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Bim-based Digital Twin development for university Campus management. Case study ETSICCP

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ABSTRACT

Innovation and digitalization are outstanding topics acquiring each day more importance for local governments, especially in Facility Management sector. Moreover, during the COVID-19 situation, new management needs emerged, especially in large public buildings. Building Information Modeling (BIM) is considered as one of the emerging technologies used to reach a total digitalization of the infrastructure. Nevertheless, BIM implementation carries important barriers with itself like, high software and hardware investments, initial BIM skills training or low data interoperability. The objective of this project is to overpass those implementation barriers. For this purpose, the paper shows the creation of a BIM-based intelligent platform for infrastructure management that leads to the development of a Digital Twin (DT). To show the potential of the software developed, a real implementation in the Civil Engineering School at Universidad Politécnica de Madrid was carried out, obtaining significant results thanks to the actual feedback of infrastructure users and managers. The novelty of this project relies on the final results achieved, obtaining a complete DT for management functionalities like space reservation, live sensors data or assets management. All of it, linking BIM models with own software and hardware development using Internet of Things and cloud computing. A multidisciplinary work is compiled in this paper, providing the reader with the most relevant challenges detected in a real digitalization process.

1. Introduction

Innovation and digitalization are outstanding fields in our current society. Local governments develop plans to promote advances in those disciplines. Digital connectivity, cybersecurity or digital transformation in the public sector are common points attached in national plans like Digital Spain 2025 (Ministerio de asuntos económicos y transformación Digital, 2020). Smart infrastructure is one of the key points in terms of heritage digitalization, especially in public institutions. Considering infrastructures as the means to provide flow services (Rice et al., 2010), some outdated facilities are being detected, particularly in university Campus. Currently, society needs evolves and demands more accurate infrastructure management techniques. During the COVID context, public institutions with important flow of people required new managements system considering parameters not controlled previously. All those circumstances leaded to a new infrastructure operation based on the concept of smart building.

The concept of smart infrastructure has evolved over the years and has been applied in multiple fields. i.e., electricity distribution, emergency systems or infrastructure monitoring (Hoult et al., 2009; Venkatasubramanian, Mukherjee, & Gupta, 2014). Authors like Hagen indicate that there is no a standard definition for smart infrastructure. Moreover, such a wide concept carries an ambiguity improvement, like occurs initially with sustainable developments as was indicated by Buckman et al. (2014). Ogie et al. (2017) collected multiple smart infrastructure definitions i.e., the first defines a smart infrastructure as an existing infrastructure that has been transitioned to a regime of major positive changes in the infrastructure level of service because of the implementation of technological innovation. To reach the smart infrastructure concept, new emerging technologies have been used. Information and Communications Technologies (ICTs) have been implemented for the maintenance or management in buildings, tunnels, or bridges (Alusi, Eccles, Edmondson, & Zuzul, 2011; Fujii, Ohta, & Endo, 2013). BIM-based DT are an additional example of technology

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associated with the concept of smart infrastructure (Liu & Tomizuka, 2003).

BIM-based DT are the key point of this research project as well as the software programming. BIM methodology could be defined as the digital representation of the infrastructure along its lifecycle, as a central information repository (Donath, 2009; Redmond, Hore, Alshawi, & West, 2012; Watson, 2011) or as a source of information to facilitate the decision making in all the project phases (NIBS, 2016). BIM is applicable in any type of infrastructure such as Bridges (Huang, Chen, & Dzeng, 2011), buildings, tunnels or roads (Cheng, Lu, & Deng, 2016; Yabuki, 2016). Thus, BIM can be the main technology, linked with others, to reach the concept of smart infrastructure. Moreover, this means an important step forward to sustainable management (Jayasinghe & Waldmann, 2020) in any project phase. However, important implementations barriers such as hardware and software investments, initial BIM and programming skills (Aziz, Riaz, & Arslan, 2017; Miyamoto, 2016; Omoregie & Turnbull, 2016; Huthwohl et al., 2016; Tawelian & Mickovski, 2016) or low data interoperability (Ali, Chen, Srikonda, & Hu, 2014) make it difficult to use this technology in the actual infrastructure management phase. To overcome the aforementioned barriers, additional software should be developed linked to BIM. In this line, research based on BIM and real time data synchronization stands out over others, working on semantic interoperability between DT models and external management tools (Eneyew, Capretz, & Bitsuamlak, 2022) or analysing existing tools into the marketplace and testing their connection capacities with DT (Fortino & Savaglio, 2023).

The aim of this paper was also to provide a BIM-based DT for a smart infrastructure management to the Civil Engineering School at Universidad Politécnica de Madrid (UPM). The paper shows the development of a management platform based on the BIM model of the infrastructure. Backend programming based on python, Frontend Programming based on html, CSS and Java Script coding. Furthermore, all management functionalities and own sensors are and linked with SQL data base and the BIM model.

The result is a complete infrastructure management platform accessible from any device through internet, with main platform functionalities like heat system control, air quality measures, occupancy rates, people flow information or space management based on academic schedules.

2. Intelligent platform development

The intelligent management platform development process was characterized by its length and magnitude. In this section, the main points related to the development of the project are described in detail. i. e. platform structure, BIM model execution or sensor synchronization with the platform. A workflow is shown in Fig. 1, which starts with the development of the 3D BIM-based representation of the DT. Once the model is in a high level and almost all the facilities are represented, the research team started with the software design and analysis considering future management needs. In this sense, Python as Backend programming language as well as Angular as Frontend Framework, were selected. Also, in this step, the UML-Diagrams were defined. Finally, the programming started, emphasizing interoperability between web-based platform, DT and real time data devices.

2.1. Intelligent platform structure

The system was developed for the Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos (ETSICCP), also known as Civil Engineering School, at UPM. It could be divided in two main parts. The Frontend and the Backend. The whole mentioned structure has been coded by the research team with no commercial inputs for web page visualization or data base interaction. In addition, own cloud server has been programmed to host the intelligent platform. The public domain purchase, SSL certificates configuration and Frontend developments allow a total secure accessibility. The main structure of the intelligent platform is shown in Fig. 2.

The research team developed the initial functionalities as a local host in its computers. All the code is pushed to an online platform repository using git. Once platform behaviour is reviewed, the platform is virtualized with all the necessary requirements to work on the server.

The server hosts the virtualized platform running on port 8080. Security Socket Layers (SSL) certificates are read, providing a safety access through any device. SQL databases connected with the platform is running on commonly database port standard, the number 3306.

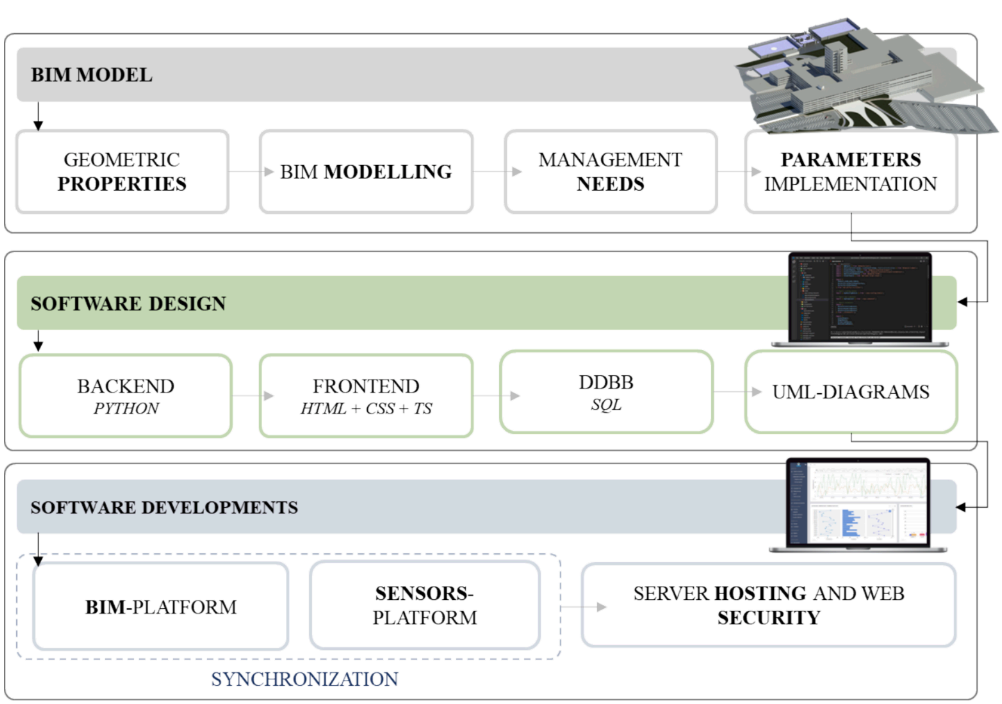

Fig. 1. Methodology workflow.

