent or barely with real-time data [38,39]. Moreover, the necessary data governance in construction does not exist [40] and is mainly reinvented for every project but not applied holistically on a life cycle basis.

In addition, the information abundance and analytical efficiency approach are insufficient to enable effective and efficient information management, especially in the operation and maintenance phase [41] (p. 14). Thus, the concept of digital twins was developed to supplement static BIM in the asset lifecycle by providing opportunities to handle real-time data [42]. If holistically applied, BIM can significantly increase the efficiency of processes [43–45] and has enormous potential to improve data quality for the Digital Twin. Furthermore, the current normative approaches for effective and efficient application of BIM of normative institutions of international importance, such as ISO and CEN, are in development and can help to standardize BIM in the medium and long term [46].

3.3. Smart Applications as Bridging Technology and Approach

The object- and project-oriented construction industry, however, is very dependent on data, its collection and use: "The effectiveness of the construction industry heavily relies on the continuous acquisition, sharing, storing and use of information via integration with available digital and cognitive technologies, and real-time data", as analysed in in-depth research [47]. Notwithstanding this, it should not be neglected that, due to public requirements, projects with BIM are in the planning and development stage that generate data. This data can only be used to a limited extent if dynamic, constantly changing usage data and "static" data, such as primary building data, cannot be integrated. Using "smart applications" can be a possible interim solution for integrating BIM and the digital twin. These smart applications are defined as "data-supported tools that provide added value for the user based on stored, static data in a BIM-supported database, combined with dynamically retrieved data, supporting the user in making regular decisions" [17]. These smart applications serve as a value-added combination of multiple data-carrying systems, ranging from enterprise resource planning (ERP) to computer-aided facility management (CAFM), with a geometric and spatial location using three-dimensional models such as BIM. The different data-carrying systems are presented comprehensively by employing an application, such as a smartphone "app". These smart applications should, however, only support the transition to a veritable digital twin in the short to medium term. In the long term, the digital twin must be made possible without implementing intermediate solutions and, thus, additional interfaces.

Therefore, achieving this smart application goal requires identifying the data necessary for the typical use of a building to order at an early stage of the building's development. Based on this data, it is also essential to determine what added value it can generate for the property's later development and what measures are required for a cost-effective handover [47].

3.4. Digital Twin as Ultimate Goal

A digital twin is a credible and trustworthy digital representation of a physical object, such as a building or asset portfolio [48], and corresponding processes [49]. A generic definition of ISO is "compound model composed of a physical asset, an avatar and an interface" [50]. Therefore, it can be concluded that a digital twin focuses on merging data from several data sources to improve data processing efficiency and collaborative decision-making [51]. Consequently, a digital twin is intended to supplement BIM with real-time enabling technologies [52]. For example, a BIM model incorporating sensors, machine learning, and algorithm simulation would deliver real-time insights that foresee potential future scenarios while supporting better decision-making. This involves creating a collaborative data system derived from a static BIM model and dynamic data retrieved from sensors and other data-collecting devices. This collaborative model allows stakeholders to improve user interaction with services or facilities, visualize alerts to maximize the performance of technical systems, and define more efficient control strategies. Furthermore, it unlocks the possibility of implementing new services that lead to new BaaS business models; therefore, digital twin technology can be used to realize BaaS.

The first approaches to integrating dynamic data into BIM were successful on a prototype basis, with the authors demanding more research to solve this issue to overcome the prototype status [52]. With the lack of digital disruption and the associated transformation in the construction industry, the necessary holistic solution is a digital twin where the physical image is constantly exchanged with the digital representation. The authors state that, if combined with lean construction thinking and artificial intelligence, the approaches of digital twins "represent a step in the evolution of manufacturing, capable of facilitating the implementation of Industry 4.0 principles". However, the digital representation [53] may not be achievable in the short term due to the limited data storage and management [54]. According to the authors, it is important to distinguish that a BIM-generated model is not a synonym for a digital twin and vice versa [54]. "Research in Digital Twins for the built environment is still in its nascent stages, and there is a need to understand the advances in the underlying enabling technologies and establish a convergent context for ongoing and future research" [55]. The earliest advances in incorporating dynamic data into BIM were successful on a prototype basis, with the authors demanding more research in solve this issue to overcome the prototype status [52].

