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# Smart Building Physical and Operational and Distributed IoT Architectures: Recent Advances and Open Issues

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**Abstract**. This paper is an exploration of some of the current approaches to building automation, which involve the broad variety of control and monitoring features that can be utilized to determine various factors, such as occupant behavior, lighting conditions, and temperature changes. At the same time, it touches upon some other innovative IoT- and cloud-oriented technologies designed for smart buildings in order to improve the comfort level, security level, energy savings and compatibility with smart grids and smart cities. Taking into consideration the broad range of technologies and their functionalities, it becomes evident that the design concept should be introduced to ensure successful implementation and adaptability. Furthermore, at the same time, new tools that are based on the building information modeling and digital twin approaches are being developed in the building design and operation area. This paper explores the approaches to designing new solutions and their application areas, highlighting some recent trends and application examples related to the usage of smart homes and buildings. In addition to that, special attention is paid to the process of choosing automation features, making it possible to integrate them successfully and providing interoperability between BMS and the Internet of Things in terms of predicting and changing their functionalities.

**Keywords**. building control system; Internet of Things (IoT); energy conservation; Smart Readiness Indicator

## Introduction:

In the current period, there are numerous adjustments in the technologies, functions, and quality aspects of the building process. For instance, in the European Union, the technical and functional needs for new buildings and their modernization have been subject to major alterations on account of the regulations that the European Commission has developed. One such regulation is the Energy Performance of Building Directive 2018 (EPBD 2018) [1] that focuses on improving the energy efficiency of building. Among others, the latest version of the directive highlights the importance of using automation and control of buildings (BACS) in achieving the mentioned objectives and provides guidance on calculating the Smart Readiness Indicator (SRI). The directive becomes crucial amid the necessity of transforming the infrastructure for both residential and non-residential buildings. This involves the creation of new technologies and systems such as renewable energy systems (RES), electric car charging stations, energy storage, and other micro-grid components. Changes have also been witnessed

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in the ICT network structure, including building automation using field bus technology. New ICT infrastructures, incorporating the IoT, improve user convenience in buildings. [2-4].

### *1.1. Evaluation of Buildings' Smartness and Energy Efficiency*

For a few decades now, specialists in the sphere of engineering and science have worked to tackle major issues with selecting and evaluating the potential of functional concepts in smart buildings [10-13]; however, innovative approaches and solutions have not ceased being found. Sources mentioned above consider solutions to IoT technology-related, automation level-related, and energy efficiency problems in building facilities of the residential and services sector. Guidelines connected with the above LPBD policy direction, LIN 15232:2017 normative document (now replaced by EN ISO 52120:2022), and current Sustainable Rating Index (SRI) project [14,15] guidelines are constantly updated and validated by practical cases studies [16-18]. In the listed guidelines, the classification of functionalities and services of intelligent systems applied in building facilities in accordance with complexity and integration degree is elaborated, while the guidelines provide indicators for quantitative evaluation of the achieved energy efficiency and smartness of BACS integrated into the IoT technology. Moreover, in the LIN ISO 52120 guideline [15] and SRI report [19], methodologies for computation of those indicators are proposed. The emphasis shall be made on the fact that both simplified and more detailed calculation procedures are offered. Simplified approaches presuppose usage of average values of indicators defined in the document and report. They allow making a preliminary estimate of potential energy efficiency savings percentage or SRI points with the minimum amount of information required concerning functionalities and services performed by BACS and IBM. On the contrary, detailed approaches imply starting calculations with multistage procedures, during which first stage includes usage of average indicators, while the following stages need more detailed description of the building under evaluation (utility profiles, technical characteristics of subsystems comprising building infrastructure, etc.). In order to ensure a higher level of precision, it is necessary to use empirical measurement data from existing constructions for verification purposes, as far as automation features, connections, integration, and parameter settings are concerned. In this respect, performing case study research with various building types situated in different countries and regions is crucial, which is emphasized by relevant scientific and technical papers [17, 20-22]. In this regard, the authors examine buildings and measure parameters in warm and cold climates, thus allowing for a transition from theoretical assumptions to actual calculations. It has been proven that the quality and volume of data are important aspects for the methodology and results of SRI calculations, as is evident from the cases considered in the mentioned publications. Undoubtedly, a more sophisticated approach ensures greater accuracy and precision when selecting appropriate BACS and TBM systems, but this requires more time (a few months) and conducting further measurements and analyzing data. Designers and architects who deal with creating designs and technological installations face similar issues, as they have done throughout the previous decades. To speed up the work, they use modern BIM and DT technology. Advanced distributed monitoring and control systems using IoT nodes can serve as the technological platforms for such tools.

### *1.2 Literature Review Methodology, Novelty, and Structure of the Paper*

The present work gives an introduction to BIM and DT approaches along with the most frequently used software in constructions for each of these methods. Their application fields and important characteristics, which contribute to design, modeling, and parametric system and

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facility analysis are discussed. The topic has been selected due to bibliometrics carried out based on BIM and DT investigations and citations on WoS and Scopus databases, followed by additional search on Google Scholar and patent databases (Google Patents, Espacenet, USPTO). In particular, the authors have compared the number and characteristics of publications in two leading scientific-technical journals. Results are presented in Table 1.

Table 1. Results of the literature review in bibliometric databases.

| Database | Publication Type | BIM | DT | BIM + DT |
|---|---|---|---|---|
| Web of Science | Articles | 111,477 | 10,433 | 642 |
| | Review articles | 5094 | 4672 | 96 |
| Scopus | Articles | 17,779 | 10,940 | 8388 |
| | Review articles | 1158 | 1084 | 2106 |

Further, the results obtained in the preliminary review stage were subject to a complete scientific and conference paper analysis. This process involved searching through publications in several bibliographic databases that have been acknowledged in construction, electrical engineering, automation, and ICT sectors. In such a way, the analysis of publications in relation to this study was focused on those publishers that provided the most relevant publications in the preliminary stage and have been acknowledged in technical sciences domain. Publishers are Springer, Science Direct, MDPI, IEEE Xplore (conferences/journals), Taylor & Francis, ACM Digital Library, and Wiley Online Library. These results are presented in Table 2.