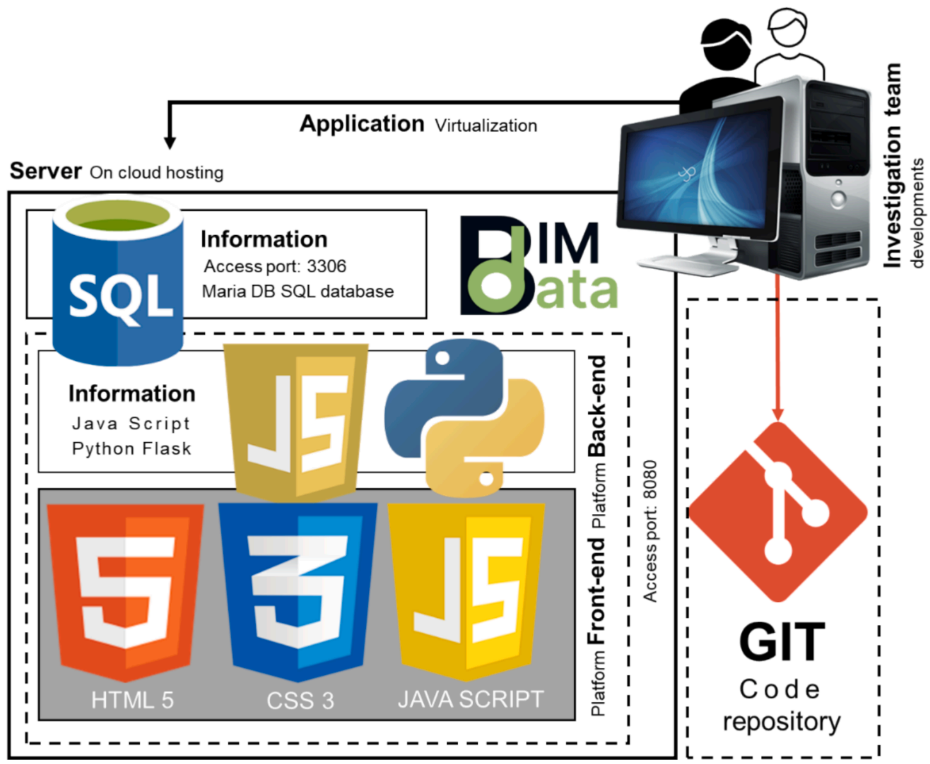

Fig. 2. Intelligent Management Platform structure.

Platform coding is divided in Frontend and Backend. Backend is almost completely based on python programming language with a minimum Java Script component. This Backend host an API development in order to interact with user inputs in the Frontend. In addition, the Backend interacts directly with the SQL database. The Frontend is based on html, Java Script and CSS. With html we structure the whole page and its content. With CSS the styles, color and animations are applicated to each html element. Finally, Java Script provides the behaviour of the web page and the connection with the Backend. The BIM model interaction is mostly developed with Java Script techniques.

Defined as the software design pattern, the Model-View-Controller (MVC) is shown in Fig. 3. SQL databases were developed to store all the BIM information or management parameters needed to improve the intelligent management platform. In the View section, also known as Frontend, HTML, CSS and Java Script programming techniques were applied to display the user a correct output and input information, even the BIM online visualization and interaction functionalities. This frontend will collect all user interactions through inputs, forms and Autodesk Forge visualization library. Then, it will interact with the Controller section, also called Backend, which is based on Python hosted in a Linux server. The data will flow from the UI (or Frontend) to the SQL Database, through the Python Backend using API and making requests. According to them, the Backend will interact with corresponding SQL Databases, returning to Frontend a response depending on request execution results. Security copies of SQL Databases are managed through an external virtual machine inside the same server.

2.2. BIM model

Although the BIM model elaboration is out of the scope of this paper, the great importance of the model inside the platform should be highlighted. BIM tridimensional model visualization has an exceptional potential of displaying the user management techniques and functionalities in a more friendly way. With BIM visualization the user

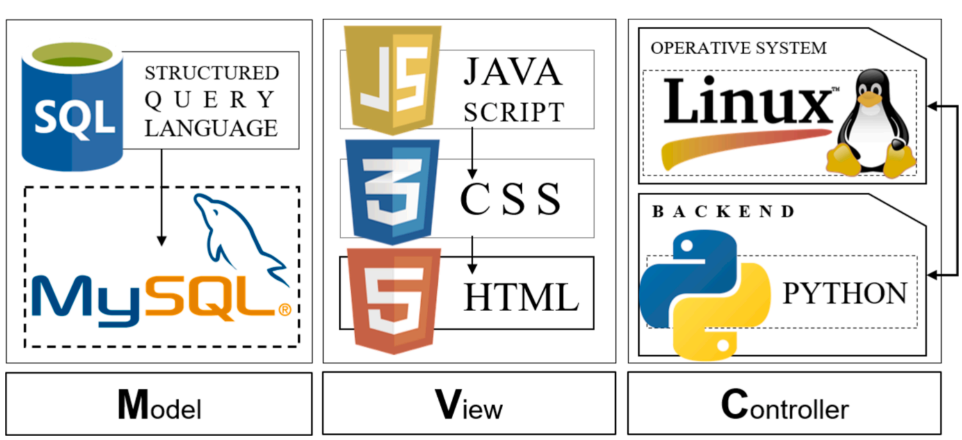

Fig. 3. MVC.

could manage the whole spaces and infrastructure elements without interacting with huge databases, just communicating through the BIM model.

Due to the complexity of this built environment, the model process took months of works and currently, the BIM model is being update every single week because of new platform functionalities. The level of detail reached in the BIM model elaboration is shown in Fig. 4.

The BIM model developed hosts the totality of spaces inside the ETSICCP building. With more than 40,000 m^2, 45 classrooms and 10 laboratories, the BIM model elaborated has an important size. Opening it in commercial standard software is a complex task and it demands a high BIM skill for the user to interact with the model. However, the BIM model visualization provided by the intelligent platform brings the users a fluid and friendly display. Moreover, unique management techniques synchronized with databases presented in this paper are not possible through BIM commercial software.

2.3. BIM model synchronization with intelligent management platform

BIM model synchronization with management functionalities of the platform is possible through Frontend and Backend programming. The process is not possible if one of those elements is missing. Interaction with BIM model and Databases is a complex task, and the functionality objective must be clear in order to develop a correct coding. The whole process of linking the BIM model with Frontend and Backend programming is shown in Fig. 5.

First of all, creating the database, which will host the information related to different BIM elements inside the model, was required. As a mode of example, if the platform had a functionality for lockers reservation, a locker database should be previously created, being capable of saving materials, owners, or rental cost information.

After the database creation, the Backend programming continues with the coding for the BIM model updating. It must be highlighted the model must be previously upload to specific external servers, depending on the visualization tool further used into the Frontend visualization. This step is shown as "Online BIM model updating" in Fig. 4.

Once the model was uploaded, a Backend resource is coded to interact directly with Frontend visualization library (interaction shown with number 1 in Fig. 4), allowing the BIM model visualization through any device, as it is shown in Fig. 4. Once visualization is achieved, is possible to establish the link between databases and the BIM model. In the case shown in Fig. 4, red color shows how a button into the User Interface (UI) of the platform can trigger a Frontend function that interacts with the Backend coding (step detailed as number 2 in Fig. 4). Therefore, all process of managing BIM information through the platform is divided into two main parts: (1) BIM model visualization and (2) BIM model data sending to SQL databases. According to different predesigned functionalities, the BIM information to manage and the Back or Frontend coding varies.

2.4. Intelligent management platform synchronization with sensors

One of the main objectives of the designed platform was to reduce the lack of interoperability between systems or technologies. In this sense, specific Internet of Things (IoT) modules are coded and implemented into the platform, providing the user specific functionalities related to different technologies.

Concerning the real time measurements, there were two types of sensors hosted in the intelligent management platform: (1) Sensors related to the measure of certain parameters, like humidity or temperature (2) and sensors focused on the infrastructure elements interaction i.e., the solenoid valve developed for the building heat system. The interaction with both types of sensors has been achieved by Backend API resources coding. The interaction process between sensor and platform is shown in Fig. 6.

The interaction process between platform and sensor is different considering the type of it. Also, the UI functionality change. Fig. 6 hosts different colours considering relation between functionality and Database. In red, the steps which will modify the database. In green, the ones which only are querying the database with no modification.