3.5. Interdependencies

The construction industry is moving almost exponentially towards digital methods without having an overarching, industry-wide plan [56], with the development considered a "continuous reengineering phase" [57]. Therefore, the mere use of keywords such as "Construction 4.0" is not conducive to linking the interdependencies of the individual approaches, which are in distinct stages of maturity in terms of development [58]. There are currently tendencies and scenarios to integrate BIM, smart applications, and the digital twin with methods from automotive production, including the lean approach, in the construction industry [59,60]. Here, however, many definitions and interpretations of terms exist, such as clear distinctions between a digital twin and the cyber-physical systems of the automotive industry, which are essential [61]. The focus of digital twins must not be on optimizing existing processes but on considering the need for new processes due to digital possibilities [62]. In this context, it is helpful to consider the several types of fragmentation in the project life cycle. For example, the project is fragmented vertically, the project team is fragmented horizontally, and associated portfolios are longitudinally fragmented [63]. Therefore, the industry must renew itself in a necessary transformational change framework [64].

The corresponding allocation of the thematic areas of BIM, the digital twin, virtual 3D models with (near) real-time data connectivity and the data collecting devices, as well as the cyber-physical systems of Industry 4.0, was shown by [61] (p. 1125), cf. Figure 1. In this context, particular attention must be paid to the intersecting areas of the circles. The intersection between the individual thematic blocks can be observed to be the largest between cyber-physical systems (CPS) and the data collecting devices.

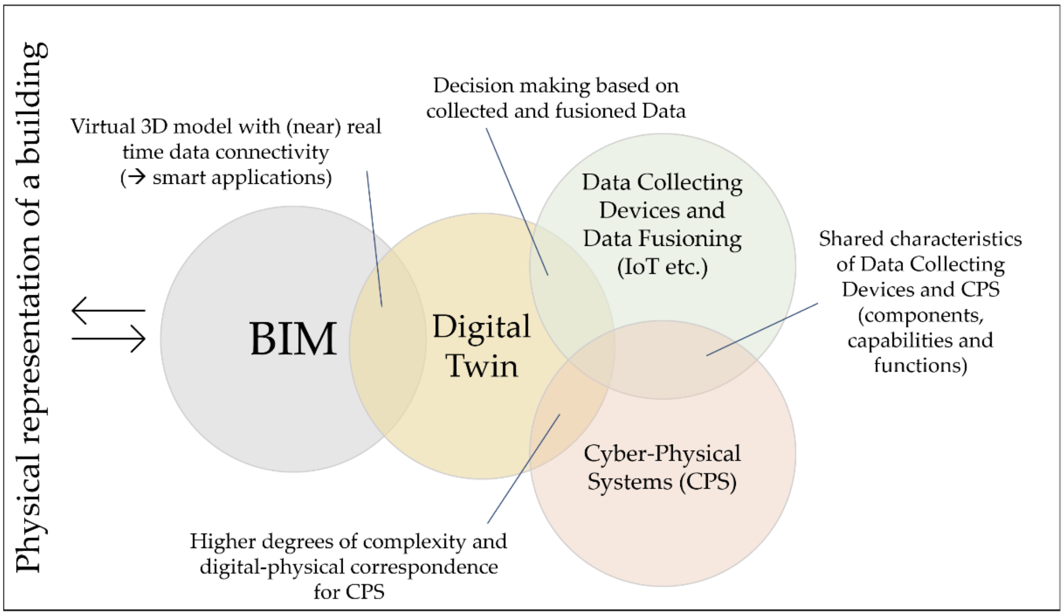

Figure 1. Allocation of Digital Twin, BIM, smart applications, data collecting, CPS based on [61].

