A Digital Twins Model Based on IFC Open BIM Models Managed on Web Platforms

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Abstract. The use of BIM has introduced a process of building digitalization in Europe and worldwide, including all the systems plant they contain. Italy and Lithuania, following European directives, have introduced national laws mandating the use of BIM for various projects. One of the challenges in using BIM platforms is ensuring data interoperability over the years. Currently, the only globally recognized model based on an open standard by ISO is the IFC data model. The management of buildings, with particular reference to energy and environmental aspects, is now one of the main objectives that all European Union states must pursue to ensure increasingly sustainable buildings. The use of digital models based on open BIM models could significantly contribute to the intelligent and environmentally sustainable management of buildings and systems. This work presents a case study of Digital Twins based on IFC open BIM models managed on a BIM web platform.

Keywords: Digital Twins · open BIM · IFC standard · IFC Web platforms · Energy managed

1 Introduction

The concept of DT was first proposed by Grieves (2005), who defined it as a virtual representation of a physical product with a bi-directional data flow. Later, Grieves (2014) expanded it into a system consisting of a physical product, a digital counterpart, and a two-way data link. Depending on the integration between physical and digital entities, Digital Model, Digital Shadow, and Digital Twin are distinguished [1]. The construction sector is witnessing a transformative shift towards digitization, driven by the need to enhance performance, ensure sustainability, and manage the inherent complexities of modern projects [2, 3].

By creating digital replicas of physical assets, construction projects can leverage Digital Twin models to monitor the condition of equipment and infrastructure, predict potential issues before they occur, and make data-driven decisions throughout the project

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lifecycle. This leads to enhanced collaboration, reduced errors, minimized downtime, and more precise project planning [4, 5].

Over the past decade, a notable evolution has been the transition from isolated digital tools to the more integrated framework of digital twins [6]. This framework brings together a myriad of technologies, including Building Information Modelling (BIM), Geographic Information System (GIS), Artificial Intelligence (AI), and real-time data sources like cameras, mobile devices, and sensors [7]. These technologies combine to facilitate the continuous exchange of information between the physical and digital realms. Driving and reflecting on this change, there is a body of research that underscores the potential of construction digital twins in improving decision-making processes, particularly during the production control phase of construction projects [6–13]. The DT concept comprises three elements: 1) a physical system, 2) a virtual system, and 3) a bidirectional data flow between the physical and virtual systems [8, 14]. Here, the virtual system should act as a digital replica or twin of the physical system, incorporating relevant data and simulation models. These models should be closely integrated, react to changes in the physical twin, and their granularity and accuracy should support the functional outputs or services delivered by the DT [15]. DT has the tendency to accelerate building energy efficiency by analyzing and monitoring a building's energy consumption. This data-driven approach aids in identifying inefficiencies and implementing strategies aimed at improving a facility's overall performance and lower energy consumption [16–18]. Table 1 examines the limitations and strengths in the application area as well as building energy efficiency. It also shows various digital technologies, such as DT, BIM, and Artificial intelligence (AI), that enhance building management and infrastructure, especially DT. The implementation of DT technologies in the construction sector has substantially increased efficiency and control. Smart sensors and building information management systems can monitor and control a construction site's operations [16, 18–21]. In construction works, DT uses sensors to continuously monitor a building's energy consumption, helping to reduce carbon emissions and improve the facility's quality [16, 18] Through the use of Heritage Building Information Modelling (HBIM) and BIM, DT can provide a comprehensive view of a building's energy consumption and perform accurate simulation and modelling, improving sustainability and lifecycle monitoring [17] Additionally, integrating IoT sensors into DT enables real-time energy monitoring, reducing carbon emissions and improving energy efficiency [22, 23]. According to Delval et al. (2024) [18], this technology can also be used to perform accurate monitoring without the need for regular inspections. For example, the Edge's Digital Twin integrates data from over 28,000 sensors monitoring temperature, humidity, occupancy, lighting, and more. This data feeds into a cloud-based platform, creating a digital replica of the building's systems, including HVAC, lighting, and energy consumption. The building achieved a 50% reduction in energy use compared to traditional offices, showcasing the benefits of real-time monitoring and predictive analytics [19]. Another, according to Yu et al. (2023) [24] to their discussion about how digital twin (DT) technology can significantly improve efficiency in port areas, mainly through the integration and optimization of renewable energy systems. It highlights that new energy power generation, such as renewable energy, is crucial for the low-carbon operation of ports. Also, Yu et al. (2023) [24] mentioned that the digital twin can provide more complete operation simulation capabilities, support interaction with various real factors, and gather operating experience to make performance evaluations more objective and accurate. This demonstrates the diverse applications of DT for enhancing energy efficiency in port areas. This category shows how Digital Twins enhances building energy efficiency by enabling real-time monitoring and predictive analytics, but high costs and integration challenges must be overcome for effective deployment.