A complete functionality example would be the one related to switch on or switch off different electrovalves of the heat system. In this sense, the user will select an option into the UI of the platform (i.e. switch on electrovalve of Room 26). This choice will be saved into the Database through an API ("modification API resource" box in Fig. 5, which links the Frontend with the Backend). Then, the sensor (electrovalve) does not interact with the same modification API, but it does with a query API (shown as "Data query API resource" in Fig. 5). Is that API which interact with the modified data and provide the information to the sensor to be opened or closed, according to the Database.

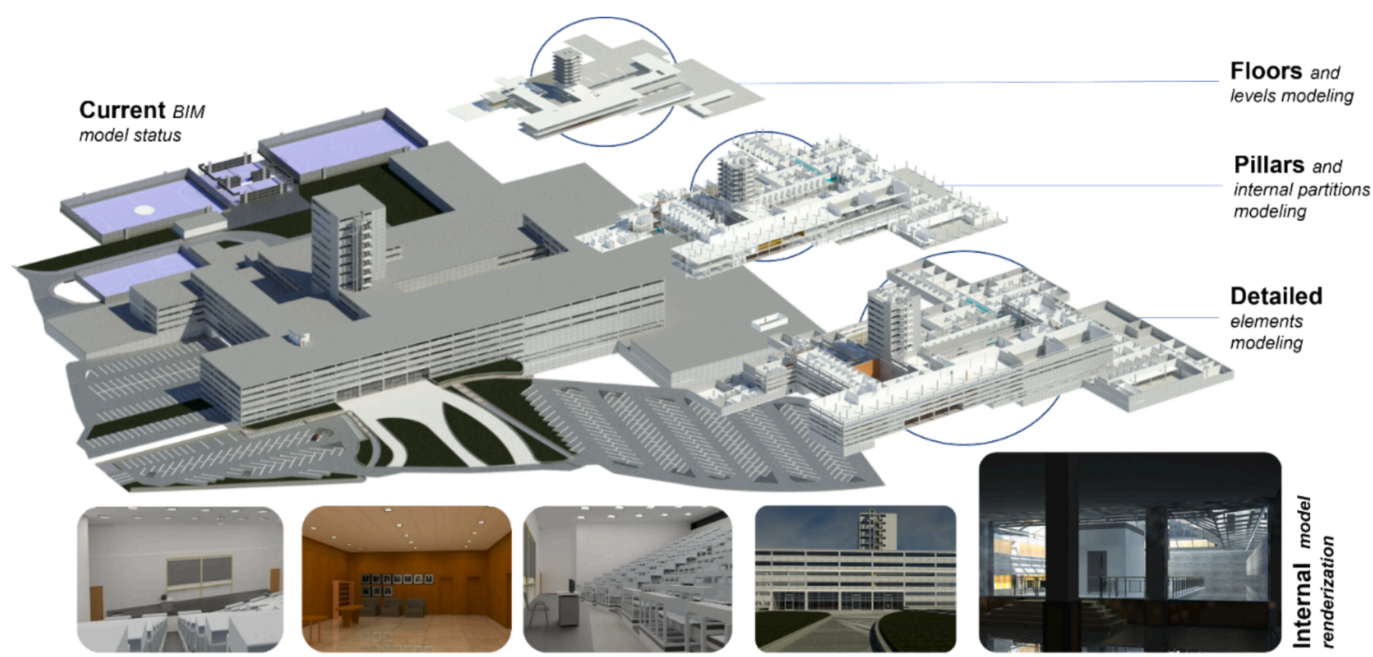

Fig. 4. BIM model of the Civil Engineering School in Madrid.

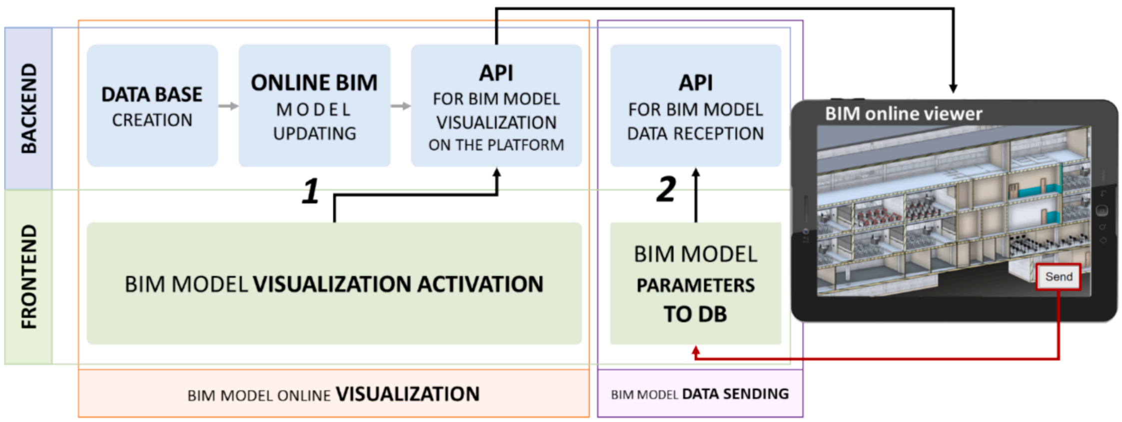

Fig. 5. BIM model Online visualization coding process.

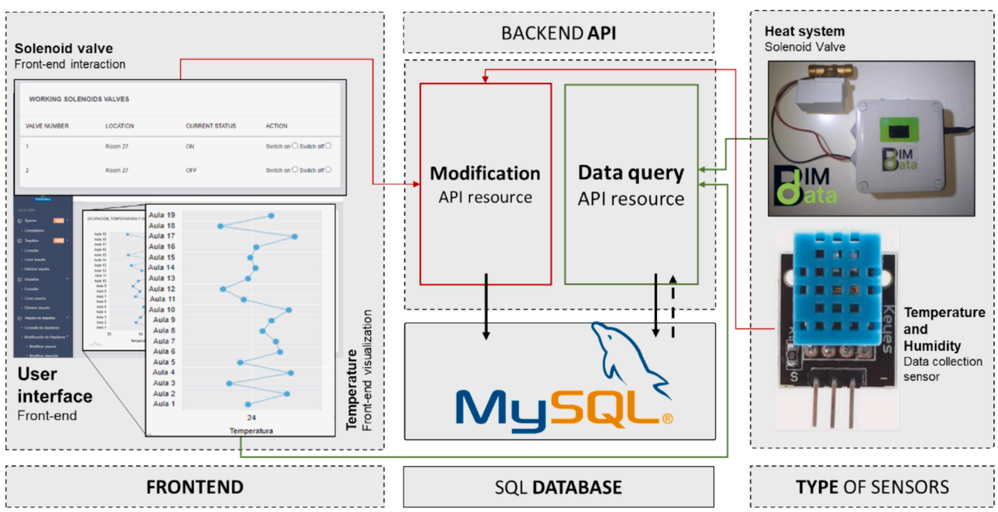

Fig. 6. Sensor-platform interaction schema.

Another example may be the functionality focused on real time data measuring of parameter, such as Temperature and Humidity. Those sensors are constantly working, sending information to the Database through the "Modification API resource" (not querying. Only saving data). Is the Frontend of the platform that, in order to provide graphical information, interacts with the "Data query API resource" (querying saved information) to get all the data related to the measured parameters and printing them into the platform Frontend or UI.

It must be highlighted both sensors demand specific coding for a correct linking with the platform. While main system is based on Java Script and Python, sensors are commonly coded in C#, allowing to send information to different APIs, which save the information into the official platform Databases.

2.5. Back-end unified modeling language (UML) diagrams

The research team designed and coded the whole platform starting from zero. This demands the use of programming techniques for a correct planification and development of functionalities. In this way, UML diagrams were applied. Defined as a tool for a system development in Software engineering (Koç, Erdoğan, Barjakly, & Peker, 2021), the UML sequence diagrams based on class diagrams are the most frequently used (Torre, Labiche, Genero, Baldassarre, & Elaasar, 2018). An UML diagram is based on the Unified Modeling Language which main objective is to represent, in a visual way, all the classes hosted in a Software design project. A summarized Backend UML diagram of the intelligent platform is shown in Fig. 7.

