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Use of BIM-FM to Transform Large Conventional Public Buildings into Efficient and Smart Sustainable Buildings

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Abstract: New technologies regarding construction, materials and facility management have led to the successful implementation of smart and more sustainable buildings. This is of special interest for the management of large and complex public buildings. However, most of these types of buildings were built in Europe during the previous century, when those technologies were still a matter of research. The appearance of Building Information Modelling (BIM) and the combined use of it with other advances in Facility Management (FM) as well as Internet of Things (IoT), Big Data and others, has opened the door to the possible transformation of such type of buildings into more efficient smart buildings without very large investments. In this study, this was studied thoroughly. In addition, the advantages and possibilities were assessed on a case study performed in the Civil Engineering School at Universidad Politécnica de Madrid built in 1969. The main objective of the paper was to show the details and possibilities to transform the building into a smart and more sustainable building by using BIM-FM techniques and self-designed sensors. The conclusions showed that using a three-dimensional model as the center of the management together with the connection with other applications, databases and facility management tools can transform the building into a Smart Building. In addition, the management of the system can be done from the web, nearing the information to the management staff and to the user. All advances were self-developed in order to satisfy the specific needs of the building.

Keywords: BIM; FM; infrastructure management; IoT

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1. Introduction

The educational infrastructure management is a heterogeneous topic. While more innovations are related to private educational buildings, public institutions usually house traditional management systems and most of their facilities were built in the previous century. Such systems are based on manual processing or paper format administrations techniques. Facility Management (FM) is an important topic for research and there are multiple published research articles. Jensen, in 2001, highlighted the importance of FM, especially for public institutions [1] arguing that it must create value for internal users of the building. Corporate Real Estate define FM as the process of associating the main functionality of the infrastructure with services hosted in it [2]. The estimated costs of exploitation and maintenance are considered over 5–15% of the university budget [3]. Moreover, most of the universities have low occupation rates considering the whole area of the infrastructure. The utilization rates reported vary from 20 to 40% [4–7]. Many university facilities in Europe were built in the decade of 1960s, as it is the case of the Civil Engineering School (ETSICCP) at Universidad Politécnica de Madrid. This fact supposes an important gap between most European universities and the denominated Smart Campus concept, which involve the implementation of technologies such as IoT [8–12], Radio Frequency Identification (RFID) [9,10,13], cloud computing [14,15] or mobile terminal accessing are implemented [13,16]. This study shows the details and possibilities of the use of BIM-FM to transform an outdated large public building into a smart managed building through a case study. However, this experience could be applicable to many buildings with relatively close characteristics, such as those university venues close in age as well as other large public buildings that share the same issues such as such as hospitals, high-schools, public office buildings, etc.

Those systems have been applied in published research obtaining energy management cost reduction [9]. However, this research seeks to implement a complete management system that enables reading, saving as well as processing and programming immediate responses as a function of occupancy parameters, temperature, or humidity. Additionally, the system can provide the users with the information in a visual environment thanks to the Building Information Modelling (BIM) model of the ETSICCP.

Unifying BIM methodology and FM brings new important profits. However, it also carries out multiple barriers in terms of data interoperability. BIM defined by International Standards ISO as 'Digital representation of functionalities and characteristics of any built element' and contributes as the central repository of information for the management [17–21]. Important applications of BIM to specific infrastructure projects such as hospitals or airports have been reported with remarkable results in terms of space management [22,23]. Nevertheless, multiple data structures are involved and interoperable, being still a critical issue [24].

Digitalization and innovation are two outstanding topics at the time of writing, especially within a COVID-19 context, where society demands accurate and effective management methodologies. Large and public buildings play an outstanding role in this situation. Hospitals, airports or university faculties entail particular management needs [25,26]. The main aim of this paper is to show the possibilities and conclusions of the use of BIM-FM obtained after the works of transformation of the ETSICCP at Universidad Politécnica de Madrid (UPM) into a smart and more efficient building, closer to the idea of Smart Campus with a digital twin of the infrastructure based on BIM methodology. All the processes described are related to years of research and development. This project opens several lines of investigations in order to achieve a digital twin unified with an intelligent management platform system. To achieve this goal, the process hosted various technologies such as BIM or Big Data associated to real-time parameters through use of Internet of Things. The main purpose of this project was to provide an efficient energy consumption in a cost-effective way, affecting mainly the lighting and heating systems.