**Table 2.** Search results from the literature in publishing databases.

| Database | Publication Type | BIM | DT | BIM + DT |
|---|---|---|---|---|
| Springer | Articles | 14,394 | 2073 | 369 |
| | Conference papers | 11,631 | 1812 | 287 |
| | Review articles | 961 | 216 | 88 |
| Science Direct Elsevier | Articles | 531,416 | 26,288 | 5831 |
| | Review articles | 55,294 | 2677 | 1232 |
| MDPI | Articles | 4573 | 1587 | 130 |
| | Review articles | 289 | 259 | 27 |
| IEEE Xplore | Articles | 10,710 | 1297 | 104 |
| | Conference papers | 42,345 | 6343 | 479 |
| Taylor and Francis | Articles | 100,179 | 31,278 | 15,934 |
| | Review articles | 2499 | 761 | 479 |

After the final filtration of sources, 75 pieces were considered relevant and dealing with various issues related to building automation and facilities management and associated problems of BIM and digital twins (DT). This paper includes most of the research articles that deal with the design of BACS and BMS systems. Additional resources related to organization and technical design have been provided. The current paper adds value to the literature by analyzing ways of designing and optimizing IoT based BACS using BIM and DT approaches in connection with the main problem of interest addressed by the research as follows:

1. Functions of BACS mentioned in EN ISO 52120 and SRI manuals may be considered while choosing and structuring BIM tools for BACS design and optimizing DT structures in buildings with respect to energy efficiency management.

2. DT structures may act as an underlying principle in the process of SRI calculation and BACS functions selection through energy efficiency analysis in buildings which is used for constructing buildings in this research.
3. Internet of Things and edge computing techniques (fieldbus networks) can act as a DT infrastructure in the course of BACS-based building operation and provide enhanced BIM parameterization while designing other buildings.

From the preliminary analysis of literature, especially literature on reviews of BIM and DT applications, it became clear for the authors that the theses mentioned above reveal new areas of usage of BIM and DT approaches and at the same time highlight gaps and problems reflected in scientific literature. Documented problems and extensive knowledge on market solutions for these technologies and techniques, reflected in the list of references of this publication, necessitate the systematization of the problem area under consideration. These thoughts became a trigger for initiating the present review, according to the authors' opinion introducing new concepts into the sphere of BIM and DT use in relation to energy-efficient buildings automation. The rest of this paper will discuss this issue as follows. In section 2, current applications of BIM and DT are introduced, together with main issues faced by BIM and DT. The third section is about current trends and issues in building design and maintenance in relation to BIM and DT. The conclusion of the paper with the directions for further research is given in Section 5.

## 2. BIM and DT Idea and Applications

BIM is a methodology and a technology which mainly serves to improve design processes and ensure proper implementation of the current buildings. Involving digital models of building parts, their assembly and infrastructure make it possible to work together of various professionals involved in the process and thus shorten construction time and improve the quality of the result [29,30]. However, technological developments of the last ten years – development of new computer technologies, new engineering software and novel technologies in constructing infrastructural facilities of buildings – extended the application spheres of BIM to include operation of buildings. Today, a number of specialists and engineering groups maintain that BIM could be used in any period of the life span of buildings and infrastructures, as seen in [30,31], and illustrated in Figure 1 below.

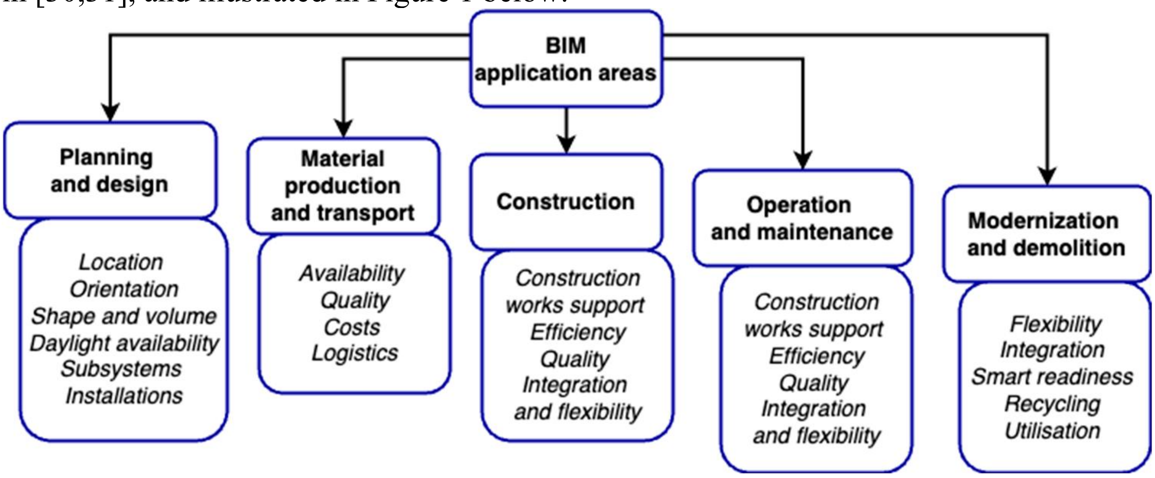


**Figure 1**. Modern, innovative fields in BIM applications.

The findings of this literature review are that the current process of building design, particularly smart building design, includes several stages in which BIM can be introduced:

1. Planning and design: This stage identifies the purposes, functionality, and possibility of incorporating various smart technologies into a building design. In the process of designing a building, the following elements are analyzed in detail: the complete analysis of a building shape, geometric properties, and aesthetics for evaluating the reliability and strength of building structural components. With the help of HVAC, plumbing, and electrical system design, optimum operational conditions and energy efficiency are ensured. Analyzing the environmental impact of the building, its energy impact on the environment makes it possible to minimize such effects. Based on building orientation, window-to-wall ratio, and other elements, with the help of BIM, designers create buildings that are functional, aesthetically appealing, environmentally friendly [31].
2. Building material production and transportation: This involves the production of materials required for constructing a building, as well as their transportation.
3. Construction: This is the actual construction process involving the installation of intelligent systems within the building. Implementation of BIM technologies during this stage involves monitoring the progress of construction, as well as taking into account issues related to occupational safety and health [32].
4. Modernization and demolition: Depending on the period of time elapsed since the building was erected, renovation and modernization can be needed, along with the incorporation of smart technology. Thus, users and facilities managers should get accustomed to new technologies,[33,34] adjusting to changing conditions, regulatory requirements, and technical specifications [35]. Eventually, due to the extended lifecycle, demolition is performed, considering the issues related to recycling building and construction materials [36].

Another useful approach/technology for ensuring the successful management of buildings and monitoring of their operation includes the use of Digital Twins (DT). [37, 38] Here, it should be noted that DTs are meant to be universal technology used in various industries [39]. As mentioned in [40-42], digital twins are the technology that is widely used in different industries including industry, engineering, medicine, etc. Also, their dynamics depend on the nature of the object being considered. The general principle behind the development of DT is described in [43] and includes explaining how the demands for products and functionality will lead to market direction and technological development. Modern DTs operate in real time with various types of data allowing to conduct interactive simulations, predicting threats, planning scenarios, etc. That is why Aheleroff et al. [27] propose to distinguish three domains of use of modern Uf technologies including the ones necessary for supporting BACS systems and enhancing building intelligence as shown in Figure 2 below.

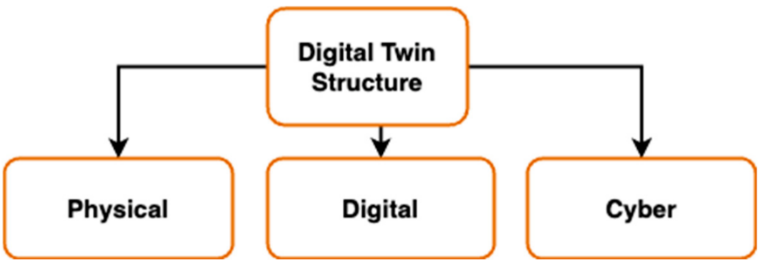


**Figure** 2. .Basic components of digital twin.

A regular DT usually consists of three main parts, each associated with a separate stage or function [27,28]:

- The real object means the real one to which the DT is related. It can be anything, from a whole city as the far end case. The physical entity has all kinds of sensors and other devices to capture the information, which is subsequently flowing to the digital side of the DT [44].
- Machine DT is one of the first types used to build and simulate the machine and, therefore, predict and prevent failures and optimize maintenance processes. The second type – a product twin – is utilized to design and test products in virtual reality. Finally, the third type – process twin – helps detect possible areas of improving performance both from practical data and past predictions.
- A cyber data processing system connects the physical and the digital objects. It is engaged, among other tasks, in gathering the sensor data and transferring the information to the digital twin. Besides, the system might employ ML algorithms aimed at predicting the behavior of the object and discovering potential faults and issues [45].

This way, the mentioned characteristics make the approach of the digital twin (DT) especially effective for assisting in building and infrastructure management procedures in the operating stage of a building and thus complementing the features offered by Building Information Modeling (BIM) [46]. As far as DT solutions require data collected from the serviced building itself, they have a tendency to engage with numerous modules of modern Building Automation and Control Systems (BACS) and smart home solutions and incorporate related services.

Regarding [49] in literature, management of building assets was discussed in terms of Autodesk BIM 360 Ops. This solution is provided via the web. It enables managers to integrate their asset data across multiple sources – including Revit, BIM 360 Field, IoT, and spreadsheets.Therefore, it is possible to review documents and models, checklists and schedules for maintenance, and history records. As a result, maintenance employees will be able to control their assets and perform any maintenance operations.

As can be concluded from [50] in references, software called Ansys Twin Builder 2024 R1 allows connecting the application called SCADE Display Visualization software 2024 R1. Thus, using the connection, users will be able to see, in real-time mode, movement, deformations, and other parameters of the simulated object in a three-dimensional space. With the help of the program, it is possible to visualize complex simulations in several physics domains and in different engineering branches simultaneously. For example, this may refer to simulations in mechanics, electronics, control theory, heat transfer, and fluid dynamics. This way, the user gets the whole picture regarding simulation and finds out interdependencies between all the components of the model.

Speaking about selecting the software used in digital twin (DT) creation and management, there is an important aspect one should pay attention to – user's needs and expectations both at the moment and in the future. Moreover, one should take into account all the available functions and consider the ease of use of the software, even though there may be different opinions on the issue. In particular, although CarnotUIBK may serve excellently to simulate energy flows in buildings, this software lacks versatility compared to other BIM software like Revit or BIM 360 Ops. However, despite all the possibilities of the latter for simulating building components, it cannot create DTs and needs some extra software to do this.

### *2.1. Investigation the High Levels of Difficulties and Lack of Information for Suitable Adoption of BIM and DT Technologies*

However, BIM and DT-based technologies find application in both construction management and building infrastructure as well as environment organization and pose various problems.