Table 1. Strengths and limitations in the area of application (Building Energy Efficiency)

Categories	Strengths	limitations
Building energy efficiency	improved sustainability and management through renewable energy integration [25] Enhanced maintenance and comfort with DT and BIM [26] Real-time energy assessment and predictive accuracy [19] Collaboration support and early performance analysis with BIM [20]	Estimating carbon footprint and intervention cost [25] Challenges in integration into diverse practices [16] High costs and data quality.requirements [19] Technical constraints and setup costs [20]

The European Union promotes the adoption of Building Information Modeling (BIM) [27–32] to improve efficiency and transparency in the construction sector. Directive 2014/24/EU [33] on public procurement encourages member states to require the use of BIM in publicly funded projects. Many European countries have introduced the obligation of BIM for large public works. For example, the United Kingdom imposed Level 2 BIM from 2016 and has since made significant progress, while Germany, France, Italy, and Spain have adopted it gradually. In Italy, the BIM Decree (D.M. 560/2017) made BIM mandatory for contracts above certain economic thresholds from 2019, with progressive extension until 2025. In Lithuania, BIM adoption is also growing, with government support for the digitalization of construction. Since 2021, the use of BIM has been mandatory for certain public projects, aiming to improve efficiency, transparency, and sustainability in the construction sector. The goal of the European directive and various national implementations is to reduce waste, improve construction quality, and promote interoperability among industry professionals, accelerating the digital transition in the European construction sector. The evaluation of building performance is complex due to the engagements of multiple criteria during the design process. If the aim is to focus on demands like energy consumption, acoustic performance, thermal comfort, indoor air quality, and suchlike, evaluation should be correlated to the design process [34]. There are a variety of decision parameters when building's specifications are considered, including the envelope, heating, ventilating and air conditioning (HVAC) systems. The goal of the building performance can be set to reduce undesirable environmental influences while maximizing indoor air quality and energy efficiency [35]. In this regard, there is a huge need to obtain better building energy performance (BEP) without sacrifice of comfort, cost, aesthetics, or other performance considerations, and the application of different strategies and improvement of technologies for energy efficiency have been increasing dramatically [36]. The performance-based design process as explained by Kalay obtains qualitative solutions for specific unifications of forms and functions in particular conditions rather than process-based paradigms [37]. Moreover, these can only be detected with multi-criteria and multidisciplinary performance evaluations. For instance, the design process of existing net-zero energy buildings depends on performance-based decisions that contain "all aspects of passive building design, energy efficiency, daylight autonomy, comfort levels, renewable energy installations, [and] HVAC solutions, in addition to innovative solutions and technologies" [38]. To sum up, performance-based design evaluates a building's performance in respect of environmental considerations as well as design functions and aesthetics. This emphasizes the combination and extensive optimization of diverse measurable building performances [39]. Currently, building information modeling (BIM) provides a platform to incorporate various stages of the design process for the investigation of a building's performance. BIM is utilized not just as a model but also as a platform that includes all the characteristics of the building, and the disciplines and systems involved. It offers a suitable platform for co-working between multidisciplinary and interdisciplinary efforts during all processes of the project. Furthermore, because it conserves necessary information about energy performance analysis, when BIM is utilized for this, it can save considerable time and effort and reduce inconsistencies and mistakes [40]. Thus, this method becomes an encouraging way to obtain various design goals for architects and engineers [41]. An important consideration here is interoperability, expressed in terms of the ability of communication involving the exchange and usage of data among at least two software tools by a majority. There is no requirement for duplication of data with the help of interoperability when transferring data between software tools, while an ability to use multiple tools with the same sets of files for different aims is desired [42]. Interoperability enables data transition among applications and the collective contribution of multiple applications. Expressed, thus, as the capability of data exchange among applications helps to improve workflows and eliminates the need for the manual copying of data from previously created applications. Such copying limits the number and range of repetitions practically available to calculate best solutions for complicated subjects like energy design, and it also carries consistency issues [43]. Interoperability through open standards, particularly the IFC (Industry Foundation Classes) data schema [44, 45], has become pivotal in enabling high-level semantic information exchange across the AEC industry. As an open, standardized file format, IFC ensures seamless data sharing among stakeholders using diverse software applications, serving as a cornerstone of the BIM process by maintaining data integrity across platforms. This foundation supports Open BIM, a collaborative methodology that relies on interoperable formats like IFC to foster transparency and coordination among architects, engineers, contractors, and facility managers. Beyond design and construction, BIM's digital model evolves into a digital twin—a dynamic virtual replica enriched with real-time data to simulate and optimize the physical building's performance throughout its lifecycle. Complementing these advances, open scripting empowers algorithmic solutions, automating workflows and expanding customization possibilities across the AEC sector [46, 47]. Thanks to IoT sensors, BIM models, and advanced algorithms, digital twins allow monitoring, predictive analysis, and optimized maintenance of buildings and facilities. Integration through the use of Open BIM models and digital twins revolutionizes the construction sector, offering advantages that can be summarized in the following points:

- Interoperability between different software and platforms.
- Real-time monitoring of building performance.
- Predictive simulations to optimize consumption and maintenance. • Intelligent building management throughout its lifecycle.
- Use and integration of artificial intelligence in the management of building systems and facilities.

In the context of systems (HVAC, electrical, hydraulic), the digital twin allows the detection of anomalies, prevention of failures, and improvement of energy efficiency. Open BIM ensures that information is accessible to all involved professionals, reducing errors and operational costs. This synergy between open digital models and real-time data represents the future of smart building automation, improving sustainability from various perspectives (energy, environmental, economic, etc.) and the multi-objective comfort of built environments.

1.1 The HVAC Simulation Laboratory

In this work, the design of a prototype plant developed at the University of Cagliari in the Faculty of Engineering and Architecture is presented, which will allow the simulation of systems plant behavior in various internal climate configurations. Everything will be managed and monitored through a digital twin created using the systems OPEN BIM model with the use of a WEB OPEN BIM platform capable of operating on BIM models in open IFC format [48–50]. The prototype plant will be developed in the Laboratory of Technical Physics and Energy at the university and will have the capability to manage, always through the Digital Twin, on a BIM Web platform, as many as 14 different plant configurations. Figure 1 shows the different plant configurations planned for the prototype. As can be seen, various generation systems are provided that allow the simultaneous production of thermal and refrigeration energy. There are also thermal and photovoltaic solar panels that will enable a more accurate simulation of the plant size related to the climatic location and their producibility. The systems based on renewable energy production can be studied for different types of envelope. In fact, the laboratory will allow the simulation of different types of building components (walls, floors, roofs) through a dynamic simulation model, managed through the WEB platform, which will allow the simulation of multiple configurations to maximize energy efficiency and self-consumption of energy produced from renewable sources.