The UML diagram host the following classes: Users, platform functionalities, Sensors, BIM visualization, BIM elements and temperature, humidity and occupancy class. It must be said this class are three classes. However, to avoid the repetition of attributes and methods, the three classes have been unified in just one class for this UML diagram. Users class collects main user information like email, password or name. Platform functionalities class register all the platform management tools, its names and the privileges needed to execute them. BIM visualization class hosts the functions needed for the online BIM model visualization. Sensors and temperature, Humidity and Occupancy classes collects all sensors and measures information. i.e., location, value, serial numbers and dates.

Inside of each class of the UML diagram, there are two rectangles. The first one shows the required attributes for the creation of the object class. In the UML diagram attached, all object attributes are marked with a "-". This indicates that the parameters are privates and accessible only inside the class. However, the second rectangle inside the class details the methods associated with the object class. Those methods are marked with a "+". This means the methods execution are accessible from out of the class.

All classes except BIM visualization class are directly related to the SQL data base. Moreover, all of them have methods which make queries or modifications of the database objects. BIM visualization class is a special one. Objects of it have specific methods to achieve the BIM visualization into the web page.

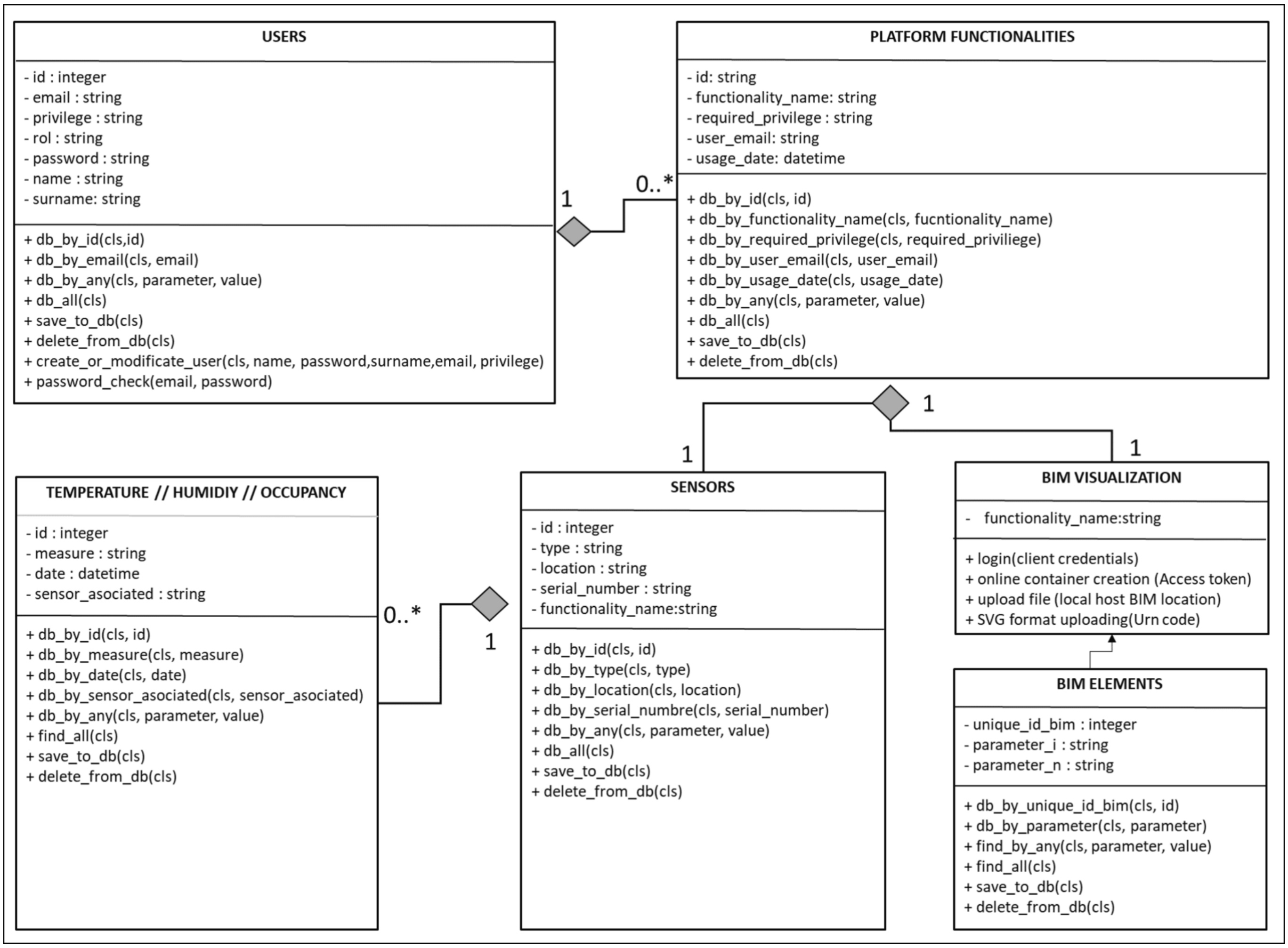

Fig. 7. UML diagram.

The relation between the different classes is the following. One user can host or access to different platform functionalities (1–0..* in Fig. 6). Each platform functionality will be directly associated with one sensor (1–1 in Fig. 6). This sensor could be linked to many parameters of Temperature, Humidity or Occupancy (1–0..* in Fig. 6).

Attributes, methods and correlations detailed in the UML diagram are being update each week due to the new functionalities and implementations of the intelligent management platform.

2.6. Server hosting and online security

One of the most important BIM implementation barriers is the lack of accessibility. Commonly, users need to buy and specific Hardware and Software to run BIM models. To overpass this problem, and provide a safety access to the web platform, the server hosting and online certificates are important topics to consider.

Concerning the Software design and coding phase, since the beginning of the project, the code has been stored in professional Git repositories. This allows the research team to code independently and push it to private cloud repository all the advances developed. Indeed, this Git code repository system is being continuously used due to new implementations and updates of the intelligent platform.

The access to the system architecture is shown in Fig. 8.The two main types of profiles involved into the platform must be considered: (1) infrastructure users and (2) development team. In this sense, development team need to have a complete access to Databases (SQL) and Linux on cloud server (through SSH connection). However, infrastructure

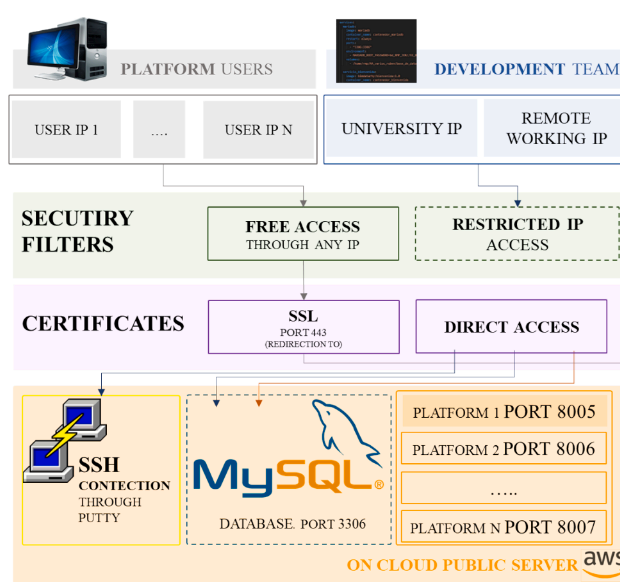

Fig. 8. Security layers for data base and online platform access.

users must access the UI of the platform, which will be located in a specific port of the on-cloud server.

The IP restriction allows to access to different parts of the architecture of the system. In this way, development team will access to Database and SSH connection, while platform users will only access to certificate SSL specific port (443). Then, a reverse proxy configured inside the Linux system will redirect the user to the specific UI port (i.e., port 8005).

3. Results

The intelligent management platform shown in this paper provide a total new management technique for any kind of infrastructures. In this project, initial programming works started being applicated to the Civil Engineering School of the UPM. Nevertheless, not only the application of the platform is oriented to buildings, also important advances in civil engineering constructions have been reached.

All functionalities shown in the following points have been coded by the research team. No commercial inputs have been considered for this project. This results section details the usage and functions of the different tools coded for the infrastructure platform. The results displayed show the final outputs provided by the platform through the user interface. Nevertheless, internal algorithms which establish connection with BIM model, backend, SQL databases or web pages behaviour are not shown in the present section.

Two main typologies of functionalities could be presented, the information and the interaction functionalities. Information functionalities are based on data collection trough sensor or BIM model and displayed through the Frontend. Interaction functionalities are related to actions collected into the Frontend platform and executed, after Backend data process, inside the building. In this paper, the platform shows the heat system control as one of those kind of interaction functionalities.