The authors assume that there are substantial overlaps between the individual aspects of BIM and DT and between DT, the Internet of Things, and cyber-physical systems. However, there is no overlap between BIM and CPS. The non-existent connection between IoT and CPS indicates that BIM primarily uses the provided static data, and thus, not the regularly or continuously changeable, dynamic data. BIM is, therefore, inevitably more of a physical representation of a building. According to the authors, "near real-time data connectivity devices" combined virtual 3D model (BIM) are compulsory to enable the transition to DT in the real-time short and medium term. These can represent smart applications that serve as a bridging technology to achieve DT.

These considerations led to the development of the BaaS approach. The proposed underlying model with its interdependencies can be seen in pyramidal shape in Figure 2. Several technological principles that build on each other must be applied. Here, the respective higher level is based on the technological and scientific foundations of the lower level ("based on") and incorporates them ("encapsulates"). It forms the BaaS model by combining Software-as-a-Service (SaaS), the use of collaboration and communication platforms in terms of a Common Data Environment in Platform-as-a-Service (PaaS), and Infrastructure-as-a-Service (IaaS) functionality to provide BaaS services implementation, deployment, maintenance, and usage [65].

Essential foundations are tools and procedures for the "Data Collection", which needs data to be specified, structured, and collected for the respective use [66]. These data collection tools form the IaaS. These data culminate and fulfil the Asset Information Model(s) (AIM). However, there is no information continuity yet in the construction industry, but many interfaces exist for growing business use cases, as case studies indicate [67].

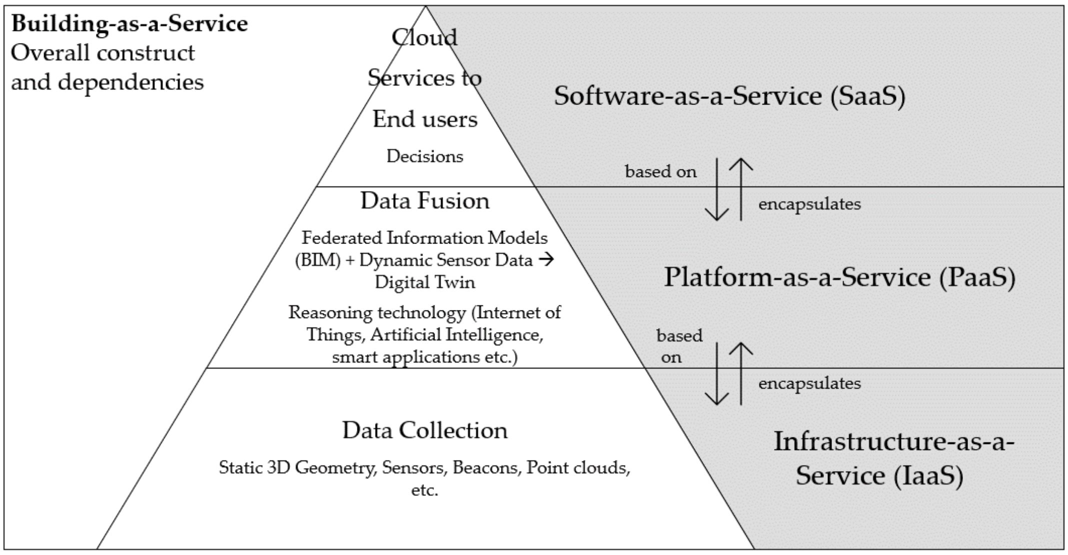

Figure 2. Building-as-a-Service Model.