This paper collects the whole process related to the transformation of the ETSICCP building. Without modifying any constructed parts, it has been possible to move the infrastructure to the concept of Smart Campus. With this framework, the research initiated on the ETSICCP traditional management system, continues with the development of a BIM model of the infrastructure following by the creation of a self-created software that links sensors with the BIM model. Consequently, it analyses the collected parameters and permits adapting the energy systems to the situation in real time with very low initial investments.

It must also be clarified that a BIM-FM system has been developed, and the ETSICCP has served as an example to show its possibilities in a large public building. The system demonstrated in this paper is not being used in all its extent and capacity as it depends on the future choices of the ETSICCP. This project provides the tools presented in this paper that have been performed and tested successfully and are available for all the users through the internet. However, the complete use of it depends on decisions of the managing staff and investments, especially in sensors for the rooms. The heating system is based nowadays on a central heating system that works only in two positions (on/off) for the whole building and is rather inefficient. Thus, single automation sensors have been developed to be installed in every room so that the temperature could be monitored. The intelligent platform designed hosts a specific module to manage the interaction with solenoid valves installed along the building. Simulations of the applications has been developed through prototypes. The total implementation of the system depends on new investments of the ETSICCP. BIM methodology barriers implementation has been solved too, thanks to the intelligent platform implementation. Total accessibility and interoperability were main keys at the beginning of the project and achieved currently low initial investments required to transform a fifty-year old building into a modern and efficient one.

Regarding energy management, A. Al-Shalabi and Yelda Turkan performed a novel framework on energy management extracting and analyzing data, highlighting the importance of dynamic BIM models to reduce the cost of facility operations and maintenance [27]. Donghwan Lee, et al. reported an optimization of operation techniques by using a control monitored system linked with BIM models. The system hosted the visualization of the model through a web browser with management parameters through use of occupancy sensors. [28]. F. Shalabi and Y. Turkan detail a BIM framework to compare energy simulation techniques with results by means of maintenance data. The system was tested in an unoccupied educational building using data collected previously [29]. Concerning the concept of efficient energy management system with BIM in universities, M. Kassem et al. developed a case to show how BIM could benefit the process and supply efficiencies [30]. A deeper research was carried out by Kung-Jen Tu and D. Vernatha [31]. Such a project boasts the exploration and application of BIM-based energy management support system, hosting environmental sensors, BIM model, energy simulation tools and data warehouse.

2. Methodology

The route for turning the ETSICCP into a Smart Building is summarized in Figure 1.

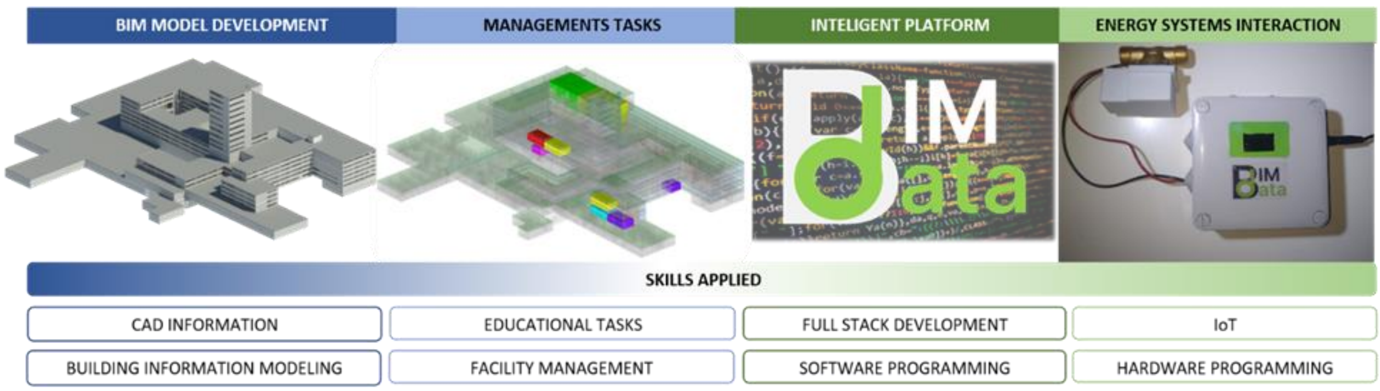

Figure 1. Methodology process followed in the research project.