3.1. Intelligent management platform access

Since the beginning, the research team took direct and constant communication with main entities of the building. Management and development teams established a multidirectional workflow. The main objective was the correct evolution of the platform to provide useful functionalities for each entity. After multiple development phases, the implementation of this project was approved. Currently, the project is being executed as a pilot, affecting to partial zones and parameters of the Civil Engineering School. Main functionalities are developed; however, the platform grows every single day with new applications, tools, functionalities or visualization updates.

One of the most important concepts provided by the management of the Civil Engineering School was the different privileges grades for users. Thus, role or privilege grade is the first operation of the platform. In this regard, functionalities vary depending on the privileges of accessing users.

When the user login into the platform, it hosts two possibilities of accessing. First one contemplates the possibility the user could not be registered yet, thus the platform will redirect it to a specific form. Once there, the user will be registered with an email, password and a specific privilege. Student, management staff and direction of the Civil Engineering School are the current type of users considered by the platform. Taking account this, once the user has been associated with a specific role, the platform will redirect him to its specific visualization. Two roles were created. Oneassociated to students functionality and other oriented to the management team of the infrastructure. The second one has a total power and accessibility to all platform functionalities. Data visualization of any parameter is allowed for this type of user, including energy consumption estimation. However, the student user platform has been restricted in several functionalities. Main objective for this type of platform user is to provide real time information for spaces along the infrastructure. Parameters like Humidity, Temperature or air quality are accessible through the platform.

The platform visualization is quite similar between different users' privileges. As it is shown previously, main differences are linked with functionalities. However, the huge potential of the BIM visualization is allowed for all privileges. Main distribution of the platform is shown in Fig. 9.

3.2. Information functionalities

In this section, most important functionalities hosted by the platform are shown. Tools related to the BIM synchronization with locker reservation, space management, infrastructure heritage management or real time parameters collection are explained.

3.2.1. Space and infrastructure heritage management and visualization

An accessible and friendly usage of all space information is quite useful for any infrastructure user. It must be considered the building extension. With more than 38,000 m^2 and 40 classrooms, the previous management methodology could not provide accessible location information to the users. Moreover, considering multiple elements hosted in each space, the platform provides filtrable and linked tables between spaces and all the elements inside of it. The visualization of the tool is shown in Fig. 10.

In position number one, the platform displays a table related to all infrastructure spaces. In this pilot project, the spaces considered are all laboratories and all classrooms. In position number two, the platform displays a table where all elements located inside the room are shown. In the same way that occurs with spaces, in this pilot project elements considered are projectors, computers and blackboards located along the infrastructure. Currently, new implementations with light systems, heat systems and furniture are being developed.

The platform has a total interconnection between spaces and heritage tables. Moreover, this interconnection is linked with the BIM model. As it is shown in Fig. 9, once the user clicks in one space, point 3 of the Fig. 9, automatically heritage table will be refreshed to show elements located in the clicked space, point 4 of the Fig. 9. Once heritage table is automatically filtered, the user could find the element of the table inside the BIM model. Clicking the element in the table, point 4 of the Fig. 9, the platform will make and autofocus directing to the element selected. The visualization of the element is detailed in point 5 of the Fig. 9 where a computer of room 2 was selected in heritage table.

Parameters considered in Space table are name, type, Floor, BIM identification, Temperature and Humidity. Name details the normal name of the room or space. Commonly, classrooms are named as Rooms to be differentiated from laboratories. Type indicates if the space is a classroom, a laboratory or a public spaces like cafeteria. BIM identification is an important concept. This parameter brings a unique ID for the element inside the BIM model. Thanks to it, the platform could save its location inside the platform SQL Databases. Temperature and humidity are parameters registered by intelligent sensors installed. As a pilot project, numerical estimation has been applied to achieve an example of numerical data.

3.2.2. Locker registration and visualization

Locker registration and visualization is a student oriented tool, very useful for management and economic teams of the Civil Engineering School. At the beginning of this project, the management of all the lockers of the infrastructure was based completely on paper format or spreadsheets, which brings multiple problems like not updated information or compulsory face-to-face reservation process.

This functionality was designed to improve the traditional locker system management. Fig. 11 shows the management provided by the intelligent platform in this regard.

Point number 1 in the figure shows a table with all the lockers of the infrastructure. The platform allows the user to click, point number two, on a row of the table a locate inside the BIM model with a total precision. The visualization of the locker is shown in point 3 of the Fig. 10. In point 4 it is highlighted the locker selection of the user.

Fig. 9. Platform login page and main interface.

Table shown in the point 1 of Figure has the following parameters. Name, Owner 1, Owner 2, Type, Floor, Status and Date. Name parameters provide to the locker a unique identification. Each name of locker is associated in SQL databases with unique identification inside the BIM Model. By this way, when the user clicks on a locker row with a specific locker name, the system checks the unique BIM id associated and search the element inside the model. Owners 1 and 2 are parameters which represents current users of the locker. Type parameter represents the two kinds of lockers inside the building. Once of it is a common locker with rectangular structure. The other kind of locker has a special structure with a shape as the letter "L". This information is quite important to be provided to the user before its registration because common rectangular lockers have double capacity in comparation with "L" shape lockers. Status parameter indicated if the locker is rented or not. If it would be rented, date parameter will show until what date it is.

With this tool which synchronize data base and BIM visualization, the user is able to check in real time all the lockers status and location. The user can compare which locker is more useful for him taking account parameters like distances to the entry or to the classroom.

Once the user has took its decision, the platforms avoid the need making a face-to-face reservation process. An internal form has been developed to make the reservation and then, pass through a payment system if it is necessary.

3.2.3. Real time and registration of Temperature and Humidity

The intelligent platform has been designed with the capability of hosting any kind of sensor parameter. Initial project pilots contemplate the installation of Humidity and Temperature sensors detection. At first stages, own sensor development has been executed. Initial sensors were based on ESP 32 as motherboards and DHT11 humidity and detection sensor. Not only homemade sensor is used in this project, but also commercial sensors are also linkable too with the platform through specific API's. The administrative process delays the actual installation of the sensors. To test this functionality into the platform, random data is used to simulate a greater number of sensors installed, as it is detailed in Fig. 12.

The platform user can check Temperature and Humidity values along the whole spaces in the infrastructure. This functionality is visible in two ways as it is indicated in Fig. 12.

Spaces temperature and Humidity could be consulted through the platform in graphical or numeric way. In table format, real time numeric values of humidity and temperature are available. Name, location and typology are parameters available too for each space. If user prefers to check real time information in a graphical way, it could be done too. In this pilot project, the historical data has been supposed for the room number 27.

This functionality provides an important base for future functionalities i.e., a systema alert that notifies to management staff when a measure is quite high or low, notifying users through mobile messaging or email are an example of it.

3.2.4. Real time and registration of occupancy

Spaces occupancy has become an important measure to consider after the COVID-19 context. Special infrastructure such as hospitals, airports or educational centers are examples of high occupation rates, where internal management is crucial. The Civil Engineering School