2 Components 'Open Bim for Hvac Test Facility Management'

A prototype has been developed consisting of innovative systems that combine air conditioning and electricity production, all managed remotely through advanced technology applied to the digital twin. This prototype uses sensors distributed throughout the system

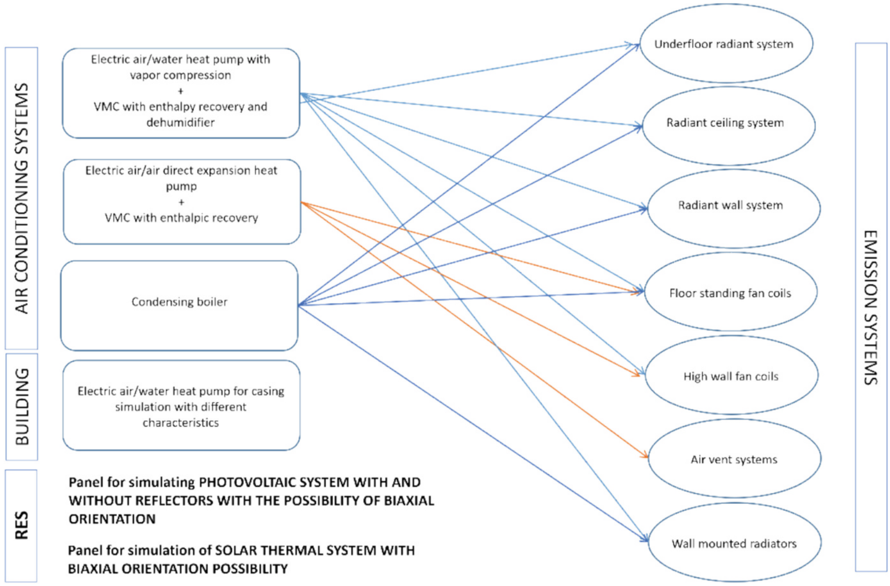

Fig. 1. A figure caption is always placed below the illustration. Short captions are centered, while long ones are justified. The macro button chooses the correct format automatically.

to collect real-time data on temperature, humidity, energy consumption, and equipment operating status. This data is sent to a digital model of the system, the digital twin based on OPEN BIM, which simulates the behavior of the physical system. The digital twin enables monitoring and optimization of system performance and allows for automatic adjustment of operating parameters to maximize energy efficiency and environmental comfort. Additionally, the system can predict faults and/or malfunctions and suggest preventive maintenance interventions, with the capability to integrate artificial intelligence. The integration of electricity production, for example through photovoltaic solar panels, reduces dependence on the electrical grid and lowers energy costs. Remote management offers the ability to control the system from anywhere using connected devices such as smartphones or tablets. This advanced system not only improves operational efficiency but also contributes to environmental sustainability by reducing CO2 emissions and promoting the use of renewable energy while maximizing self-consumption. In summary, this prototype represents a step forward toward smarter, more sustainable, and autonomous buildings.

2.1 Air Conditioning System

The air conditioning systems designed for the prototype are based on various types of generators, including heat pump generators with direct expansion, air-to-water systems, absorption units, and, finally, a small combustion generator. For example, Mitsubishi mono split air conditioners (with direct expansion and air-cooled condensers) are known for their efficiency, reliability, and advanced technology. These air conditioning systems are designed to provide optimal comfort in residential and commercial environments, ensuring precise temperature control and quiet operation.

2.2 CMV Air Exchange System

Controlled Mechanical Ventilation (CMV) systems with a variable air flow rate of up to 500 m^3/h and a thermodynamic heat recovery unit represent an advanced solution for ensuring high-quality indoor air and optimal energy efficiency. These systems are ideal for medium-sized residential and commercial buildings, where maintaining constant and controlled air exchange is essential. The thermodynamic heat recovery unit is one of the distinctive features of these systems. This device not only recovers heat from the extracted air but also employs a thermodynamic cycle to further enhance the efficiency of heat transfer. This process allows the incoming air to be heated or cooled with minimal energy consumption, significantly reducing operating costs. Air quality is ensured by advanced filters that remove dust, pollen, and other pollutants, thus improving the healthiness of indoor environments.