The process begun with the application of BIM techniques to the old CAD information registered about the building. The result was a three-dimensional model of the building ready to host different management tasks independently of its nature. Once the BIM model had enough parameters to proceed with a management methodology, multiple management tasks were studied and applied through use of the BIM model. This step provided the research team the confirmation about the capability of the BIM model to host a certain management task data at the center of the management.

The third step supposed a step forward for the project. The intelligent platform was linked to the BIM model, so that management tasks and the final users could access and manage the information with different privileges. The platform is accessible through all devices via internet. Therefore, no BIM education is required for any agent involved. Moreover, personalized visualization and utilities were created to satisfy special needs of the management staff. As a result of this point, BIM DATA start-up was created. Linking BIM profits and adaptative tool for management tasks, the platform acts as intelligent system interacts with the infrastructure with no human input needed. However, the systems hosted the possibility to load or download the most common data formats used in the traditional management methods. Internal algorithms of the platform were performed in order to translate any kind of management data into either BIM representation information, graphical information, table information or even scheduling information in .ics format.

In the fourth step, sensorization provides the intelligent platform with real time data and the system analyses and proceeds consequently to affect lighting, heating or air conditioning systems as a function of parameters such as temperature, occupancy, or humidity.

Each building has its own management, and it depends daily on people involved in it, thus was totally necessary to listen carefully their needs and the operation protocols. This is the reason why FM and educational management was of remarkable importance in this process. Without the experience of the management staff, it is highly probable to develop a useless tool. From web design to back development is needed to provide BIM information to final user via the Internet. Python, C++, HTML or Java Script were used to create the intelligent platform. The system communicates via internet with sensors of occupancy, temperature or humidity and collects data from SQL databases and the platform interacts with the infrastructure after algorithm execution of data processing.

Hosting outstanding topics as BIM modelling stage, FM BIM-based sensors applications, data collection and analysis or even intelligent platform development, this paper provides a significant step forward in the university management. Previous research such as those developed by F. Shalabi and Y. Turkan [29] show BIM frameworks to compare energy simulation techniques with results by using maintenance data. M. Kassem et al. [30] developed a system with BIM framework through a case study to show how BIM could benefit the process and improve efficiency. In this study, a FM BIM-based framework was implemented as well as the modelling process starting from zero and the development of an intelligent platform as the key tool in order to use the three-dimensional model as the center of the management.

Donghwan Lee, et al. presented an optimization of operational techniques by using a control monitored system linked with BIM models [28]. Deeper research was carried out by Kung-Jen Tu and D. Vernatha [31]. This project showed the exploration and application of BIM-based energy management system, hosting environmental sensors, BIM model, energy simulation tools and data warehouse. In this study, a different perspective of a monitoring system was developed. Through an intelligent platform with no commercial software, the whole management of the building can be performed from both the data management and the visual point of view. In addition, specific maintenance tools for each type of user were created. In the same sense, self-developed hardware was implemented too in order to monitor temperature and occupancy. As a mode of conclusion, this study shows the entire process starting from zero and the needs for the transformation of an outdated building into an intelligent and efficient one, which implies a significant advance in the state of the art.

3. Project Development

The first step was developing a BIM infrastructure model of the building. The ETS-ICCP was built in the 1960s decade and counts with a total surface of 38,970.84 m^2. The School was designed for more than 4000 students of the different academic degrees such as Graduate, Master or PhD. In Table 1 more detailed space areas are shown, revealing the magnitude of the management needed to provide internal users a correct usage of the spaces. Educational management, administration tasks, maintenance, cleaning, or space reservation are daily tasks. Nevertheless, there is no connection between those management tasks. Infrastructure management staff deals with paper format information and with a total manual processing. Thus, it works with a traditional management system with low efficient rates in terms time spending.

Table 1. Total areas of teaching rooms.