Furthermore, the data collected in this way must be consolidated to generate a specific added value for further use, for example, in the context of use in facility management [68]. This is the second step, the "Data Fusion", which uses collaborative platforms and Common Data Environments in a PaaS approach to consolidate, federate, and aggregate the collected data. Finally, as a third step, SaaS must support the end user in making the correct decisions based on the available data. In this context, this applies not only to purely "static" data for planning or construction but also to dynamic data that arise during the use of an asset [52]. This requires a constant exchange between the various organizational levels. This continuous exchange ensures the continued running of BaaS. In this case, the use of smart applications can aid in promoting the transition from digital twin to BaaS while also supporting the United Nations' Sustainable Development Goals (SDG) [69].

4. Results

This paper proposes a conceptual approach for implementing the "as-a-service" approach in the construction industry to transform buildings into platforms for information providers and consumers, shifting from service(s) in a building to viewing the building as a service-dominant, logic-based asset. To achieve and implement information-driven planning, construction, and maintenance, other foundations must be created at the industrial and normative level, such as data structures, data governance processes and associated handover protocols. Yet, this paper employs the design science research approach in gathering and combining theory constructs, BIM to the digital twin, and enabling technology to create the proposed conceptual framework.

The proposed framework demonstrates the process of implementing the Building-as-a-Service (BaaS) model, which includes Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), and Infrastructure-as-a-Service (IaaS), as shown in Figure 2. Based on Figures 1 and 2, a conceptual framework was developed that demonstrates the process and possibilities of BaaS (Figure 3). In addition, it illustrates the proposed conceptual framework, which is discussed in Section 5. For this purpose, an ideal-typical situation is assumed. This conceptual framework is to be evaluated and optimized in further studies based on case studies.