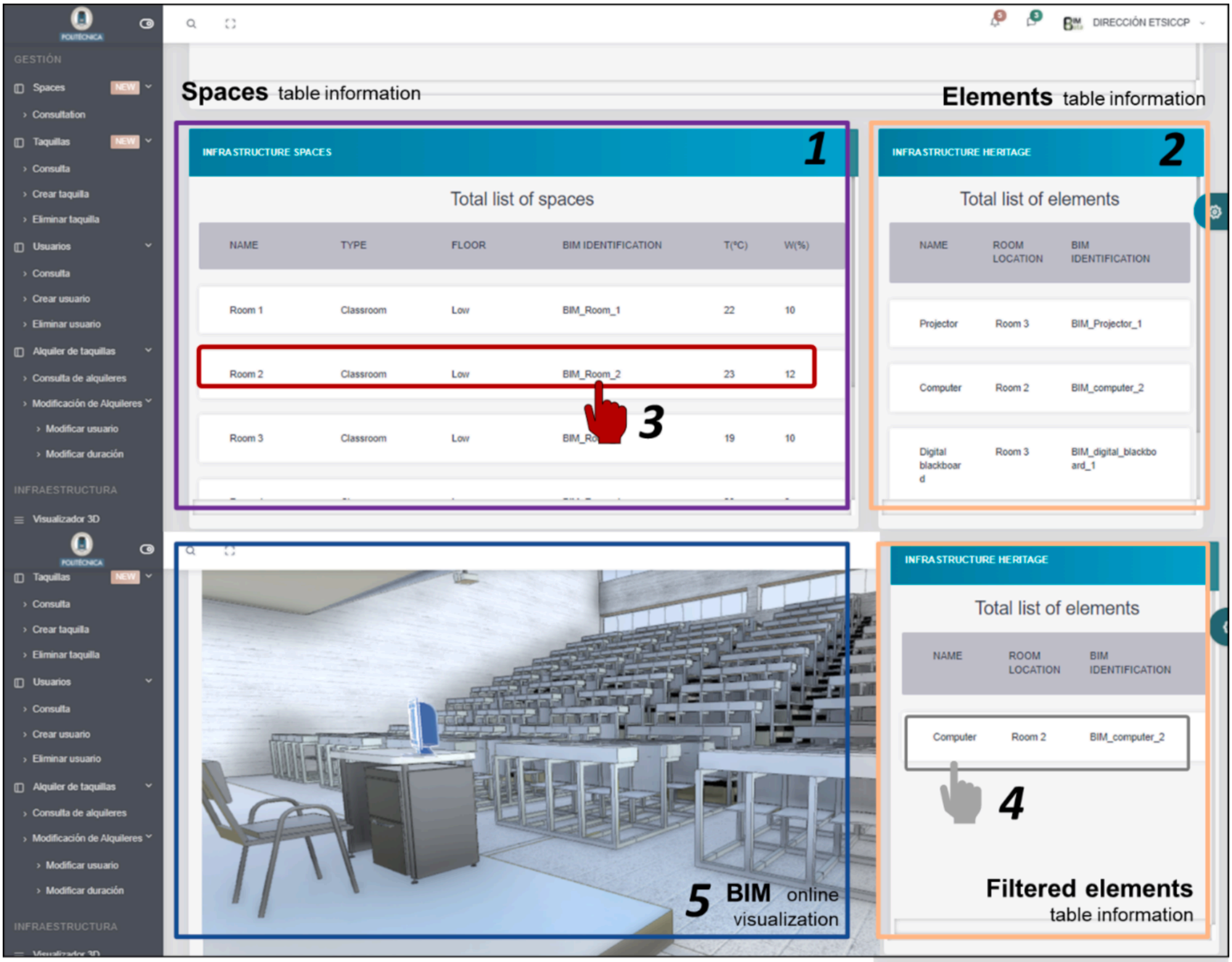

Fig. 10. Space and heritage platform functionality.

hosts many degrees related, not only to university degrees, also to master's degree or doctoral studies. With such as important transit of people, this project developed a tool to detect and predict the internal workflows of the infrastructure.

Through the intelligent platform is provided real time data and historical measures of occupations for spaces (Fig. 13), quite similar as temperature and humidity information previously described in this paper. However, this module goes one step beyond. Based on the counting person system implemented in previous research of the team (Pavón, Arcos, & Alberti, 2020; Pavón, Arcos, & Alberti, 2020; Pavón, Alberti, Arcos, & Chiyón, 2021), the intelligent management platform is able to provide internal estimated occupation of each space, according to different Origen-Destination Matrixes (ODM's), as it can be seen in Fig. 13.

Thanks to the BIM model, ODM's consider each room, laboratory or entrance as an Origin or Destination point. For different time steps along each day, is possible to detect which space generates or attracts more internal paths. ODM's applications results are saved into the SQL databases of the Intelligent platform. Therefore, if user need to know an estimation of how much people will be in the cafeteria at twelve o'clock, it will use the following tool, shown in Fig. 14.

The developed functionality shown in Fig. 14 follows this workflow. Point 1 shows the form programmed by the research team. In this form, the user could enter a complete date, including hours and minutes. When send button is clicked, point 2 will appear. This point hosts the estimation results provided by ODM's in a graphical way. With this tool the user could see the occupation evolution along the day of different spaces. Moreover, with the appearance of the graphical information, a blueprint of the infrastructure is shown. In first platform stages, those blueprints were updated with dynamo programming and were attached to the Frontend as a simple image html tag. However, currently it is working on a total interconnection with BIM model blueprints with Java Script and Python programming techniques. This process will make possible to send data directly to the BIM model blueprints without necessity of Dynamo usage.

3.2.5. Interaction functionalities. The infrastructure heat system control

The intelligent management platform developed did not only host functionalities associated to the data collection of the infrastructure. Additionally, in this first version the chance to interact directly with the building was achieved. Following the main requests made by the management team of the ETSICCP, new heat system was proposed.

The Civil Engineering School infrastructure is more than 50 years old. In this regard, there is an important lack of information updating, especially in terms of electrical or water facilities. In this project, the focus is on the heat system facility, which was built as a unified system for all the building, with no sectorization by areas or spaces. Thus, when only partial sector of the building is being used, the total heat system of

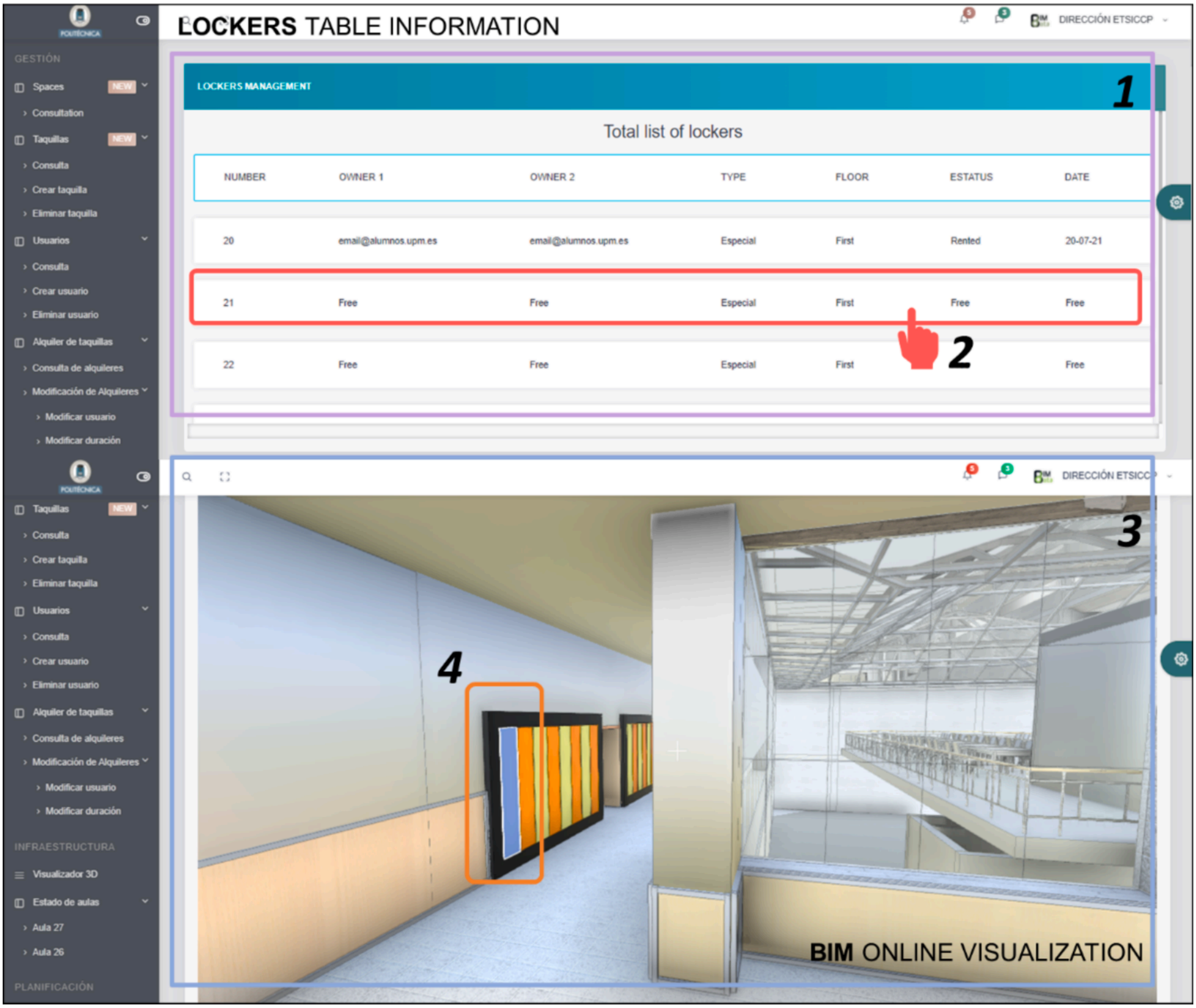

Fig. 11. Locker management platform functionality.

the infrastructure must be switched on, even for empty spaces. For that reason, a sectorization of the heat system was needed.