Name and Number	Area	Name and Number	Area
José Echegaray Room	69.61 m^2	Room 24	101.16 m^2
Room 1	238.88 m^2	Room 26	329.94 m^2
Room 2	115.08 m^2	Room 27	330.64 m^2
Room 3	117.68 m^2	Room 28	57.82 m^2
Room 4	238.87 m^2	Room 29	59.52 m^2
Room 5	57.82 m^2	Room 30	58.78 m^2
Room 6	59.52 m^2	Room 31	58.78 m^2
Room 7	58.78 m^2	Room 32	57.22 m^2
Room 8	58.78 m^2	Room 38	100.10 m^2
Room 9	57.22 m^2	Room 39	100.02 m^2
Room 11	54.90 m^2	Room 40	58.67 m^2
Room 12	56.39 m^2	Languages Room	57.26 m^2
Room 13	56.39 m^2	Room 45	103.25 m^2
Room 14	56.39 m^2	Room 46	101.16 m^2
Room 15	56.39 m^2	Ag. Betancourt Room	56.70 m^2
Room 16	56.39 m^2	CAD Room	55.67 m^2
Room 17	56.39 m^2	Exam room	1652.12 m^2
Room 18	56.39 m^2	Informatic room	90.56 m^2
Room 22	113.49 m^2	Turing Room	121.18 m^2
Room 23	103.25 m^2	Total	5289.32 m^2

3.1. BIM Model Development

As indicated in the methodology subsection, the initial step of the project was the manufacture of a tri-dimensional model of the building and other depending facilities using BIM possibilities. With the complex characteristics of the building, the BIM model hosted many challenges. An initial BIM Execution Plan (BEP) was detailed. Main points of the ISO 19650 [24,25] were studied and applied considering aspects such as the Level Of Information (LOI) required. In this way, the infrastructure was divided into public and private areas. Public zones were related to all accessible areas inside and outside the building where a standard user could access. Private areas encompassed other relevant spaces such as laboratories or private offices. CAD ground layouts and manual measuring of all height levels was made. The initial steps related to the CAD to BIM information transformation is attached in Figure 2. Once the CAD information was attached to the model, internal and external modelling begun. All the aspects indicated in BEP, considering the future management tasks, defined the LOI associated to each zone. A high LOI was assigned to public areas and a lower LOI to the private zones. The modelling process can be seen in Figure 3.

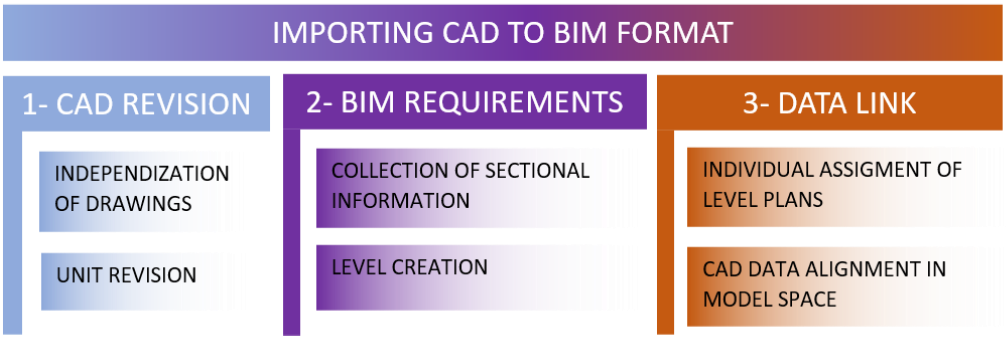

Figure 2. Flow char of CAD to BIM information transformation.