There are also problems found in literature and existing in research in connection with the adoption of such technologies to facilitate the design process and integration. These issues include not only innovative LOL networks and BACS functionality associated with infrastructure in smart buildings but also many other aspects. Table 3 highlights the major issues:

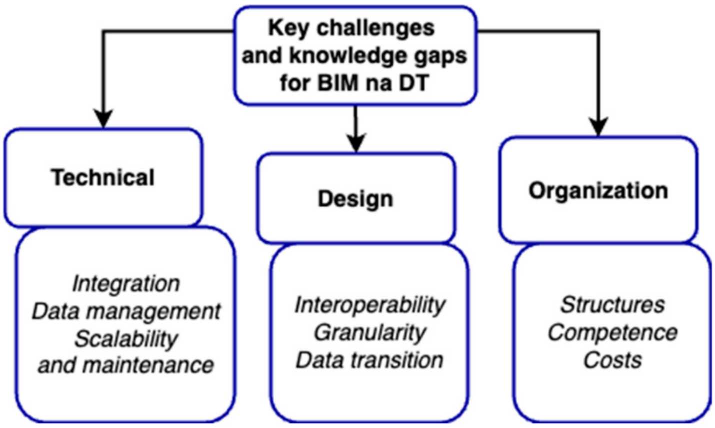


**Figure** 3. Key challenges and knowledge gaps for BIM and DT.

***2.1.1. Technical challenges and Limitations.***

One significant direction in which further research is needed pertains to the development of the BIM-DT integration, according to the literature (cf. [23, 30, 51, 52]). As stated in the cited literature, in order to address this problem, it is necessary to consider the impact of open standards, including the IFC standard in case of BIM data, along with data sharing in cloud environments in the context of digital twins. In particular, standardization is critical to the resolution of the majority of problems and obstacles that exist in the area of BIM-DT integration. This is because standardization will help to ensure consistency in data and avoid data loss as it passes through different project stages. Furthermore, it will lead to increased efficiency, better cooperation, faster information flows, and, consequently, time savings. These factors are especially important in terms of the application of BIM and DT technology in the architecture of distributed fieldbus automation systems, where network nodes lack the computing resources and memory capacity (edge modules) (11, 53, 54). One relevant initiative is the development of frameworks and best practices for the integration of digital twins by the Digital Twin Consortium [55]. However, regardless of these efforts and developments, all such projects have yet to be implemented, and no unified standard has been adopted for BIM-DT data integration.

However, data consistency can be challenging in large-scale projects. It is necessary to have adequate technological infrastructure and reliable software that allows for ensuring uninterrupted interaction between BIM and DT. It is important to pay special attention to ensuring the security and privacy of transferred data. In this regard, the creation of a data management plan becomes crucial. [28].

***2.1.2. Design Challenges and Caps***

It is possible for problems to occur during the entire process of integration. First of all, some of the potential sources of problems during this process include the vast array of file formats used in different BIM software programs. The key goal in the creation of translation tools is efficiency during this process. Information loss during the process of data transfer from one stage to another is an unavoidable phenomenon [52]

Another concern relates to granularity and scale of projects. Inadequately granular or overly detailed BIM and Df models may turn into heavy and burdensome to handle objects. Not very granular objects can be of no help in terms of making decisions regarding certain actions. Big problems are inherent in the adjustment of granularity in accordance with project needs [53]. A promising solution lies in the implementation of LOD models – models that define particular degrees of granularity of BIM objects, see [54]. An analysis of this approach is made from the standpoint of using this tool as means of facilitating FM practices in buildings and providing immediate assistance for facilities managers in solving issues related to reliability [55], interoperability, [56] and usability of building information in the course of its operational and servicing phase [57]. Moreover, further improvement of the tool can be thought of in the scope of DT. [57]

#### *2.1.3. Challenges and Gaps in the Organization*

According to the work done by Yang et al. [30], a major research gap lies in lack of case studies analyzing the application potential of BIM and DT under BACS organization along with integration into IoT networks of various facilities. It is particularly relevant since BIM and DT should be applied to some new areas, in particular to improve FM operations and develop organizational approaches for making buildings more energy-efficient. The use of BIM and DT solutions, especially integrated ones, requires significant expenditures, which should be taken into account by both organizations and investors. In turn, before adopting BIM and DT technologies, it is vital to conduct a proper cost-benefit analysis. According to Zou et al. [26,61].

## *3. BIM and DTs-Recent Advances in Development and Challenges for the Future*

In particular, in connection with the subject matter of the paper, trends and problems related to the development of the intelligent building industry, on the basis of which there has been an increased need for building automation and control systems (BACS) services to ensure efficient functioning of building infrastructure systems, as well as methods for their integration, should be noted. To meet this requirement, automation functions are understood as those services that need to be implemented through the use of distributed network systems, IoT networks among others, based on cloud technologies. This concept correlates with the definition of the BACS service as presented in the technical report [19]. However, taking into account possibilities of implementing the functions of automation within distributed IoT networks, presented in papers [54,62,63], it can be suggested that services of control should be used as an organizational tool of data object function integration. Moreover, building upon this idea, the concept of Buildings as Services (BaaS) is currently being developed.

### *3.1. Following the implementation of the IoT paradigm and data-driven approaches.*

All of the solutions mentioned above were built using data derived from both design assumptions and regular requirements and from operational data. In particular, the information about the condition of subsystems constituting building infrastructure, the level of use intensity of individual rooms, and prevailing there environmental conditions plays an important role in this regard. Besides, major innovations concerning the approach to collecting and processing data necessary to use BIM and DT models in building applications took place recently. Instead of being based solely on BIM data, the information coming from fully distributed IoT sensors and monitoring systems along with other kinds of data are used. As a result, more complete DT, which reflects the state of the object in a more accurate manner, and is directly connected with tasks performed by BACS and BMS becomes available. One should note that nowadays efforts are made to expand BIM and DT models with data derived from diverse sources (BACS sensors and actuators, smart meters, and others). Thanks to this innovation, modeling and analyzing realities and facilities become possible [23,76-78]. Besides, whereas before only traditional

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approaches were used to monitor facilities (periodical measurement and observation), in the case of D'Ts engineers are able to create realistic simulations. They can perform virtual experiments and analyze future functioning of a building thus optimizing its performance. What is more, in a safe virtual space one can check how the application of some innovative technologies (e.g., photovoltaic panels or intelligent energy management systems) can be done [47,79,80]. Moreover, thanks to DTs it is possible to evaluate impact on the environment and find the optimal solutions. Thus, using the simulation it will be possible to choose most ecological materials, heating systems, ventilation devices. Consequently, thanks to DTs it becomes easier to develop energy-efficient buildings requiring minimum amount of water and emitting less pollutants [25,79,81].

