A BIM-BASED FRAMEWORK FOR FACILITY MANAGEMENT DATA INTEGRATION IN HERITAGE ASSETS

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ABSTRACT: *The operational phase of a real estate asset accounts for approximately 80% of the overall investment and management costs throughout the entire life cycle of the building, and the activities of space management and monitoring of building components and systems play a crucial role in ensuring the well-being and health of users. The AECO (Architecture, Engineering, Construction, and Operation) industry is transitioning towards a new framework governed by data-driven processes. In this context, Building Information Modeling (BIM) can support the utilization of big data generated throughout different stages of the building's life cycle, thereby establishing itself as a dynamic repository of information at the center of a constellation of systems used by a Facility Management body to achieve specific objectives (such as CAFM, ERP, BMS, etc.).*

The proposed study aims to define a processing framework for the collection and management of data aimed at the implementation of DT of existing real estate assets, created based on the integration between BIM platforms and IoT technology oriented to subsequent developments of big data analytics and AI applications. The objective is to support in the operational phase of buildings the decisions of the various operators involved in planning scheduled and/or corrective maintenance actions and to generate content, recommendations, best practices by formulating predictive analysis on managed assets. In particular, a critical analysis is made of the various approaches available for the definition of an IT architecture to support IoT reference models, which will find application in the monitoring of some existing assets of the University of Florence's real estate managed by the Building Area, digitally implemented on a BIM platform. The contribution is part of a broader research activity carried out as part of the PNR Project, "BIM2DT. BIM-to-Digital Twin: information management to support decision-making in the building life cycle."

KEYWORDS: *Facility Management; HBIM; Digital Twin, IoT.*

1. INTRODUCTION

For several years now, the digitization of the construction process has been a primary objective of governments, organizations and in general stakeholders in the AECO sector (Daniotti et al., 2022) to reconfigure a production sector that, with different graduations in different countries around the world, lags historically behind the manufacturing sector in gathering the benefits that technological and process innovation through Information Technology can return in terms of efficiency, competitiveness and economic, environmental and social sustainability.

In particular, the introduction of regulations at the national and international level regarding the information management of the construction process with Building Information Modeling (BIM) tools and methodologies in public supply, service, and works contracts has necessitated the redefinition of structured and planned flows of data and information exchange between the various stages of the delivery and operation process of real estate assets. More recently and in line with the Industry 4.0 approach, many organizations and business operators are orienting their decision-making processes toward data-driven strategies especially in the management of complex estate assets (Mêda et al., 2021). In fact, the operation phase engages about 80 percent of the total investment and management costs of a building's life cycle (Volk et al., 2014), and the management and monitoring activities of spaces, building components, and facilities play a decisive role in ensuring the well-being of users and health and safety in living and working places. The use of BIM in Facility Management for an organization therefore becomes a key step in improving and optimizing the operation and maintenance activities of managed assets and, in a broader perspective, in contributing significantly to achieving the goals set by the European Green Deal and Sustainable Development Agenda 2030 (Ciribini et al., 2016; Mirarchi et al., 2018).

Currently, information management of an existing asset in the operation phase is conducted through different tools and platforms, including Computerized Maintenance Management System (CMMS), Computer-Aided Facility

Management (CAFM), Building Automation System (BAS), Integrated Workplace Management System (IWMS). However, there is a lack on creating an integrated system to manage multiple information distributed on different databases. In this context, BIM can act as a centralized repository that can hold all the information about the building and its surroundings (Qiuchen Lu et al., 2019). In fact, much of the information produced in the design and construction phases is lost and only a small portion is passed on to the next operation phase usually in the form of spreadsheets with 3D information added according to client specifications. This loss of information can be avoided, or at least reduced, through the use of standardized and shared practices and procedures among the different actors in the supply chain, but also through open and interoperable exchange formats (Patacas et al., 2015). This type of information, which we can define as "static", can also be combined with "dynamic" information from the collection of heterogeneous data, both in terms of protocols and formats, during the use and management phase of the real estate.

In particular, the rapid spread of the Internet of Thing (IoT) in daily activities has made available real-time data and information on many aspects of the operating conditions of buildings and their surroundings, which can be usefully employed by facility managers to improve building performance management, reduce energy consumption, optimize routine and extraordinary maintenance operations and increase user satisfaction and well-being. All this leads to the creation of a "digital twin" (Boje et al., 2020) of the building aimed at the management of existing assets, enabling a two-way exchange of information between the physical and digital worlds.