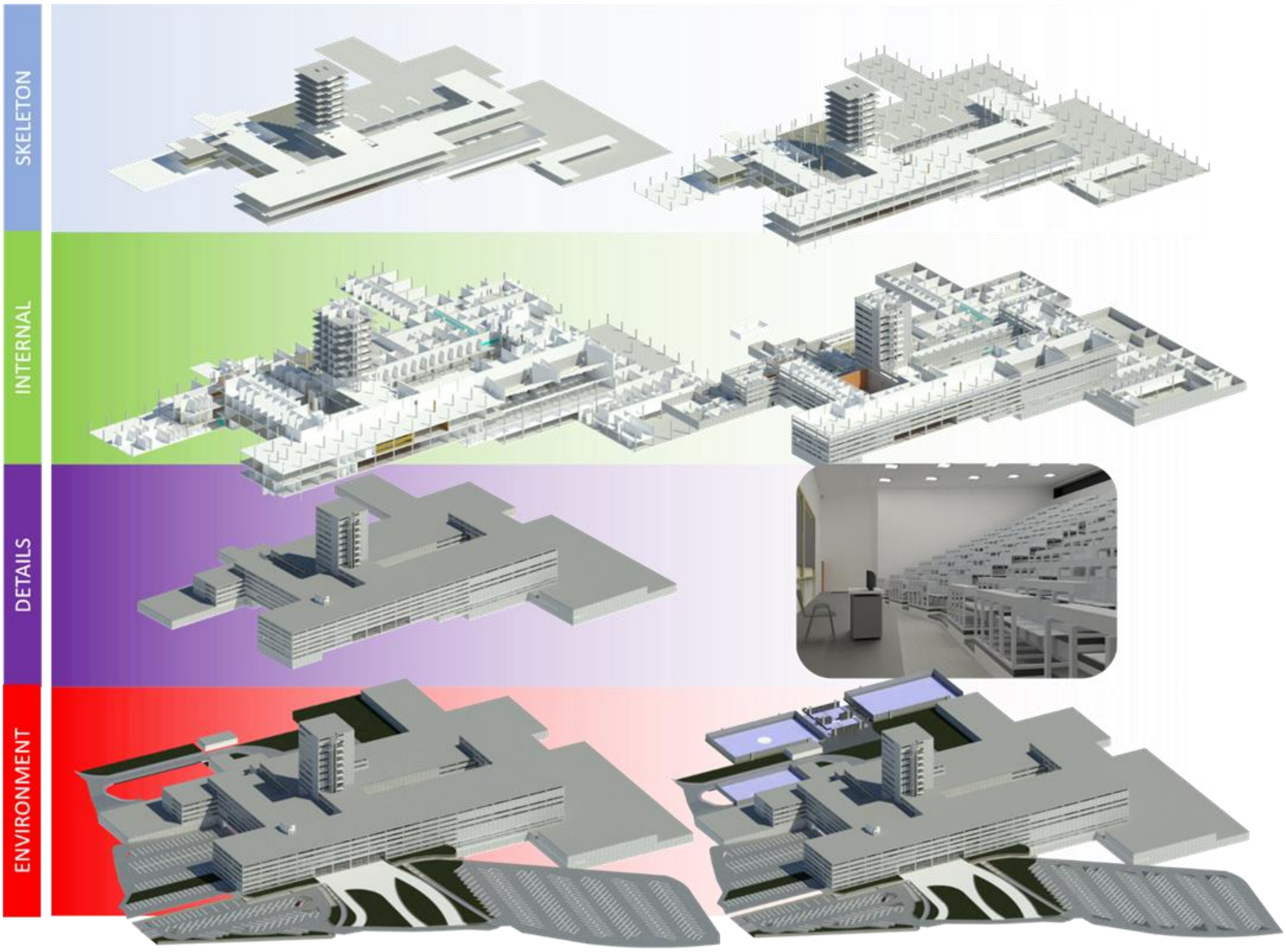

Figure 3. Flow chart of the BIM modelling.

Once the skeleton and the internal division of the BIM model were executed, parameters assignation to zones, areas or elements begun to provide a facility management methodology. The following parameters were attached to the different areas or elements in the BIM model:

- UPM code. This a management technique used by UPM. All al spaces are registered with this alphanumeric code. Moreover, inventory elements are also registered with a particular UPM code. The correct and total assignment of this code to all BIM elements provides a useful graphical environment to management staff for consulting them.
- Department. Parameter assigned to different private or public areas.
- Classroom occupation and capacity. Parameter assigned to classroom provided by a parameter assignation to each desk position.
- Connections. Parameter assigned to specific element modelled inside the classrooms called "Connection box". This parameter host aspects such as HDMI, USB type, VGA, computer system or projector quality.