Leveraging fully the potential of BIM and D'Is, there are challenges related to technology and organization that the construction sector is facing. Data quality attributes essential for BIM at semi-advanced level using open BACS standards (i.e., KNX, LonWorks, BACnet) include completeness of data, complexity of data, and flexibility of data, according to Vieira et al. In addition, Vieira et al. analyze the standardization process of BACS. Also, the paper [30] notes some research directions for future developments in the sphere of using BIM in the case of designing and integration of BACS.

Automation challenges include integration of processes, diversity of formats, and a shortage of qualified personnel. The challenges include exchange of data on BIM/DT platforms, transition gaps from designing to operations, and adapting model granularity for each stage. Issues related to BIM/DT in organizations also play an important role in this. Speaking about [23] mentions the necessity of optimizing organizational structures for BIM/DTS application. Having solved these issues, BIM and D'Ts will be the useful tools which will increase the efficiency of construction projects significantly, decrease the costs, reduce the number of mistakes, and make the projects more profitable. According to [85], BIM and the 'lo'f allow having a constant flow of information, however, the connection between the model and its real prototype is not always complete because of such issues as software change, missing parts, or software version error. These issues are inherent in the D'S as well.

Last but not least, there is the recent trend related to the introduction of artificial intelligence (AI). It is one of the popular trends not only in automation of industries and buildings but also in BIM. AI has already provided different opportunities for designers and engineers. For example, it helps automate some processes including the creation of documentation, clash checking, and quality control. With the help of artificial intelligence, people can save time, labor, and money. Besides, it can be used for analyzing data and proposing modifications for improving efficiency and reducing energy consumption. AI is used to generate photos and videos, and it helps people visualize the project [9, 19, 3]. One of the major benefits of AI for BIM is the cost-effectiveness of finding out mistakes and optimizing projects at any stage. With the help of such technology, one can have more time for creativity and making better decisions. Moreover, such solutions will make buildings and their designs aesthetically pleasing and sustainable. Thus, the AI trend in BIM has just started developing; however, it has significant potential. It is recommended to observe the process in order to benefit from it [57,94,95].

## 4. BIM and DTs as BACS Design and Management Process Enablers: Potential, Issues, and Research Avenues

Taking into account the novel contributions identified in Section 1 and trends and challenges described in Section 3, the authors of this review suggest extending the concept of the use of BIM and DT technologies and methodologies in the sphere of design, construction, and exploitation of the building. In particular, it would be reasonable to take into account two basic tendencies of innovation in the area of building. These include smartness and comfortable use on one hand, and energy efficiency improvement, renewable energy sources application, and preparation to introduce smart grids on the other hand. In this regard, according to [26,27,69], it is clear that the significant point of such concept is integration between physical and digital layers. Hence, the authors of this paper propose using cloud services as an integrator also in case of introducing BIM and DT solutions, see Fig. 4 below.

In this way, it would be possible to develop optimal control parameters for building infrastructure equipment and use predictive models effectively. Meanwhile, DT models could also facilitate the mechanisms for improving energy efficiency of the building through appropriate selection of BACS and TBM functionalities parameters not only during designing but also dynamically during exploitation.

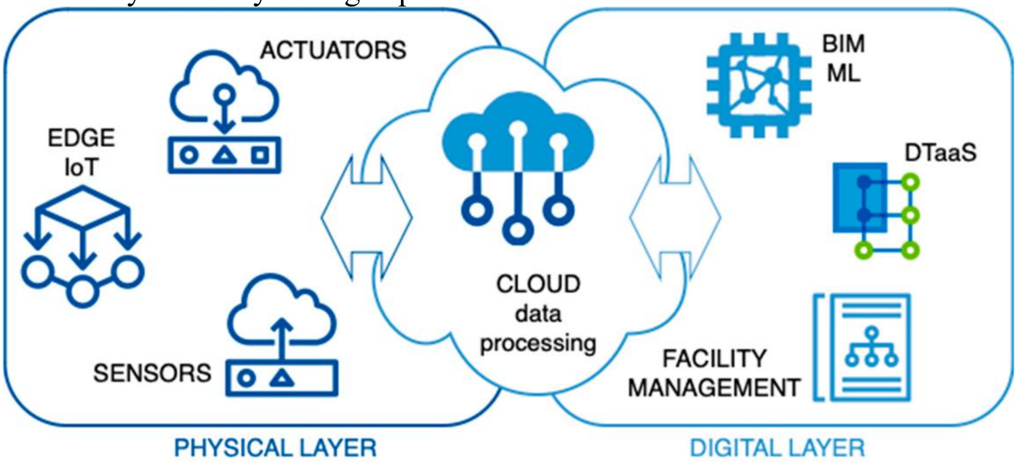


**Figure 4.** The Idea of a BIM-DT Platform with Building Aluminum Cross Section (BACS) and Lot-based Support in Buildings. [26,27,69].