This contribution represents a first outcome of a wider research activity within the PNR Project, *"BIM2DT. BIM-to-Digital Twin: information management to support decision-making processes in the life cycle of buildings"*, which intends to define an operational framework for the collection and management of data aimed at the implementation of DTs of existing real estate assets, created on the basis of the integration between BIM platforms and IoT technology oriented to subsequent developments of big data analytics and AI applications. The objective is to support the decisions of the various operators involved in the planning of scheduled and/or corrective maintenance actions in the operational phase of buildings, and to generate content, recommendations, and best practices by formulating predictive analyses on managed assets. In particular, it is proposed a critical analysis of the various approaches available for the definition of an IT architecture that supports an IoT reference model, which is structured according to protocols parallel to those that today support the Internet infrastructure. The IoT model thus identified, will find application in some existing assets of the University of Florence's real estate managed by the Building Area, digitally implemented on a BIM platform.
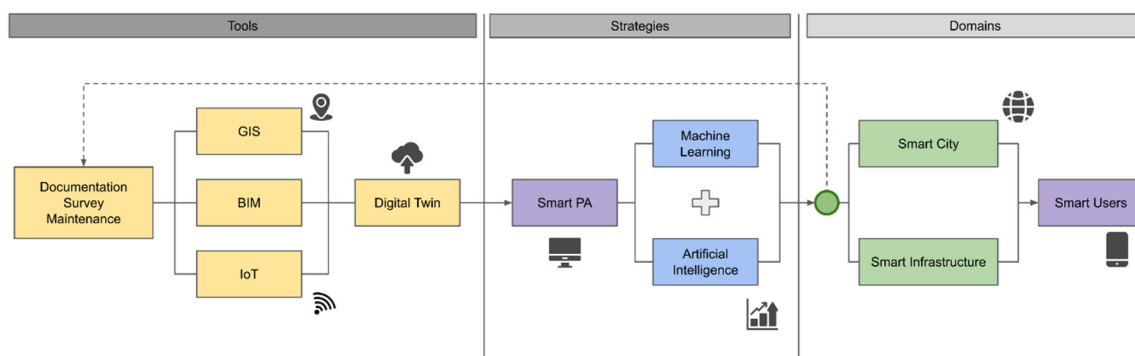

Fig. 1 – Conceptual outline of the BIM2DT research project theme

2. INTERNET OF THINGS FOR THE MANAGEMENT OF BUILT ASSETS

Buildings are complex systems, from which a large amount of data (environmental, comfort, security, ...) can be collected by Building Management Systems (BMS). This data, which until now was stored locally, is moving to a cloud environment, increasing the adoption of IoT solutions. The BIM methodology itself is evolving with web-based and data-driven solutions. A major problem is the heavy reliance on native solutions that confine facility managers to proprietary platforms and do not provide the opportunity to develop evaluations across multiple systems. The information associated with BIM elements is also usually unusable outside modelling environments, and only a few applications have started to integrate data from different types of sensors. With the increasing demand for smart buildings, there is therefore a need to develop applications capable of accommodating heterogeneous data, which are transmitted according to different formats, protocols and languages. The starting point, however, must be an understanding of the infrastructure that revolves around the world of the Internet of

Things and how this can be used to improve and implement the semantic content of information models produced using BIM methodology.

2.1   Internet of Things Model

The term Internet of Things (IoT) was first coined in 1999 by British engineer Kevin Ashton, co-founder of the Auto-ID Center at MIT (Ashton, 1999). In 2001, the MIT Auto-ID Center presented its vision on the topic of IoT, which the International Telecommunication Union (ITU) later drew on in its 2005 Internet Report. The latter defines the term IoT as *"a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies"* (Overview of the Internet of Things, 2012). The Internet Society instead speaks of IoT technologies as *"scenarios where network connectivity and computing capability extends to objects, sensors and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention"*. Beyond the definitions, of which there is still no universal one (Rose et al., 2015), we can conclude that around the topic of IoT, new scenarios are developing concerning the tools and methods of digital management of building assets.

When we speak of the Internet of Things, we are referring to any type of smart object capable of connecting to the Internet via a wired or wireless connection (through a dual communication capacity: M2M, machine-to-machine, and M2H, machine-to-human), and consequently having an active role within the communication processes. In order to be able to define a smart object, however, we need certain fundamental characteristics: the sensing component, i.e., the ability to gather information from the real world or to perform an action following an input, a unique identifier to identify the source from which the data is received, a connection to the Internet, for communication and notification of the information, and finally, one or more software platforms for the analysis and processing of the data collected

The term IoT, in its simplest form, can thus be considered as the intersection between the internet infrastructure, objects and data. Other more complex definitions, however, lead to the inclusion of standards and processes, as these technologies make it possible to connect objects to the internet in order to exchange data according to industry standards that guarantee interoperability and enable the execution of mostly automated processes. We thus find ourselves having to manage not only an exchange of information between individuals but also between single devices. The potential applications of this technology are many, from smart home to smart cities, smart healthcare, smart retail or even connected cars.

The main question to be asked is therefore how it is possible to achieve this type of interaction between very often heterogeneous systems and tools and to provide a simple and immediate service for the end user, both in the working environment and in everyday life actions. To address these problems, communication standards were created for specific areas, corresponding to the heterogeneous application areas of the IoT. We may, for example, have the need to have efficient communication with minimum packet loss but at the same time have a latency that allows communication to be defined almost in real time, or we may have the need for a less reliable protocol but with the peculiarity of operating on low performance and low power hardware. Each protocol offers certain functionalities or combinations of functionalities that make it preferable to others. Recurring factors that determine the preference of one protocol over another include geographical location, power consumption, physical barriers and hardware cost.