3.2. Facility Managament

Initial management system of all educational schedules through the BIM model was considered. This management methodology started by linking the model with the schedules of all the degrees, the locker reservation and the main classroom facilities inventoried. After the sudden lockdown due to the COVID-19 pandemic, the management system was developed to study the internal movements inside the building and provide information to the management staff to retake the classes in the academic year 2020–2021 with the safest possibilities.

The paperwork format was transformed to spreadsheets and databases and the schedules were linked to the BIM model obtaining a filterable by time graphical environment of all the infrastructure, where classrooms in use are highlighted. Figure 4 shows the process of scheduling digitalization and the result of applying it into the BIM model of the ETSICCP model.

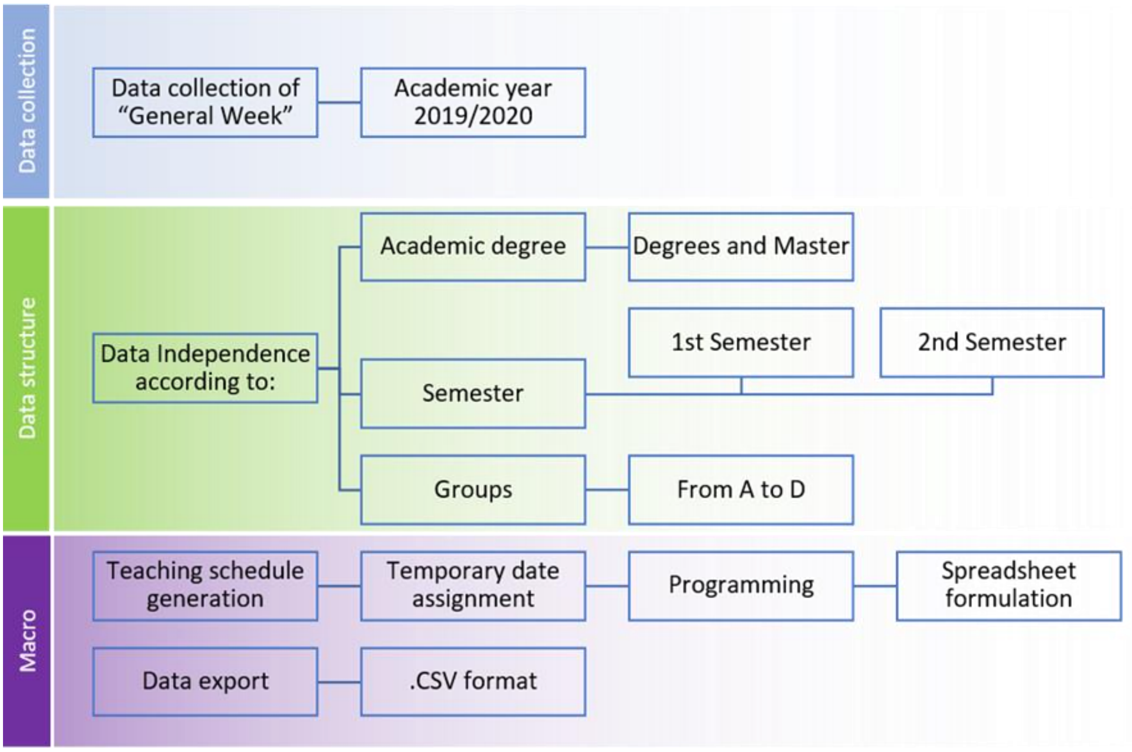

Figure 4. Scheduling digitalization and BIM model link.

Considering the management parameters, a locker management system linking spreadsheets with BIM lockers elements was carried out through use of Dynamo programming, as it is indicated in Figure 5. The figure shows a simple process of information linking between spreadsheets as databases and the BIM infrastructure model of the ETSICCP. The spreadsheet data structure hosts main management information needed for locker reservation, such as owner, rental period or registration number. By using Dynamo, internal elements of the BIM model and its parameters could be filtered and modified through dynamo commands. The impact of dynamo in this research project decreased as phases advanced due to the implementation of complete programming system although it is of great interest for the intercommunication of BIM models and datasheets in the conventional development of projects.