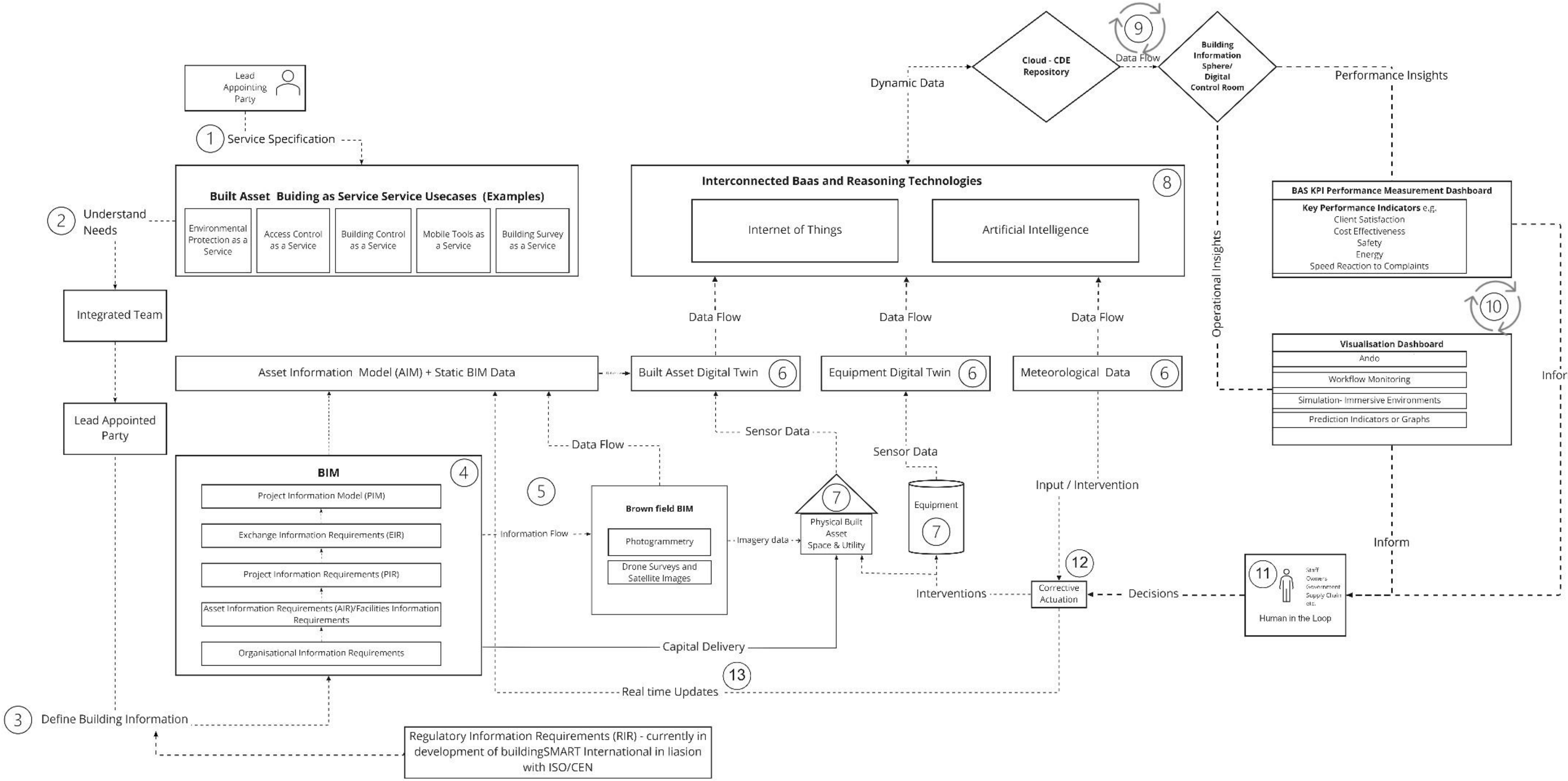

Figure 3. Conceptual framework for the implementation of "Building-as-a-Service".

5. Discussion

The framework is discussed in an ideal-typical project for better comprehensibility. The process is outlined before the applicability is shown in a case study and the general discussion of the framework takes place. To not overload the existing concept and conceptual framework, data security and data safety topics are not explicitly mentioned, as these are considered fundamental tasks of the people, project, portfolio, and organization.

5.1. Procedure

In a typical construction project, the Lead Appointing Party formulates the necessary service specifications (marked as (1) in Figure 3). This is carried out by defining service use cases, and their respective Key Performance Indicators (KPIs) aligned to the core business and support services. The respective requirements must be understood (2), and corresponding integral teams must be formed to work through the common tasks. The Lead Appointed Party is usually tasked with defining the relevant building information or coordinating this with the other appointed persons and companies (3).

Regulatory requirements also influence the so-called Regulatory Information Requirements, which are currently being developed internationally. Employing information management through BIM, the corresponding data containers are provided, used, and developed (4). This begins with the receipt of the Organizational Information Requirements (OIR) and the requirements for the assets (AIR) and those of the project (PIR). In addition to the integration of corresponding Exchange Information Requirements (EIR), a Project Information Model (PIM) is created. From the totality of the requirements under (4), an Asset Information Model (AIM) is produced, which primarily contains static data, i.e., data necessary for planning and realizing the asset that does not change frequently. In the case of an existing property, these data are used to support the Brownfield BIM and to make use of further services there, such as the photogrammetric recording of actual conditions—the data from which are also passed on to the Asset Information Model in a data flow (5).

This static information model can create a Digital Twin based on this static data (6, left). For this digital image of a built asset, other data suppliers and sources must be included, such as equipment or meteorological data (6, middle and right). For this, dynamic data provision must be made possible. It requires so-called sensor data (7) based on "reasoning technologies" (8). Internet of Things and Artificial Intelligence can be supportive here and lay the corresponding foundations for the digital provision of continuously changing data. It is essential to recognize consumption patterns and use them to operate the building efficiently and effectively. The measured and provided dynamic data are collected in a Common Data Environment (CDE), processed, and presented in a "Digital Control Room" (9) to obtain performance insights and trigger events. This is a continuous process, as indicated by the circular arrow.