### *4.1. Standards, Requirements, and Approaches*

In this connection, the development of a new concept is necessary, especially in view of the recently established standards and guidance documents regulating the choice of options and regulations concerning the selection of BACS functions and intelligent building services. As far as the latter is concerned, it should be noted that among the mentioned standards ISO 19650:2018 "Organization and Digitization of Information About Buildings and Civil Engineering Works, Including Building Information Modeling" should be considered as one of the major and widely used approaches regulating the principles of applying BIM in organizing building functionalities [96].

The presented document includes all of the important recommendations on managing building life cycle. Besides, it highlights the ability to use BIM as an effective tool to improve facility usage, efficiency, and building operation as well as designing. The standard covers a wide variety of aspects such as: (i) flexibility and versatility of different BIM strategies; (ii) requirements for information management concerning asset delivery stage and corresponding information exchanges via BIM; (iii) information management, as the management process, including those that arise during asset management involving BIM; (iv) procedures for making information exchange decisions based on the criteria laid out in ISO 19650 to ensure high-quality project or asset information model; and (v) guidelines for the management of BIM security and information security acquisition, creation, processing, and storage when implementing any other project, asset, product, or service. It can be concluded from the above that modern buildings require not only software, but also hardware for implementing BIM solutions. In this way, supporters of integrated application of BACS technologies, IoT, and cloud services claim that such integration can become a basis for successful designing of BACS capabilities and automation systems in buildings and organizing facilities management operations. [97].

An example of current efforts in this direction, especially towards making BIM standards more universal and unified regarding building data, can be considered the creation of the open COBie (Construction Operations Building Information Exchange) standard [98,99] as another crucial aspect of digital transformation in construction management, leading to an improvement in building management and reduction in costs. This open standard establishes all the required rules of universal exchange of data associated with the building. Thus, it ensures digital transformation. The use of this technology will enable interoperability of data from such systems as Building Information Modeling (BIM), CMMS, BMS. In addition, it helps ensure the quality and

4.1.1. Performance of BACS and Energy Efficiency

As BACS has grown considerably in the past two decades, it is crucial that apart from standardizing data and communications protocols, we should also standardize automation functions and protocols governing the interactions. LIN 15232 standard, which is titled as "Energy performance of buildings – Impact of Building Automation, Controls and Building Management" was approved and revised many times in the early 2000s. According to the 2017 edition [14], there are four types of BACS (A-D), depending on their impact on energy performance (refer to Fig. 5 [8,101]). Please note that this classification differs from the energy performance classes specified in EN ISO 52003. [102].

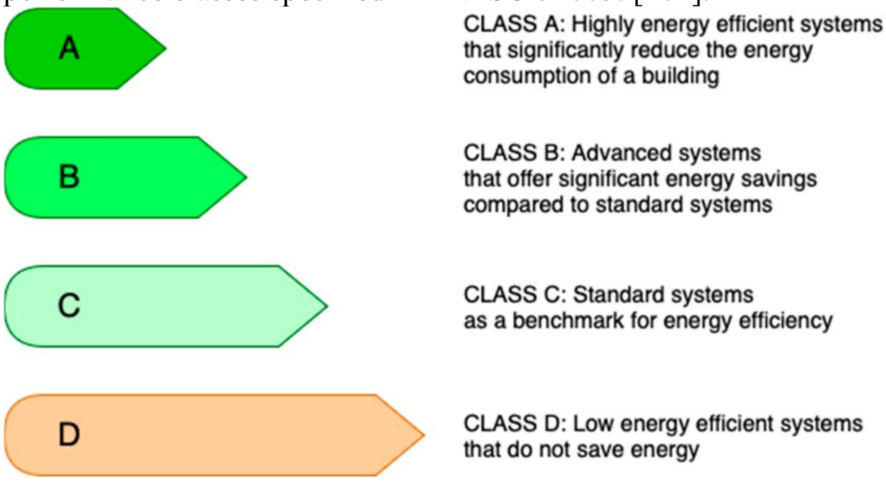


**Figure 5**. Classification of BACS in accordance with EN 15232:2017.

As has been shown in [103], the standard can be used even at the design and prototype stages. In other words, a concise list of control features along with the basic indicator calculation technique is useful for designing buildings without detailed data about BACS and TBM principles. This way allows optimizing the design and functions variants' assessment. Further, during the construction process, a building can help determine the areas where there is an opportunity to decrease the amount of energy used. As a result, integrators can consider many options for temperature management and lighting in terms of daylight, occupancy, and other aspects. However, as is mentioned in [104], there is a discrepancy between EN 15232:2017 assumptions and reality. The standard claims that with more automation, one will save more energy. Nevertheless, in practice, users manage to bypass such systems in order to achieve their purposes. For example, users may cover sensors detecting daylight presence and occupancy [5,105]. People might be unaware of the consequences of their actions. Hence, raising the awareness of specialists and common people is necessary. Besides, case studies for buildings of various kinds are also quite useful, because they take into consideration differences in the scenarios of utilization of buildings as well as in the geographical locations of these buildings. These criteria define the application scope for BIM while designing buildings and D'T techniques during the exploitation period when BACS and BMS are installed in buildings.

The EN 15232 has been superseded by the EN ISO 52120 in 2021, with slight amendments acknowledging the impact of TBM in BACS and modern BMS for local energy grids and micro-grids. The EN ISO 52120 is concerned with energy performance in buildings with BACS and TBM. Refs. [106,107] point out that the EN ISO 52120 increases awareness of the energy efficiency benefits associated with building automation as well as procedures for assessing BACS operation and installations for increased energy efficiency (Figure 6).