The inapplicability of classical communication protocols even in the context of IoT devices depends on the minimal requirements in terms of hardware and power consumption required by these devices. It has therefore become necessary to develop new technologies that do not require complex computational efforts for sometimes very simple devices. The fundamental objective of an IoT architecture is to connect the physical world with the digital one, and over the years many entities, both international organizations and individual developers, have implemented new communication mechanisms, leading us today to have a wide choice of protocols at our disposal. Protocols that, however, were not designed to interact with each other, as they are based on different concepts and ideas. International organizations therefore, in order to prevent the vertical fragmentation of different commercial solutions, have set themselves the goal of defining open communication standards and mapping the traditional IP-based stack to the new IoT concept, understood as a network of heterogeneous devices connected to each other. Cisco, IBM and Intel have proposed an IoT reference model (fig.2) to standardize the concepts and terminology used in the IoT world based on seven levels. These levels are represented by:

1. physical devices and controllers: these are terminals that send or receive information;

2. connectivity and communication between objects and networks: information must flow both horizontally between objects within the network, and vertically between different networks; gateways may be introduced for older devices not equipped with IP;

3. edge/fog computing: is the data processing layer closest to the network with minimum latency from the data collection point;

4. data accumulation: is level of data collection and storage; converts data-in-motion to data-at-rest;

5. data abstraction: level of data aggregation from multiple devices and simplify data access to the application by creating schemas and data views;

6. applications: provide the desired output through the interpretation of available information;

7. collaboration and processes: level of involving people and business processes to make IoT application useful.
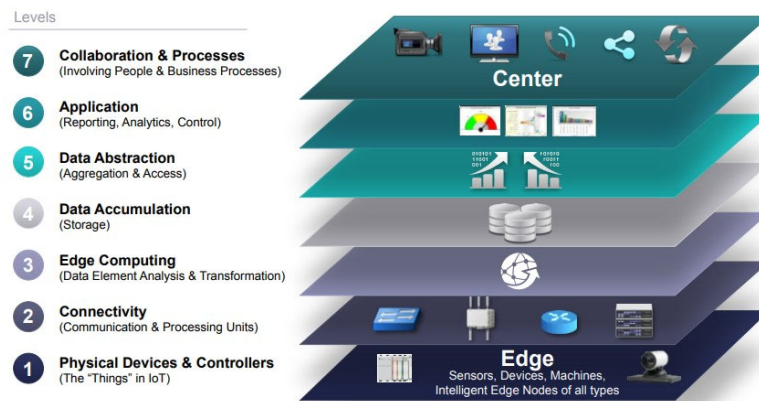

Fig. 2: IoT Reference Model presented at IoT World Forum by Cisco, IBM and Intel

This reference model follows the subdivision already used for the Internet, namely the OSI (Open Systems Interconnection) model, which consists of seven layers grouped into three media layers (physical layer, link layer and network layer) and four host layers (transport layer, session layer, presentation layer and application layer). Technologies such as Bluetooth and Wi-Fi use the lower communication layers while DDS or MQTT use, for instance, the application layer.

2.1.1 IoT Devices

The first elements that make up an IoT network are the devices themselves, which can be grouped according to their characteristics. According to the ITU, hardware platforms can be classified according to their computational and connection capabilities into three classes (Bormann et al., 2014):

a) class 0, devices very limited in memory and information processing capabilities that sometimes do not even have the necessary resources to communicate directly with the internet in a secure manner and therefore rely on other devices such as proxies, gateways or servers;

b) class 1, devices with certain limitations and that cannot talk to other nodes on the internet that use "a full stack protocol as HTTP, TLS and related security protocols and XML-based data representation". However, they are able to use a specific protocol stack for limited nodes such as COAP and participate in the conversation without the use of gateways;

c) class 2, less limited devices capable of supporting the same protocol stack as servers or notebooks. They can still benefit from the use of lighter and less energy-consuming protocols. Devices such as Arduino and Raspberry microprocessors fall into this class.

From this classification, it can be seen that not all devices are able to connect to the Internet or process the collected data in situ. To facilitate the transit of information to the end platforms and to reduce the computational load, gateways are introduced, i.e. elements used, not necessarily, to establish communication from one device to another or to connect IP-based devices, which are not able to connect directly to the cloud environment. The data collected by IoT devices is in this case transmitted to a gateway, processed in the perimeter devices and then transmitted to the cloud. The use of gateways reduces latency and transmission size and also offers a higher level of protection to data-in-motion. When data is processed locally by the same device that collects it, it is called *edge computing*; when it is sent to a gateway for peripheral processing, it is called *fog computing*; and when it is sent and processed

within a cloud-based repository, it is called *cloud computing*. IoT applications can then be integrated with a data analytics engine for analyzing and customizing the output.