Based on previously defined and measurable key performance indicators, KPIs are presented (10) to obtain continuous operational insights in this loop, to support people in making decisions, and thus, control the facility services and integrated services (11). Decisions made based on measured values lead to corrective actuation (12), i.e., trigger events that occur in the operation of a building which controls equipment, trigger actuators, etc. (11). In the event of major structural changes or damage, for example, the Asset Information Model piece of information is sent to the model and can be updated in real-time (13).

These are continuous processes to be able to offer Building-as-a-Service. Therefore, it is essential to use the disclosures in Figure 2 with the data sources that build on each other. Based on these data chains and information flows, which build on each other, further services of the building can be enabled and offered.

5.2. Requirements and General Classification of the BaaS Framework

IaaS provides the appropriate infrastructure for offering PaaS [65]. Static BIM models and sensors are considered infrastructure for IaaS leading to a digital twin PaaS. Thus, BIM and real-time data connectivity lay the framework for developing a digital twin. For example, the (BS) EN ISO 19650 series procedure may be used to obtain a digital twin [70]. Due to the international validity of the ISO standard, it can be concluded that—subject to national developments—this is also the case for other countries. The Lead Appointing Party can establish the fundamentals of Building-as-a-Service (BaaS) through the Organization Information Requirements (OIR) [70]. Therefore, it is essential to identify the proposed BaaS use cases. When developing BaaS use cases at this level, it is critical to consider the Gemini principle of ‘purpose’. This ‘purpose’ is divided into three sub-themes by the principles: public good, value creation, and insight [49].

The use cases must comply with the ‘purpose’ principle to promote the public good, corresponding value creation, and insight. The OIR shall outline how data and information will support the Building-as-a-Service use cases, operational and capital expenditure strategy, and informed decisions throughout the project life cycle (all following normative references in this paragraph [71]). Following the OIR, the Lead Appointing Party defines the graphical and alphanumerical data, information, and documentation required for the lifecycle operation and management of the built asset via the Asset Information Requirements (AIR). Following the AIR, the Lead Appointing Party gathers high-level information for the Project Information Requirements (PIR), which must be derived partly from the OIR. PIR focuses on the information needed by the Lead Appointing Party at important decision points during the design and construction process. The Exchange Information Requirements (EIR) should identify the information that the client will require from their integrated team and the format and time frame for receiving it. Furthermore, it specifies the data supplies needed for the project’s development and the functioning of the wholly developed asset, as well as the expected information outputs in the form of documents, model files, and structured data. During the early lifecycle phases of design and subsequent execution, the information model associated with the project is created, referred to as the Project Information Model (PIM).

The necessary structuring requirements for the criteria of the PIM are specified in the EIR. As a result, this federated building information model can contain non-graphical data and supporting documentation in addition to alphanumerical data. The Asset Information Model (AIM) is a federated model that collects the data and information needed to enable asset management. It provides all data and information required to operate a built asset. AIM comprises models, data, documents, and other records related to or required for the operational phase of a built asset. AIM can provide graphical and non-graphical formation, documents, and metadata. AIM can represent either a single asset or a portfolio of assets. AIM can be built utilizing current asset information systems, new information, or data from a PIM established to build a new asset. The AIM can be derived through reality capture for brownfield-built assets such as point clouds, drone surveys, and satellite images [49].

The transformational impact of digital twins is built on their ability to communicate with other forms of digital twins [72], which allows them to extract greater value from the built environment [73]. This can be accomplished by connecting digital twins of the built environment to other digital twins, such as machine and equipment digital twins and meteorological digital twins [74].

BIM and digital twins are two separate concepts with unique differences, and BIM and digital twins are compatible concepts that may complement one another [75]. Even though the terms BIM and digital twin are used redundantly and interchangeably, a clear distinction must be made: a BIM model is not a digital twin but an essential subset and a tool for one [54]. To achieve PaaS digital twin, data fusion should be performed by linking data from BIM models and dynamic sensor data and applying reasoning technology to improve data processing efficiency and decision. As a result, digital twins are intended to complement BIM models with real-time enabling and reasoning technology. Sensor technology can capture real-time data from the physical representation. With the use of artificial intelligence and machine learning, data enables the synthesis and transformation of data into a human-readable format to gain useful insight [76] into the selected BaaS use case.