Assuming this challenge, the research team developed a sensor interactive with already existing heat system facilities and with the intelligent management platform. As a pilot project, two solenoid valve sensors were developed for the room 27, which is one of the most important spaces of the whole infrastructure, with more than 350 students' capacity.

The sensor was based on a ESP32 motherboard and a solenoid valve powered by 12 V. Nevertheless, ESP32 is powered by 5 V. For this reason, an internal voltage variator was implemented. Fig. 15 shows a picture of the platform tool.

The user could find in the UI an initial BIM tridimensional model visualization and a table hosting all sensors of the infrastructure (points 1 and 2 of the Fig. 15). In this table, each solenoid valve sensor host following parameters: Number, Location, Current Status and Action. Number is a numeric value assigned to each sensor and must be unique. Location provides to the user where the sensor is. Current status shows if the solenoid valve is on or off. Finally, action parameter brings to the user two possibilities: one to switch on the sensor and another to switch off. If user clicks in one of those option, point 3, a direct action will be sent to the sensor, point 4. As well, if user clicks in a row of table, point 5, the BIM visualization will be updated to the space in which the sensor is located. In this case, a redirection to the Room 27 is shown in (point 6).

This is one of the tools with more potential of the platform. Currently, new versions are being developed to achieve a total interaction between parameters such as occupancy, temperature and humidity with solenoid valves sensors, trying to develop a preventive maintenance based on Artificial Intelligence (AI).

3.2.6. Future functionalities implementations

The management platform shown in this paper is in constant evolution. One of the main characteristics of this project is its scalability. As an automatized platform, once administrative user loads a BIM model, new SQL databases are created according to BIM model properties. Therefore, the platform is applicable to any kind of educational building.

Regarding to the nearest future, all functionalities shown in this paper want to be improved to achieve a total interaction with the infrastructure. Installing homemade or commercial sensors are the next step once the interaction with the platform has already been tested. Also, new functionalities of controlling and notifying are being designed. In addition, AI advances are being implemented to estimate parameters or maintenance needs. Those future steps may follow this roadmap: (1) keep DT model and environment updated. This is a compulsory task

Fig. 12. Real time Temperature and Humidity platform module.

since the first version of the platform was launched, (2) detail new management functionalities, improving platform services for specific teaching buildings, (3) implement AI algorithms, both for improve exiting functionalities or develop new ones, such as predictive maintenance and (4) expand the DT environment to other official teaching institutions to check their viability. However, this roadmap is just a proposal. New technologies and devices are emerging and, probably, one of those possible new advances, may also improve the platform, changing the drafted roadmap.

4. Discussion

This project focuses on the implementation of a complete digital environment at the Civil Engineering School at UPM. The development and implementation of the Digital Twin (DT) used a BIM model as the central hub for visualization and information, along with custom software and hardware developments. The benefits of BIM have been shown by multiples authors, outstanding the information repository (Donath, 2009; Redmond, Hore, Alshawi, & West, 2012; Watson, 2011), facilitating the decision making for all project phases (NIBS, 2016) and different types of infrastructure, such as bridges (Huang, Chen, & Dzeng, 2011), tunnels or roads (Cheng, Lu, & Deng, 2016; Yabuki, 2016). Also, the most important implementation barriers, like the need of initial BIM skills (Aziz, Riaz, & Arslan, 2017; Miyamoto, 2016; Omoregie & Turnbull, 2016; Huthwohl et al., 2016; Tawelian & Mickovski, 2016) or the low data interoperability (Ali, Chen, Srikonda, & Hu, 2014).

Considering previous published research, this project aimed to solve the most important implementation barriers. To reach that objective, the study did not only use BIM or visual programming developments, also collected noticeable advances in software and hardware programming. Comparing to other projects of infrastructure management based on BIM, this study promoted a DT environment accessible for any user of the infrastructure such as students, teachers or management staff. The technical detail of linking SQL databases, IoT sensors and BIM through an own web-based software tool was the main goal of the study.

Regarding to data collection and DT interoperability, published literature show that efforts were focussed on linking DT with external management tools (Fortino & Savaglio, 2023). However, there is slight presence of self-developed software. In this sense, the paper details an own web-based software tool linked with DT and IoT. The paper provides with results on technical and detailed programming process needed to achieve a total interoperability. The main structure of the platform, recommended programming languages for each task, programming steps and UML diagrams show relevant advances compared with previous studies.

It is important to highlight the collaboration of direction and management staff of the ETSICCP at UPM with this project. The limit of data privacy was also worth to be mentioned. Some initial ideas, such as attendance records, were stopped due to data protection. According to this, all functionalities detailed are correctly aligned with current law in terms of privacy.

5. Conclusions

This paper shows the development of a BIM-based DT management platform for the Civil Engineering School at UPM. As it occurs in many

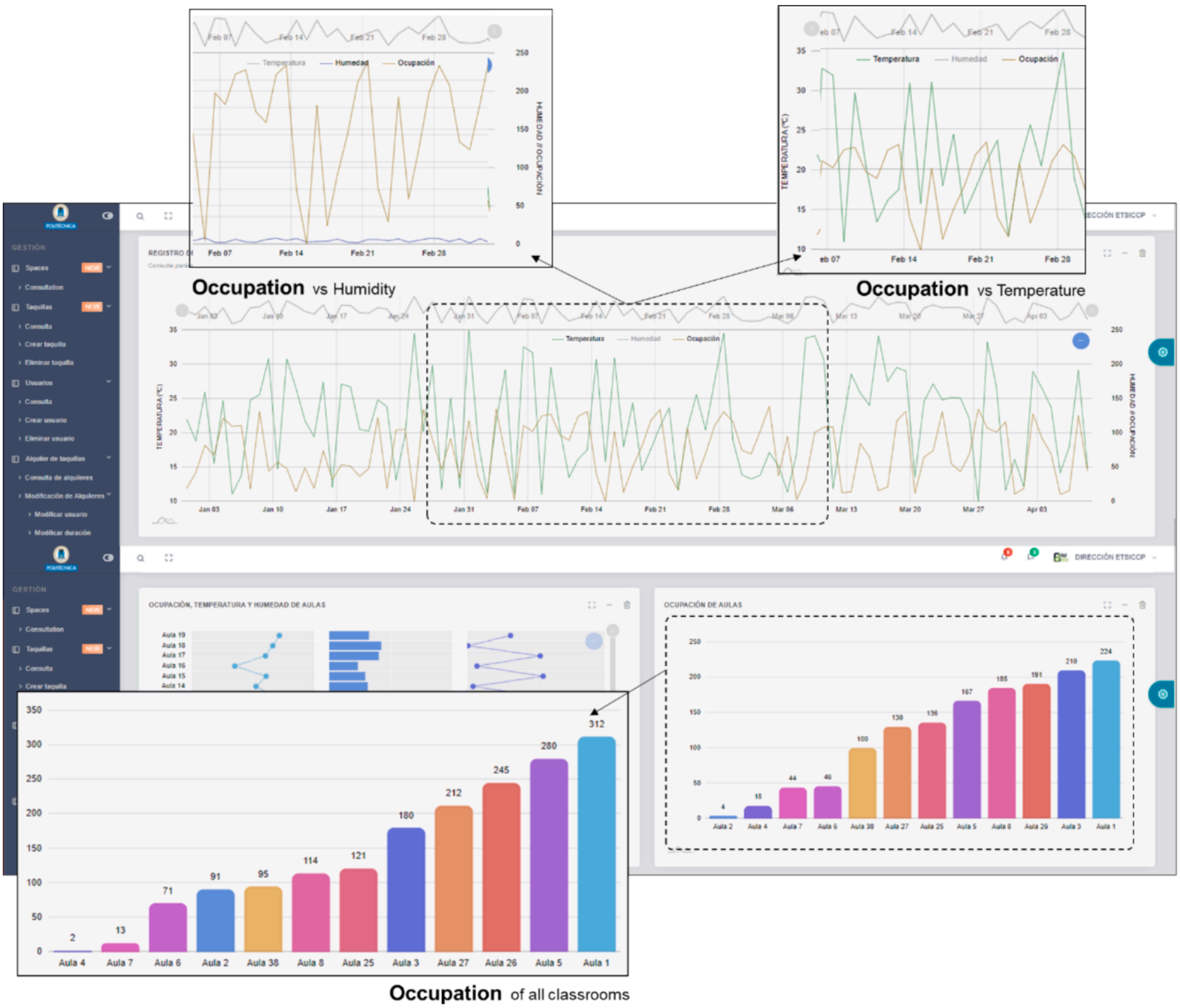

Fig. 13. Real time occupation platform module.

university facilities along Europe, the Civil Engineering School in Madrid was built in the decade of the 60 s. At the beginning of the research project, no new technologies were being implemented. Traditional management methodology was used for the majority infrastructure services. The research team started with the development of the BIM model. Once it was fulfilled, initials platform functionalities were designed for each type of user (administrators, management team and students) and coded either Frontend or Backend environment, using SQL databases and on-cloud servers to provide a total and safety access through any device with internet connection.