2.3 Management System Based on Digital IFC Open BIM WEB Models

The Management System based on IFC Open BIM WEB BIM Leader digital models represents a revolution in the field of construction design and management. This system leverages Open BIM (Building Information Modeling) technology to create detailed and interoperable digital models using the IFC format. The adoption of IFC Open BIM enables efficient collaboration among all professionals involved in the project, such as architects, engineers, and builders, facilitating the exchange of information and reducing communication errors. Thanks to this interoperability, the digital models can be utilized throughout various phases of the building lifecycle, from design and construction to management and maintenance. The WEB BIM Leader system integrates these technologies into a web platform accessible from any internet-connected device. This allows for centralized and real-time project management, enhancing transparency and operational efficiency. Users can view, edit, and share digital models, monitor project progress, and coordinate activities more effectively. Another significant advantage of this system is the capability to perform advanced analyses and simulations, such as evaluating energy performance and cost management. This helps make informed decisions and optimize resources, contributing to more sustainable and profitable projects. In summary, the Management System based on IFC Open BIM WEB BIM Leader digital models is an innovative and comprehensive solution for managing construction projects, improving collaboration, efficiency, and sustainability. Figure 2 shows the main open formats for files managed [44, 45, 51, 52] through the BIMLeader platform created by BuildingSMART International [45]. These formats allow the management of almost all necessary information through their open format, which enables information interoperability.

Figure 3 shows the developed prototype system consisting of the chamber equipped with various thermal emission systems (R1), a cold chamber capable of reaching very low temperatures (−26 °C), and all the systems for generating thermal and refrigeration energy. The 3D MEP model represented in Fig. 3 is a phase of project study and is currently under further study to be improved before its construction.

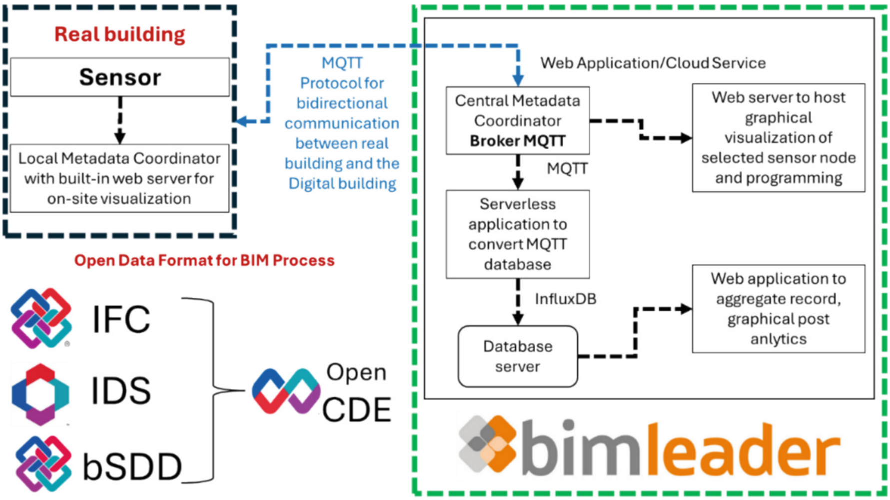

Fig. 2. Flow diagram of the Management System based on IFC Open BIM WEB digital models.