Related to COVID-19 context, new management tools were designed and implemented to the initial utilities detailed in Figures 4 and 5. As a complex building with classroom capacities over 200 students in specific cases, occupancy for different time steps along the day is a highlighted fact to consider. For this purpose, a transport engineering technique to study the movements along a region was considered. Origin-Destination Matrixes (O-DM's) where applied inside the infrastructure. Further details can be found in references [25,26]. The building was divided in areas where O-DM's were applied. A selection of the most important classrooms and special spaces like cafeteria or public transports zone were selected to be implemented in the mentioned matrixes.

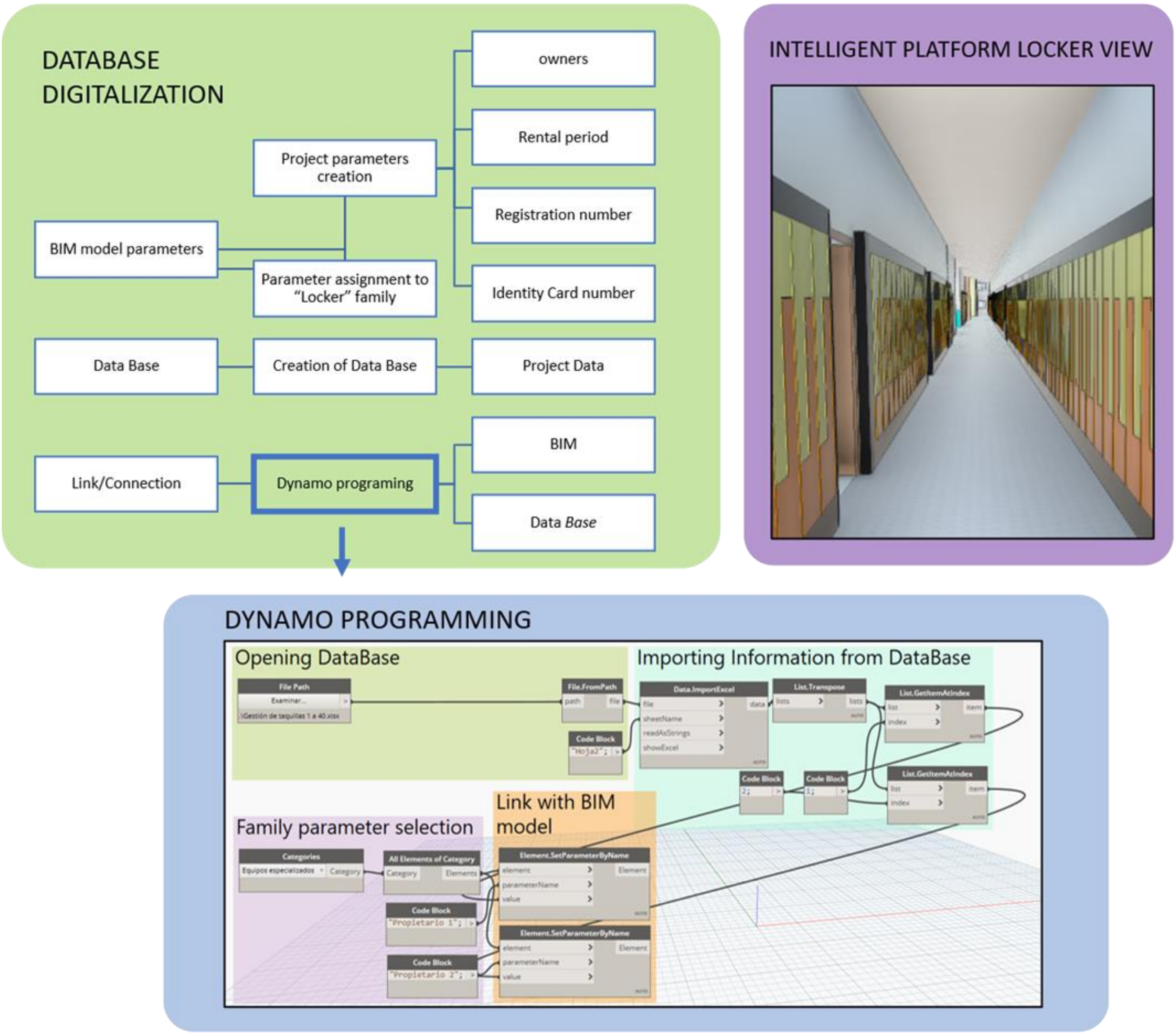

Figure 5. Locker management system linked with BIM with Dynamo programming.