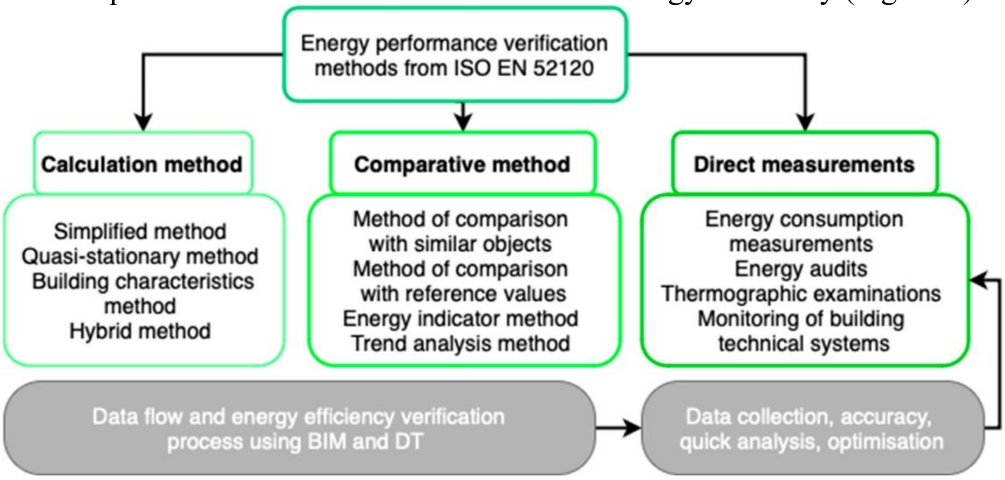


**Figure 6.** Methods for verification of energy performance according to EN ISO 52120 with the potential support of BIM and DT applications.

The standard describes and explains three verification approaches used alongside performance indicators for calculation and comparison procedures. Each of these methods has the ability to use BIM and DT in order to verify BACS and BMS installation. However, while many of the important issues affecting building energy efficiency are discussed, there are some that do not receive the needed attention. These critical components of energy saving systems have been described by Vandenbogaerde et al. in the paper [13]. In their model, the authors evaluate building load, user behavior, climate and maintained temperatures to adjust system activity and control energy consumption depending on these variables. Technical parameters, like control algorithm and sensor resolution, are also considered by the researchers to guarantee proper building control and optimization. The location of the building is assessed for better utilization of sun rays and reduction of dependence on artificial lighting. Moreover, the ratio between windows and walls is taken into consideration in order to make sure the amount of natural illumination is sufficient but does not cause overheating. As the authors point out, taking into account all these issues is crucial to decrease energy consumption associated with lighting and heating/cooling systems. Ignoring these criteria may cause underestimation or overestimation of the energy savings.

DT systems are discussed in the publication [108] as well. The authors note that there is no lack of DT studies in literature as evidenced by many citations; moreover, the issue of thermal comfort is considered in a number of papers. In the framework of the critical analysis, regions of the world that require additional attention in terms of this knowledge are described. Moreover, the analysis identifies the variables (humidity, air temperature) that are consistently mentioned in many publications, providing hints on what factors will be interesting to examine in the future.

**4.1.2. BACS and Smartness of Buildings**

Based on the practical application of EN 15232 and EN ISO 52120, the Smart Readiness Indicator (SRI) was proposed in 2018. At first, the SRI was included in the Directive of the European Parliament and the Council (EPBD, 2018). Later, the results of work done in 2020 produced a thorough methodology for assessing building readiness for intelligent solutions [19]. At the moment, voluntary participation in EU Member States is being implemented. It is worth noting that the SRI estimates the building's readiness to be "smart" but does not evaluate the current performance of the building in terms of performance or energy efficiency [16,22,80,109-112].

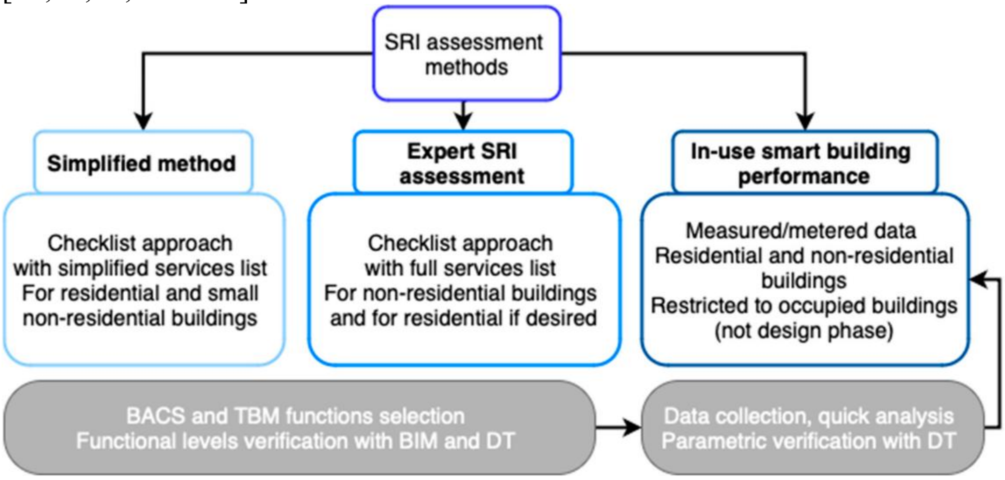


**Figure 7**. Methods of assessing SRI  with prospects for application to BIM and DT.

The exact calculation of SRI makes it possible to distinguish buildings which can help to produce energy. It is an important aspect for urban management. Besides, the use of SRI might become beneficial in managing power networks in aspects of generating, transmission, and distribution. In particular, special attention needs to be paid to public buildings, including educational establishments.

The EN 15232 has been superseded by the EN ISO 52120 in 2021, with slight amendments acknowledging the impact of TBM in BACS and modern BMS for local energy grids and micro-grids. The EN ISO 52120 is concerned with energy performance in buildings with BACS and TBM. Refs. [106,107] point out that the EN ISO 52120 increases awareness of the energy efficiency benefits associated with building automation as well as procedures for assessing BACS operation and installations for increased energy efficiency. [114]. According to Figures 6 and 7, the use of D'I's and BIM technologies in combination can significantly speed up the process of data gathering and analysis, thus making it possible to enhance accuracy of computations.