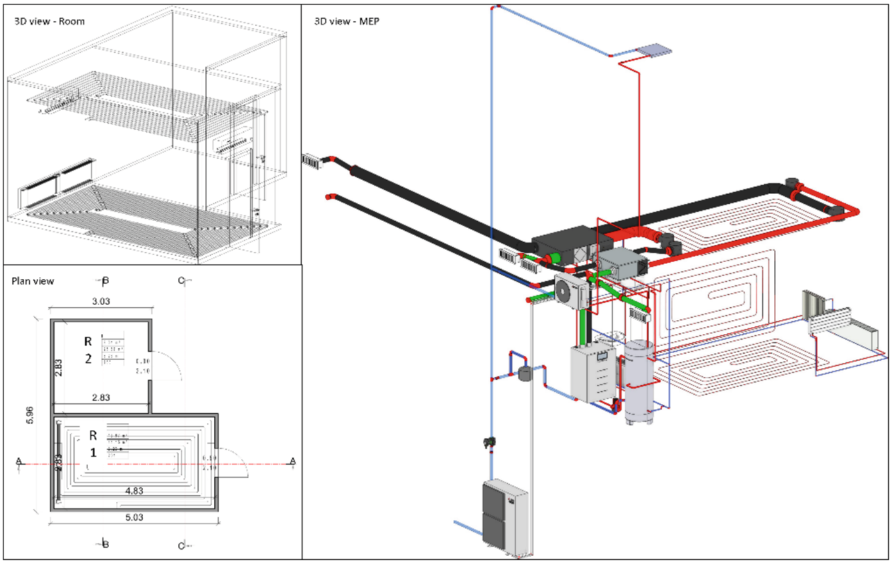

Fig. 3. Prototype system in the design phases: chamber and plant systems for the chamber.

3 Digital Model and MQTT Protocol

MQTT stands for Message Queuing Telemetry Transport and is a standard messaging protocol according to ISO/IEC 20922:2016. It is designed for communications requiring low energy consumption or when bandwidth is limited.

MQTT operates on a "publisher/subscriber" paradigm: every client can act as both a publisher and a subscriber, and it receives information only from the topics it has chosen to subscribe to. The MQTT broker (server) manages communication between connected devices. A subscriber client that wishes to receive information subscribes to the designated topic. When a publisher client has an update on one of its topics, it publishes it to the broker, which then sends the update to all subscriber clients registered to that topic. Efficient communication via MQTT offers numerous advantages both in terms of data handling and energy consumption, thereby benefiting the environment. This enables IIoT devices without continuous power supply to better utilize their batteries, optimize energy consumption, and extend their performance lifespan. Additionally, MQTT ensures reliable message delivery, which is particularly important in the context of industrial automation and process digitalization. Data acquisition and flow communication are essential aspects for maximizing benefits. In light of this, we can state that MQTT stands out for:

- Lightweight and reliable performance
- Scalability of communication
- Data security

3.1 Integration of KNX and MQTT

It is possible to use both protocols simultaneously, and in many cases, this combination can offer significant advantages. Indeed, various product series allow the integration of a KNX/MQTT network. They enable the publication and retrieval of data to/from an MQTT server and a KNX network. These gateways provide quick and easy access to the IoT world and are compatible with IoT servers supporting the MQTT protocol. MQTT communication can be encrypted using TLS/SSL protocols, ensuring a secure and protected connection. These converters are very easy to configure and enable the IoT system to interface with the KNX world. On the KNX side, it is possible to connect all common KNX devices such as temperature sensors, shutters, light switches, actuators, alarms, and more.

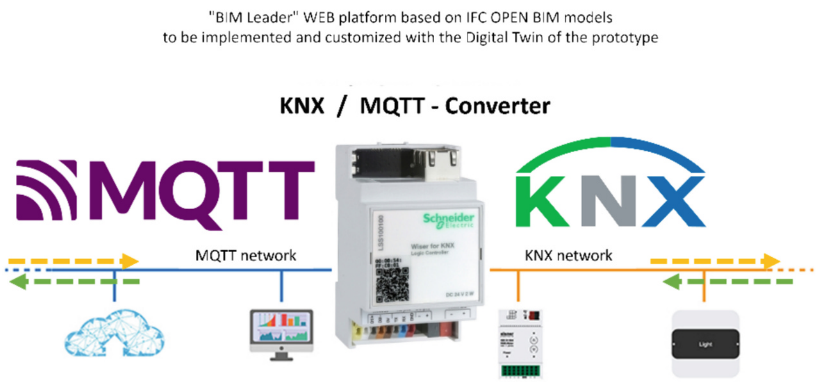

Fig. 4. Flow diagram of data exchange between prototype systems and the internet network

Figure 4 shows the interface between the KNX protocol, used for the management and control of all plant devices, and the MQTT protocol used for internet communication.