2.1.2   Protocols and connectivity

The concretization of the IoT concept has been made possible by the introduction of communication protocols, the most significant of which are: WSN (Wireless Sensor Networks), used in particular for sensing operations (environmental sensors); RFID, a system based on the use of radio-frequency waves, consisting of tags, readers and a back-end system that allows each ID to be associated with the corresponding physical object and any information relating to it; the NFC protocol, produced by Philips, Sony and Nokia, used to transfer data from one device to another over short distances.

From these communication protocols, all the new standards we use today have developed, which we can group into two main classes, one short-range and one long-range. The short-range, low-power category is usually used for smaller environments such as homes or offices, which can be defined as Personal Area Networks (PAN). It includes technologies such as Bluetooth, NFC, Wi-Fi, Z-Wave and ZigBee. The long-range network category, on the other hand, allows communications up to 500 m with a minimum amount of energy. Within this category we find technologies such as LPWAN, from which proprietary solutions LoRaWAN and SigFox derive, as well as cellular IoT technologies such as NO-IoT, LTE-M and EC-GSM-IoT proposed by 3GPP.

Within a specific network, devices communicate according to a particular type of protocol, i.e. a set of rules that work on different layers of their reference model and according to which data is transmitted and received along Internet backbones. The IoT is thus to be understood as a network that lives in parallel to the traditional protocols used, for instance, for the web (fig. 3)
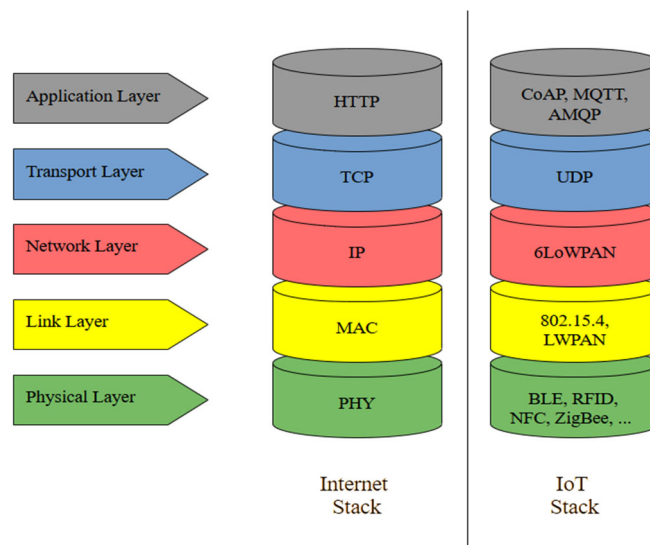

Fig. 3: IoT and Internet architecture

At the **application level**, that is, at the interface between user and device, we find the following protocols:

- CoAP (Constrained Application Protocol) (Shelby et al., 2014), a bandwidth and network constrained protocol designed to bring web functionality to devices with limited capacity. It uses a binary format rather than a text format like HTTP, for whose integration it requires the use of an intermediary (proxy);
- MQTT (Message Queue Telemetry Transport) (Banks et al., 2019), a messaging protocol designed for lightweight computer-to-computer communications, used primarily for low-bandwidth connections to remote locations. It uses an author-subscriber crtiteria and is ideal for small devices that require bandwidth efficiency and battery usage;
- AMQP (Advanced Message Queuing Protocol) (Godfrey et al., 2012), a specification for interoperable messaging for message-oriented middleware (MOM), creates interoperability between messaging middleware. It allows a wide range of systems and applications to interact, creating an asynchronous messaging system complementary to the http protocol.

The **transport layer** enables and protects the communication and transmission of data between different layers; within it we find:

- TCP (Transmission Control Protocol) (Eddy, 2022), the dominant protocol for most Internet connectivity. It provides host-to-host communications by splitting large data sets into individual packets and resending and reassembling packets as needed;
- UDP (User Datagram Protocol), a communication protocol that enables process-to-process communication and runs over IP. UDP improves data transfer rates over TCP and is optimal for applications that need lossless transmissions of information.

The **network layer** helps individual devices communicate with the router; in this layer we find:

- IP (Internet Protocol), many IoT protocols use IPv4, while newer implementations use IPv6. This recent IP update routes traffic over the Internet and identifies and locates devices on the network.
- 6LoWPAN (IPv6 over Low Power Wireless Personal Area Networks) (Kushalnagar et al., 2007), is an IoT protocol conforming to the IEEE 802.15.4 specification that works optimally with low-power devices with limited processing capabilities. It allows the creation of wireless networks with devices that use the IP protocol for communication, through an intermediate layer placed between the MAC and network layers.
- BACnet (Building Automation and Control Network), is a protocol developed by ASHRAE, and reported within ISO 16484-5, for managing building automation systems. Its goal is to create application protocols adaptable to all building control needs and transportable from one of the existing physical network technologies.

The **data layer** (MAC) is the part that transfers data within the system architecture, identifying and correcting errors found in the physical layer; within it we find:

- IEEE 802.15.4, an IEEE standard based on radio waves for a low-power wireless connection. It is used with Zigbee, 6LoWPAN and other standards to create embedded wireless networks;
- LPWAN, networks allow communication between distances of 500 meters to more than 10 km in some locations. They arise to meet the special needs of the many applications that require wider coverage but do not need high bit-rates. The LoRaWAN network, developed by the LoRa Alliance, is an example of an LPWAN network optimized for low power consumption.