The novelty of the paper is based on the capability of the results to overpass all the BIM implementation barriers shown by multiple authors. Lack of interoperability, need of specific Hardware, need of Software license payment or need of BIM skills are example of some of the barriers that have been overcome. Also, project scalability to other educational institutions should be highlighted. The software enables to collect any kind of DT and create automatically specific Databases needed for the management. Therefore, if managers own a 3D model of the infrastructure, this Software will provide an easy and fast DT implementation, supported by IoT, Cloud-computing and BIM.

The platform provides the users with all the BIM benefits without the implementation barriers. Also, data interoperability was increased. The platform links the BIM model with SQL data bases, and them could be modified through most standards data formats. Moreover, special functionalities have an export option to the most common standard data formats like.xlsx or.docx. Therefore, the infrastructure management staff do not require to program a dynamo code to import worksheet formats to the BIM model. The intelligent platform will do it for them. With this tool, the transition from traditional management methodology to a new digitalized one is quite easier, promoting the use of new technologies. In this regard, comparing to previous research, this project hosted not only technology related to BIM, also links it with other ones like IoT, Cloud Computing or Big Data what lead to the DT of the ETSICCP. In this sense, the most important challenge was overcome, the interoperability between DT and all the aforementioned technologies. Regarding the linking with the DT, for this specific version of the platform, Autodesk Forge was used as a visualization library. However, some rigidity was found during the development. Therefore, new versions of the platform are based on IFC (Industrial Foundation Classes) standard, to link BIM with other functionalities without the need of specific software. All this digital environment provides with a great amount of information, such as real time data of sensors or occupation rates, all linked to the DT. Future developments linking the data with heat or lighting systems could reduce considerably Energy consumption. Currently, the most important benefit is the DT implementation as a possible unique management system. In which is possible to collect data bases and visual information of separated tasks, i.e. maintenance schedule, locker reservation, space management, teaching schedules,

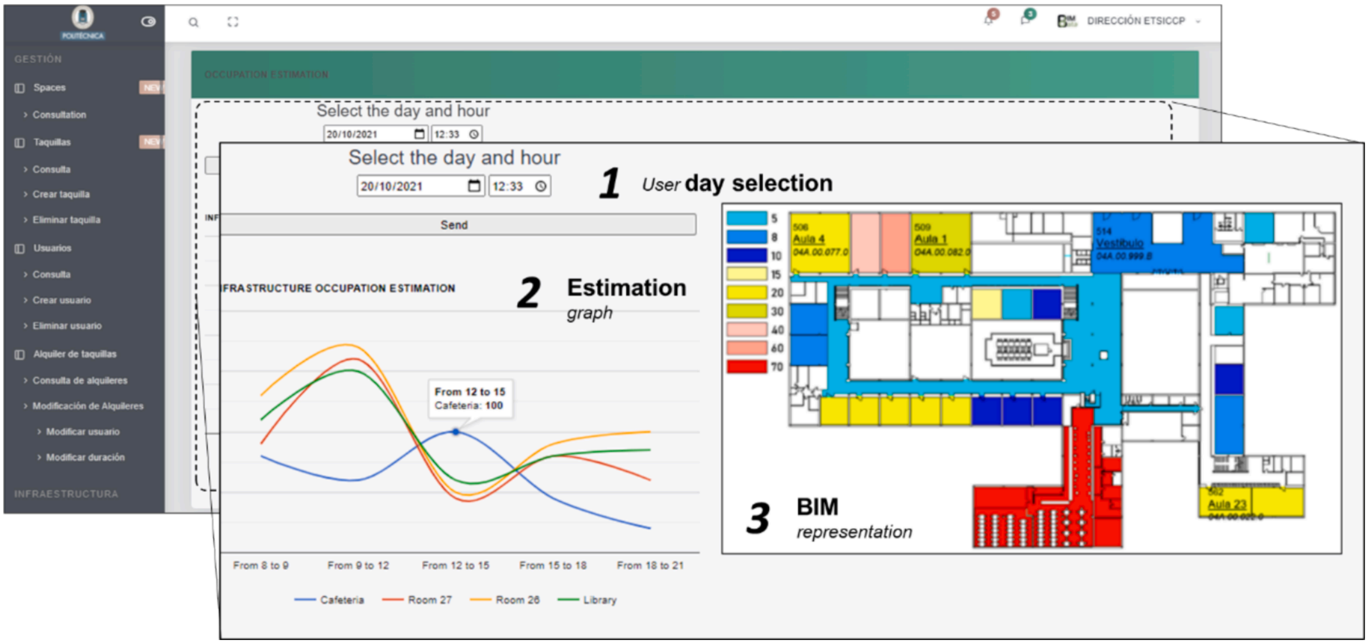

Fig. 14. People flow estimation platform functionality.

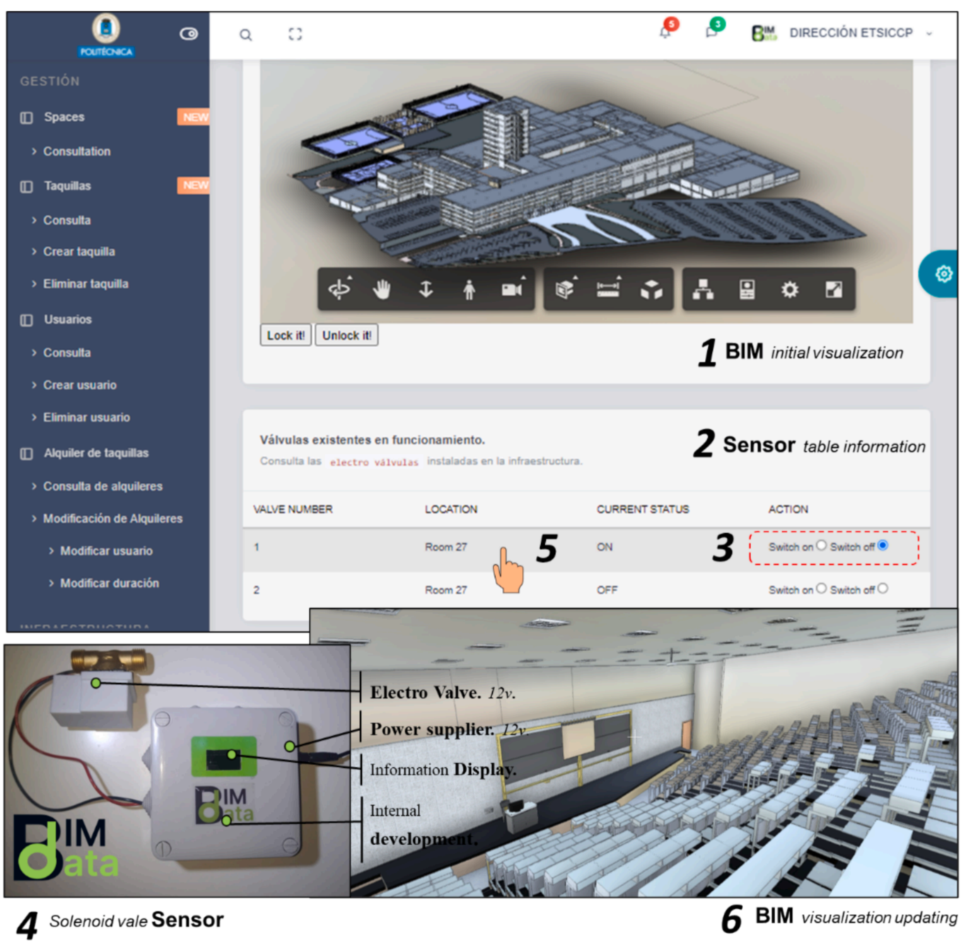

Fig. 15. Heat system interaction platform functionality.

real time data or students' notifications. This management system enables to host any kind of information, and it can even link it with DT representation is the main result of the project.

Regarding to future works, the platform provides a perfect base for new technologies implementations, like Natural Language Processing (NLP) or AI for preventive maintenance. Also, the result overstands due to the scalability of them, being applicable to any teaching infrastructure. The more management data collected into the system, the more possibilities of training AI to provide realistic estimations of different infrastructure management tasks.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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