Consequently, PaaS provides the appropriate data reasoning technology for offering SaaS. Software-as-a-Service (SaaS) storage of dynamic data on cloud services and secure end-users access to service performance and operations insights. SaaS must ensure that it can serve as a secure, unified source of truth by utilizing a cloud-based common data environment (CDE). The CDE provides the essential standards and procedures for collaboration and data interoperability, resulting in a "single source of truth". Common data management should include governance and information handling procedures based on a specified and agreed-upon set of standards for governance information, taking into account security, ownership, accuracy, rationality, review, electronic transmission standards, information sharing guidelines, and accessibility [77]. Furthermore, the Gemini principle of 'trust' should be considered to ensure information security, openness, and quality [78].

The digital control room, which also serves as the building information sphere, is presented as a solution that aims to provide a consistent approach to delivering performance insights such as BaaS KPI measuring, monitoring, and visualization; it allows stakeholders to visualize real-time BaaS performance and act on insights for corrective actuation.

5.3. Exemplary Case Study

Shanghai East Hospital, connected with Tongji University, is an A-grade general hospital located in Shanghai's Lujiazui commercial district in East China (all information in this case study from [79]). Shanghai East Hospital's new clinical facility, which is associated with Tongji University, was designed and constructed to achieve a "continuous lifecycle integration", integrating medical treatment, teaching, scientific research, first aid, prevention, and health care, which allows for building managers to see the status of the building at any moment in a visual interface during its entire lifecycle. The concept of continuous lifecycle integration and early movement of the general contractor contributed to the realization of a fully functional digital twin.

The builders employed a digital twin to integrate static and dynamic data from more than 20 management systems, optimizing all phases of the building lifecycle, from design through operations and maintenance. The building's control centre is powered by a digital twin software solution that allows for real-time visual management via a digital control centre and is supplemented with Artificial Intelligence (AI)-based diagnostic modules. The case study emphasized the continuous integration of big data throughout the lifecycle, from design, construction, pre-operations, and maintenance to operations and maintenance. Terabytes of static and dynamic data were integrated into a unified digital twin system, including building geometry models, attached property information, common building automation systems, repair and maintenance systems, security management system, and so on.

The continuous integration process for general contractors' entire lifecycle and early involvement of facility teams has proved effective. Managers can see the detailed state of the entire hospital using real-time visual management, which is significantly more efficient than manual operations. Big data services were created as a backend to show high-density data streams reliably. As the operation directs day-to-day management activities, the real-time state of the hospital building is now displayed in a modern control centre. With this real-time mechanism, the digital twin has shown far more promise than traditional BIM technology, which will assist professionals in transitioning from BIM to the digital twin.

Intelligent digital twin diagnosis functions and professional artificial intelligence models were combined to form a diagnosis engine that works in tandem with visual management functions. Enormous volumes of dynamic integrated data supported quick facility diagnosis and operating suggestions automatically transmitted back to reality. The instance case demonstrated the potential strength of using the digital twin to give buildings facilities management services, core business and support service insights, and corrective actions.

6. Conclusions

This research identified the need for a shift in the concept of services in the operational phase of buildings, where users become beneficiaries of building services rather than just building services via the BaaS approach. The research provides theoretical foundations, BIM, smart applications, and digital twins. The research illustrates a second stage design science-proposed BaaS model and further proposes a conceptual framework for the practical implementation of the BaaS model. The BaaS model combines SaaS, PaaS, and IaaS functionalities to provide BaaS services. The second stage of design science research is presented in this study; the third stage is research exploration. The researcher will strive to validate the industry's proposed model and conceptual framework to identify practicability and applicability constraints.

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