Table 1: Most common IoT protocols

Protocol	Standard	Frequency	Distance
NFC	ISO/IEC 18092, ISO/IEC 21481, ISO/IEC 28361	13.56 MHz (universal frequency)	Max 10 cm (with other frequency you can obtain different distances)
Wi-Fi	802.11n (2009) – 802.11ac (2014)	2.4 GHz – 5GHz	50 m (indoor) – 100 m (outdoor)
BLE	Bluetooth v.5 (based on IEEE 802.15.1)	2.4 GHz	50 m
ZigBee	ZigBee 3.0 (based on IEEE 802.15.4)	2.4 GHz	10 – 100 m
Z-Wave	Z-Wave Alliance (proprietary technology)	800 – 900 MHz	10 m (indoor) – 100 m (outdoor)
6LoWPAN	Based on IEEE 802.15.4	Multiple physic support	20 m
LoRa	LoRaWAN (ITU-T Y.4480)	ISM 868/(915) MHz	10 km

The **physical layer** is the communication channel among devices in a specific environment; part of this layer are:
- Bluetooth, developed by Ericsson in 1994 and defined by the IEEE 802.15.1 standard, is an alternative to wireless information exchange using radio waves. It is optimal for high-speed data transfer up to 10 m. BLE (Bluetooth Low Energy) is a newer implementation that significantly reduces power consumption and cost while maintaining a connectivity range similar to that of classic Bluetooth;
- Ethernet, a wired connection that provides a fast data connection with low latency;
- LTE (Long-Term Evolution), a wireless broadband communication standard for mobile devices and data terminals. The LTE standard increases capacity and speed of wireless networks and supports multicast and broadcast streams;
- NFC (Near Field Communication), a set of communication protocols using electromagnetic fields that allows

two devices to communicate at a maximum distance of 4 cm. When the two devices are brought close together, a peer-to-peer network is created that allows both to exchange information. They are typically used for contactless payments for mobile devices, ticket creation and smart cards;

- PLC (Power Line Communication), communication technology that allows data to be sent and received over existing power cables. It allows an IoT device to be powered and controlled over the same cable;
- RFID (Radio Frequency IDentification), uses electromagnetic fields to track otherwise unpowered electronic tags. Compatible hardware provides power and communicates with those tags, reading their respective information for identification and authentication;
- Wi-Fi, standard 802.11, is a standard in homes and offices. It does not always fit all scenarios because of limited range and 24/7 power consumption;
- Z-Wave, mesh network that uses low-energy radio waves for appliance-to-appliance communication. Being a proprietary technology, it is based on a different architecture on all layers;
- Zigbee, developed by the ZigBee Alliance, now Connectivity Standards Alliance, IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal local area networks with small, low-power digital radios. It is typically used in the context of the smart home where we find battery-powered devices. The total uptime is limited and most of the time the device is in a power-saving state (sleep mode);
- Thread, developed by Nest and other companies, is based on the 6LoWPAN protocol for a mesh connection;
- Matter, an open standard for the Smart Home developed by the Connectivity Standard Alliance with the aim of improving the compatibility and security of IoT devices.

2.2 BIM and IoT

In recent years, the massive development of digital technologies for acquiring data from variously deployed sensors for a multiplicity of uses and purposes, both within buildings and in the urban environment, has necessitated an expansion of the traditional semantic domains of the construction industry with particular reference to BIM-based information management processes (He et al., 2021; Tomalini, 2022). Created initially as a method for exchanging data between different silos, BIM today is increasingly being approached with concepts such as big data, IoT, and AI, which are seen as potential solutions for automation and inclusion of broader environmental contexts. The evolution of interoperability solutions, from ISO STEP to IFC to IFCOWL, is leading to the transformation of a static BIM to a new web-based paradigm.

In fact, the information model must be able to accommodate and store not only data-at-rest, produced in the survey and/or design phases, but also to manage data-in-motion, coming in real-time from devices for monitoring the environmental quality of architectural and urban spaces. However, the inclusion of IoT sensors within an asset should only be considered as a starting point for the implementation of a Digital Twin (Sacks et al., 2020). Indeed, there is no single DT solution, as this may vary from time to time based on specific needs, just as its implementation is subject to evolve over time.

Thus, the use of BIM methodology, and its extension to the Digital Twin concept, can bring enormous benefits for those involved in FM as it allows: planning of asset management systems and effective cost estimation; prediction of operational problems and improvement of maintenance activities; increased accessibility and security of information; reduced waste; and more reliable documentation (Singh et al., 2021). On the other hand, for IoT devices, many communication protocols and semantic models are available to support information exchange between devices but there is only partial integration with the IFC schema for the building.