**4.2. Perspective for New Solutions**

The dynamic nature and capability for learning of the D'T and SRI may assist in making decisions in a more knowledgeable way. Collaboration using both instruments is possible within several stages of the project implementation. The D'f allows scenario simulation, whereas the SRI specifies what optimal activities should be undertaken, thus promoting the optimization process. Real-time updating is applicable to the D'T, while metrics can be changed within the

SRI as per the changing requirements and conditions. Features that the Df and SRI have in common provide a basis for further investigation in developing intelligent systems. The combination of the above-mentioned innovative technologies gives rise to certain prospects and possibilities including modeling and simulation as suggested by [115]. Together, they might play an important role in optimizing building management and operations. These technologies reveal significant potential in the smart city and building area [17].

**4.3. Issues of Significance and Research Prospects**

The most important challenges and tendencies that have to be taken into account in regard to the development of BIM and DT methods and technologies. The mentioned above aspects are particularly relevant to the successful realization of the mechanisms of function design within BACS and the technical organization of the IoT-based distributed network, as well as their verification through application to the process of designing and operation of buildings and other types of physical infrastructure.

It should be noted that one of the most important tasks to facilitate effective and comprehensive interaction between BIM and DT platforms and the physical elements of distributed BACS networks is the guaranteeing of the dependability of data and their integrity, as well as the communication and processing processes performed with their help. Availability of real data is one of the most crucial factors that define the efficiency of the employment of BIM and DT technologies together with BACS and BMS methods. It is worth noting that although the LIN ISO 52120 and SRI methodologies provide recommendations concerning the selection of the necessary functions, control services, and monitoring of buildings' operation, they do not imply specific technologies to be used for this purpose. In such a way, an open environment is created to implement various technical approaches for the organization of the distributed automated system and related technological components. However, practical experience acquired during the implementation of BACS and BMS shows that the most optimal results can be achieved using open technologies only [116–118].

The necessity to create new mechanisms of intercommunication between different protocols and media at the level of objects, providing opportunities for data interaction with the higher-level networks (Internet) while ensuring the highest level of communication security, data encoding, and compliance with real-time operation conditions for automation modules.

The parameterization of selection and arrangement of BACS control functions and services, as enabled by the LIN ISO 52120 standard and adapted to the SRI, can be regarded as the best set of parameters to be implemented in BIM and DfS tools. Indeed, as mentioned above, not only does the utilization of this set of criteria help with the design and operations of buildings, but it also allows for benchmarking and monitoring their performance. The SRI offers the opportunity for benchmarking and monitoring the Building Sustainability Index, which would allow building operators to assess the effectiveness of BACS- and To'l-based projects and discover ways of improvement. Support in this aspect can be gained via integration of real-life system installations and simulation based on D'I models, which not only allows for scenario simulation, but also analysis of changing utility parameters of buildings, such as fluctuation in energy tariffs, variations in loads applied by household devices, and infrastructure of microgrids.

It is necessary to mention the aspect of sustainable practices' promotion beforehand. It becomes particularly important when considering how effective energy management systems should be created for both energy production/distribution and energy provision services to prosumers, whether it concerns complex buildings or independent facilities. The implementation of sustainable management practices is encouraged by both standards through utilizing technologies, such as IoT devices and cloud services. Accordingly, the inclusion of criteria mentioned above into BIM applications, which have become increasingly common in building design/development, would increase awareness concerning implementation of sustainable development practices among designers and investors.

**5. Conclusions**

In this article, a literature review was conducted to summarize modern scientific achievements in terms of the development and implementation of technologies and methods associated with BIM and DT approaches. Analyzed datasets relate to their applicability in the sphere of technologically developing BAS that can operate in IoT networks. For these purposes, in this review, the authors investigate tendencies in the development of such models and technologies; their new features and prospective potentials. Within the framework of the initial diagnosis, assumptions and objectives set for this research paper (Section 1), this analysis reveals gaps and possible barriers that may hinder the further development of the idea of synergy between technologies and approaches to BIM and DT implementation in the design, construction, and operation of smart buildings with advanced BAS services and functions. The main purpose of such solutions is to ensure high energy efficiency and increase occupants' comfort by using new approaches to managing energy infrastructure and buildings in general. As mentioned before, due to being implemented according to EN ISO 52120 and SRI guidelines, it is possible to implement these processes not only in BIM models but also in DT algorithms and patterns, thus realizing them via modeling, prediction, monitoring and optimal control of building automation. It is especially important nowadays since building infrastructure becomes more and more complicated and diverse. Modern smart buildings with RES and energy storage become active participants of smart grid systems and energy markets as prosumers. Consequently, new methods must be used while designing, constructing and operating such buildings (especially those with BACS/BMS and IoT). The purpose of this research is to develop universal and practical tools for the use of designers, installers, users, and maintainers. In the course of elaborating this problem within this research paradigm, the authors formulate the key thesis of the original contribution concerning the prospects of successful and productive usage of LIN ISO 52120 standard recommendations and the SRI as such. The key point here is that these components can be successfully used as an important part of Building Information Modeling (BIM) and Digital Twins (DTs) technology for modern buildings, both new constructions and retrofit facilities. For meeting the standards which appear on the market at present, there is needed special software, which would help to accelerate the process of designing and would allow developing intelligent features. Moreover, it becomes essential to operate and monitor the parameters of the building through all phases of its life cycle. Therefore, the authors pay their attention to a technology that promises to change the market and optimize many buildings – the digital twin. As for specifics, this issue concerns the technological design of Building Automation and Control Systems (BACS) via distributed IoT technologies with using cloud services in order to reach more precise BIM models, DT patterns, and parametric settings of control and managing features.

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