MQTT is a versatile and powerful protocol for communication between IoT devices. Its lightweight architecture and quality of service mechanisms make it ideal for applications where bandwidth and reliability are crucial. Therefore, its use is well-suited for the prototype under investigation in this research. In conclusion, the integration of the MQTT protocol into an open BIM web management platform for a prototype of air conditioning and electricity production systems represents a significant innovation. This combination enables efficient and secure communication between the various components of the system and the BIM model, facilitating real-time management and monitoring. The open BIM platform allows for greater interoperability and collaboration among different stakeholders, improving the design and maintenance of the system. MQTT ensures fast and reliable data transmission, optimizing performance and reducing response times. In summary, this integrated solution makes the system smarter, more efficient, and more sustainable, flexibly addressing energy and environmental needs.

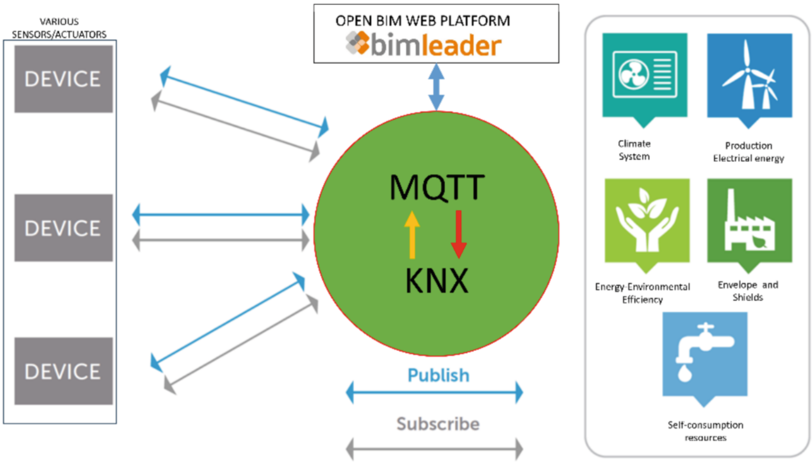

Fig. 5. Flow Diagram: MQTT–KNX and BIM Leader Web Platform

Figure 5 shows the flow diagram used to manage the different components of the prototype system through the MQTT and KNX protocols. These protocols will form the basis of bidirectional communication between the prototype system and its digital model.

4 Conclusion

In conclusion, a prototype has been studied to simulate and manage the building-plant system to be developed at the Engineering and Architecture campus of the University of Cagliari. The prototypal system will be created in the Technical Physics Laboratory and will have the ability to manage, always through the Digital Twin on a BIM Web platform, as many as 14 different plant configurations, significantly expanding the results obtainable in the field compared to the single specific configuration already adopted.

The goal is to create and develop a simulation, prediction, and management system for building-plant systems based on Open BIM technology managed on web platforms. This system will allow the implementation of management logic aimed at optimizing energy efficiency and maximizing self-consumption of energy produced by renewable energy sources, considering the various configurations of both the plant systems and the different types of building envelopes. The management system is a fundamental aspect of all plant systems and is designed based on a digital model replicated on a web platform that processes interoperable data formatted according to the Open BIM-IFC model. The use of open models based on BIM to realize the digital model for real-time management of the building-plant system represents a significant technological advancement. The entire initiative is aimed at maximizing energy and environmental efficiency, as well as self-consumption of energy produced by renewable energy sources (RES). This is achievable because the model can monitor and implement logic that considers not only the plant system but also the entire building-plant system within a specific environmental context in which it is actually inserted. The implementation of the prototype thus becomes a main and innovative aspect of this research.

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