For example, some studies have focused on integrating open protocols such as BACnet and the IFC schema, creating specific MVDs to represent BAS information within BIM models at different stages of the building process (Tang et al., 2020). Even the use of extensions to the IFC schema, however, is still an immature process and provides only limited support for the integration of this information (Wang et al., 2022). In addition, the IFC format is designed for transferring data from one tool to another and is therefore not meant to be dynamically modified or transformed. The definition of Linked Data (LD) and the Web Ontology Language (OWL) has recently tried to address these issues.

Given the limitations of the IFC schema some organizations have begun to develop alternative or complementary data schemes such as the Brick Schema, which provides a semantic description of the physical, logical, and virtual assets within a building and their relationships. This schema is defined using the Resource Description Framework (RDF) and is thus integrable with Semantic Web standards and Linked Open Data. Within it, classes such as sensor or plant-type equipment find broader description, and since version 1.3 the schema also includes support for linking Brick models and the sensor network with communication protocols such as BACnet, facilitating the achievement

of a digital twin. An IFC model can contain within it a link to the Brick model via a unique identifier contained within the *IfcLibraryReference* instance, so that an external platform can retrieve information from both schemas.

3. A FRAMEWORK FOR APPLYING DIGITAL TWIN TO BUILT ASSETS

A processing framework is defined for the collection and management of data-in-motion from IoT and subsequent integration with data-at-rest allocated in a BIM-based common data environment, aimed at the creation of a Digital Twin of existing real estate assets, oriented to subsequent developments of big data analytics through AI applications. It is thus intended to support the decision-making processes of the different operators, owners, facility managers, technicians and experts involved in the operational phases of buildings and to be able to plan planned and/or corrective maintenance actions, generate content, recommendations, best practices and formulate forecasts on managed assets. Particular insight will then be conducted for the optimization of integration processes between BIM and IoT in relation to interoperability and data-set exchange issues in the creation of DTs, and to enable real-time visualization of monitoring data from BIM models for Facility Management.

The proposed approach involves the implementation of BIM models from the data and information held by the owner, which manages the real estate assets, whether of geometric (2D/3D), alphanumeric or documentary type, enriched with the additional semantic content useful for the subsequent management phases. Upstream of this operational phase, however, an in-depth analysis must be developed of the activities carried out within the same estate property concerning the maintenance and functionality of the assets in terms of actions carried out, resources and available infrastructure, aiming to define the organization's information requirements (OIR), to which all the information exchanges that will govern the various management processes must be informed. This should converge in the compilation of a BIM Guide for the implementation of the organization's asset information models, which can standardize their delivery processes among the various internal operators, or external suppliers, following specific standards and best practices adopted by the company.
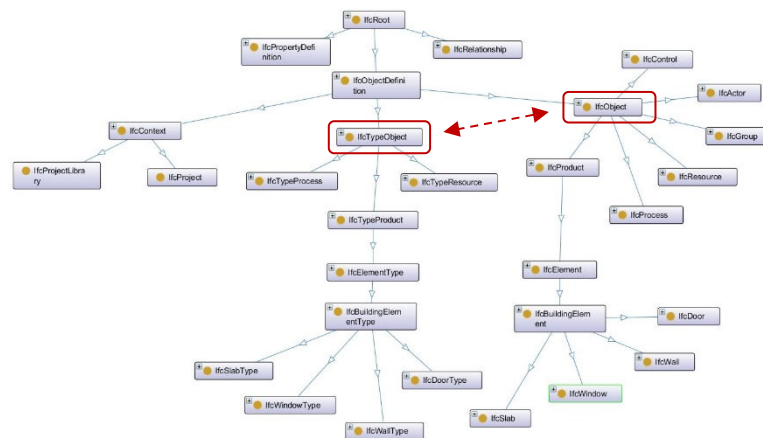

Fig. 4: Derivation path of IfcObject and IfcTypeObject inside IFC schema

The addressee of this research is a public institution and consequently it is necessary to think not only in terms of proprietary formats but how the various building elements and their information should be modelled and delivered to the maintainer. After compiling the OIRs the next step is therefore to draw up matrices based on the Level of Information Need concept that allow us to catalogue all the assets within individual buildings so that we have a complete technical record of the minimum information to populate our models. This also allows us to begin to create a library of general BIM objects that can be used in any building, and associate to each of these the relative class of the IFC schema with the appropriate psets necessary to convey the required information. A first reasoning must be made on the naming convention to be adopted for the creation and use of such objects, since if we look at the proprietary Revit software, for example, we find the distinction between family name and type name, while within an IFC model we can observe many instances of the same object (*IfcObject*), each with its own name, typically distinguished by a progressive number, and different types (*IfcTypeObject*) which instead perform the function of template for the assignment of homogeneous parameters for that grouping of objects (fig. 4). Types and instances in this case are both derived from the superclass *IfcObjectDefinition* and therefore have a horizontal

relationship with cardinality [1:N] and not a vertical dependency as proposed by proprietary software. This entails the assignment of different names as the former must be understood in a generic context regardless of the project (*IfcProject*) in which they are placed, while the latter have their own identity when placed within a floor (*IfcBuildingStorey*), or a room (*IfcSpace*), and consequently are assumed to require, in a management type environment, a code capable of representing this position and not being generic for the whole building. The second reasoning must then be done on the parameters relating to these entities. Finding a correspondence between the parameters already in use by an organisation and those prepared by the IFC schema is not always trivial or easily represented by the tools in use today. Where it is not possible to find this relationship, in fact, custom psets created within the BIM authoring software will be used to meet the needs of the client, knowing that they may be subject to change over the years as a result of future changes to the schema proposed by buildingSMART.

In parallel, a data environment will be set up to collect, index and process data from a number of IoT devices deployed within the assets (Fig. 5). These devices are to be chosen based on the observations presented in the previous chapters and will need to enable real-time collection of environmental, or other designated, information. There will then be a breakdown by layers, where the physical layer will be represented by the device itself; the latter will send the collected data to one or more gateways, or directly to the cloud, for indexing and aggregation of the information (Data Storage Layer). Then the data, depending on the type, can be integrated within appropriate databases (Data Integration Layer) and retrieved through appropriate processes or APIs within software applications for real-time analysis and querying.
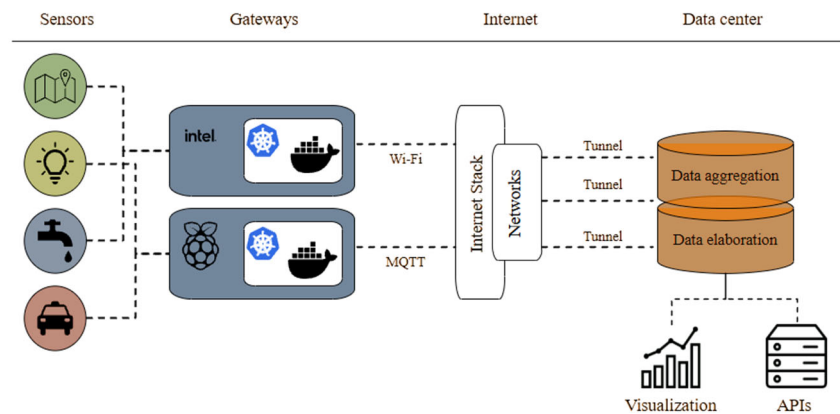

Fig. 5: IoT framework

Aware of the impossibility of directly integrating dynamic information within a BIM model, and in particular within the IFC schema, it is necessary to adopt an intermediate platform that acts as a collection and processing point for all the data collected. The workflow envisages the inclusion within the BIM models of digital representations of the sensors (*IfcSensors*) that will be inserted into the real environment with a series of parameters describing their characteristics and the use of a unique identifier (*IfcTag*) that can be used as a key for association with external DBs. This reference must necessarily be the same as the one present in the DB created from the data collected by the various sensors. The use of a cloud-based platform finally allows us to combine these two databases, representative of two different semantic domains, for the creation of customised queries and dashboards useful for the maintenance of an entire portfolio of assets.

3.1 The case studies

A PNR EU Next Generation research project, entitled *"BIM-to-Digital Twin: information management to support decision-making in the building life cycle"*, has been initiated as part of a collaboration with the University of Florence's Building Area, with the aim of developing information management of built assets belonging to the university's real estate stock through the implementation of BIM information models aimed at facility management.

The Building Area is divided into three Process Units - Real Estate, Building Plan, Ordinary Maintenance - in addition to Administrative Support, to which are added two specialized services called "Fire System Management (GSA)" and "Control and Maintenance of Asbestos Containing Materials". In particular, the tasks of the Ordinary Maintenance PU are those of planning and scheduling of ordinary maintenance interventions, coordination of technical referents allocated in the various territorial offices, monitoring the need for programmable maintenance interventions and requests for urgent interventions, and coordination with the Property and Logistics Services Area

in cases of integrated interventions.

Facility management operational services managed by Ordinary Maintenance UP are divided into: 1) Maintenance services, 2) Cleaning and environmental hygiene services, and 3) Reception and porterage services. Each operational service includes various activities that are divided into: ordinary activities (predefined or supplementary) or extraordinary activities (breakdown or on-demand). Maintenance Services include all activities aimed at maintaining the functional state and preservation of the building's systems and construction components. Specifically, the categories of systems managed as different maintenance services are the following: Electrical system, Water system, Heating system, Air-conditioning system. Elevator system, Firefighting system, Security and access control system, Networks, Minute building maintenance.
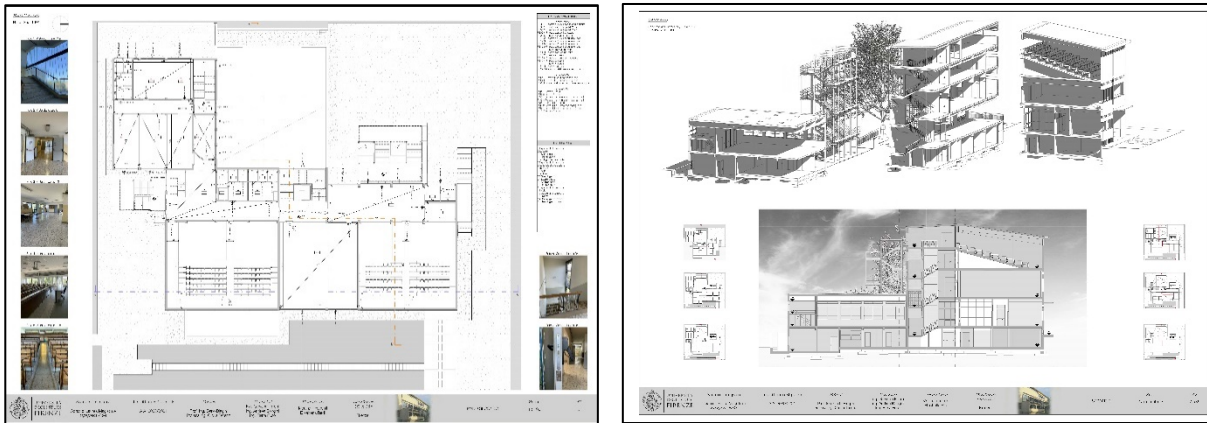

Fig. 6: Layout from BIM model of an asset of University of Florence

The managed real estate portfolio is characterized by numerous assets, different both in terms of function, construction, system, etc., and historical-architectural value, which require different intervention methodologies and maintenance systems from case to case. Precisely with regard to management and maintenance processes, the University has been equipped for some years now with a dedicated IT tool for the management of its real estate assets, namely Infocad.FM by Descor s.r.l., a corporate partner in this research. The backbone of this tool is the centralized and standardized Technical Registry within which all the information (documents, data sheets, CAD plans, photos, etc.) used, by those who interact in various capacities with the properties, converge.

The buildings in the archives are subdivided by municipality and geographical area. Each building is also currently accompanied by all the patrimonial and urban planning documentation that distinguishes it (cadastral extracts, property titles, lease or loan contracts, etc.). Despite this rationalization effort there are still many difficulties in the information management of these assets mainly due to the heterogeneity of the available data and information, since in many cases these documents are still in paper format. Therefore, there is a need to move to an information management using BIM tools and methodologies, so that data and information about the building are produced, managed, stored and exchanged in a secure, reliable and consistent way within a CDE, which allows not only the uploading of files but also the writing of metadata related to them (Paparella & Zanchetta, 2020).

The launch of the research project saw the selection of pilot cases and the implementation of a number of built asset information models, which will serve as the test bed for the testing of IoT models and the subsequent development of Business Intelligence (BI) to support facility management activities. Specifically, the asset model of each building is organized into federated models related to the different disciplinary domains-architectural, structural, and systems to facilitate the management of the model's information content in the subsequent stages of data extraction for technical performance simulation (fig. 6). The various modeling stages are developed depending on the type of geospatial data available through CAD-to-BIM and/or Scan-to-BIM processes and through the use of Autodesk Revit BIM authoring software, which will be followed by export to IFC format, mapping all elements to the correct schema class.

A phase of analysis of the history of the maintenance actions carried out by the Ordinary Maintenance UP and the related costs incurred for each building investigated is also underway, in order to define strategic lines of improvement in the FM of the managed assets to be conducted through the preparation of an IoT model for environmental monitoring, energy consumption and in general the efficiency of the facilities. In particular, this will make it possible to identify those spaces within the buildings that, in relation to their conditions of use, can be a source of useful data to be acquired by sensors (temperature, humidity, pressure, air quality, movement,

brightness, etc.).

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

The use of BIM tools and methodologies in the information management of the operational phases of a built asset with its extension to the Digital Twin concept can bring enormous advantages from an economic and management perspective for the owner entity and more specifically for facility managers.

The "BIM-to-Digital Twin" research project, to date in its start-up phase, aims to implement a Decision Support System (DSS) within Facility Management activities through the integration of BIM platforms and IoT technology, geared toward subsequent developments of big data analytics and AI applications. The system should accommodate different types of structured and unstructured data from different sources and enable integration with the IoT model identified for the specific experimentation conducted in the various case studies identified.

This contribution aimed to develop a broad survey of the various approaches available and the problem still open for defining an information technology architecture, which supports the implementation of IoT sensors that can be integrated with the BIM information models of built assets for more efficient management of maintenance and operation activities implemented by owners. Despite the wide variety of communication protocols and semantic models for information exchange between IoT devices there is still only partial integration with the IFC scheme for building classification. Extensions of the IFC schema still provide immature and limited support processes in integrating this type of data. In fact, the IFC format was not designed for data-in-motion transfer from one tool to another and thus to be dynamically modified. The definition of Linked Data (LD) and the Web Ontology Language (OWL) has recently tried to address these issues.

Promising developments can be recognized in the Brick Schema where within it classes such as sensor or plant-type equipment find wide description, and connections between Brick models and the sensor network with specific communication protocols are also included, facilitating the implementation of Digital Twins.

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