The application of this technique is based on the following formulation named as Equations (1)–(3).

$$\lambda = \text{“Sconteo”}/\text{“ET,d”}, \quad (1)$$

$$Aj = \sum_{i=1,}^{i=13} Xij \quad Gi = \sum_{j=1,}^{j=13} Xij \quad Xtij = \sum_{t=1,}^{t=5} Xij \quad (2)$$

$$Xij' = Xij \times \lambda, \quad (3)$$

The nomenclature of each element is detailed below:

- ET,d: Total daily surveys registered.
- Sconteo: BIM-FM counting system.
- λ: Expansion factor;
- Gi: Internal paths generated by zone "i".
- Ai: Internal paths attracted by zone "i".
- Xij: O-DM element related to zone "i" and "j".

- Xij′: i, j term in the amplified origin–destination matrix; Amplified O-DM element related to zone "i" and "j".
- Xtij: i, j term in the total daily origin–destination matrix; Total daily O-DM element related to zone "i" and "j".

Equation (1) reflect the "Expansion Factor". This parameter enables to adapt the information collected by the BIM system to the reality. Its application is only used in cases where the surveys collected are less than 25% of the registration of the BIM counting system. The result is Equation (3). Equation (2) reflects the formulation related to each zone or area inside the building acting as Attraction zone or Generation zone. By this way, it is possible to detect occupation hot spots along the building for different time steps.

The formulation and matrixes were applied for different time steps. From to 8:00, 9:00, 12:00, 15:00, 18:00 and 21:00. As a result of those matrixes applicated to indicated times steps, Tables 2 and 3 shows global results of a daily example.

Table 2. Total daily internal path generated by each time and space interval.

Total Generated	A	B	C	D	E
Lunchroom	0	83	100	54	44
Teaching room 27	0	159	52	64	73
Teaching room 26	0	146	65	93	107
Library	0	139	33	92	57
Teaching room 1	0	149	49	88	100
Teaching room 2	0	112	45	58	66
Teaching room 3	0	102	56	78	63
Teaching room 4	0	99	61	95	70
Administrative room	0	93	50	106	86
Break Zone	0	95	73	102	93
Bus station	340	69	77	97	104
Subway	274	59	100	65	74
Parking area	370	62	141	146	143

A = 8:00 9:00 h, B = 9:00 12:00 h, C = 12:00 15:00 h, D = 15:00 18:00 h, E = 18:00 21:00 h.

Table 3. Total daily internal path attracted by each time and space interval.

Total Attracted	A	B	C	D	E
Lunchroom	80	58	101	49	41
Teaching room 27	90	159	50	79	58
Teaching room 26	134	164	50	90	102
Library	116	149	62	80	88
Teaching room 1	160	157	47	84	101
Teaching room 2	150	101	43	69	63
Teaching room 3	98	90	56	64	84
Teaching room 4	57	110	47	95	80
Administrative room	55	109	54	103	86
Break Zone	44	88	73	84	76
Bus station	0	72	92	111	101
Subway	0	50	103	89	57
Parking area	0	60	124	141	143

A = 8:00–9:00 h, B = 9:00–12:00 h, C = 12:00–15:00 h, D = 15:00–18:00 h, E = 8:00–21:00 h.

COVID-19 pandemic affected the main building characteristics, especially its capacity of hosting students. With Spanish norms, initial security separation of two meters was considered. Thanks to the BIM model, a total study of the normative measures affecting the building was developed in one week. Results showed two meters of security distance lowers the classroom capacity to 33%. Considering the possibility of reducing from two to one meters of security distance, a protection helmet screen was implemented for the lectures of the academic year. Thus, classrooms capacity grew from 33% to 50% making viable the face-to-face lectures for the academic year 2020/2021.

All occupancy criteria or capacities were linked to the BIM model providing users and management staffs with graphical visualization of those parameters. An example is provided in Figure 6, where occupancy for 10:30 h of an example day is showed.

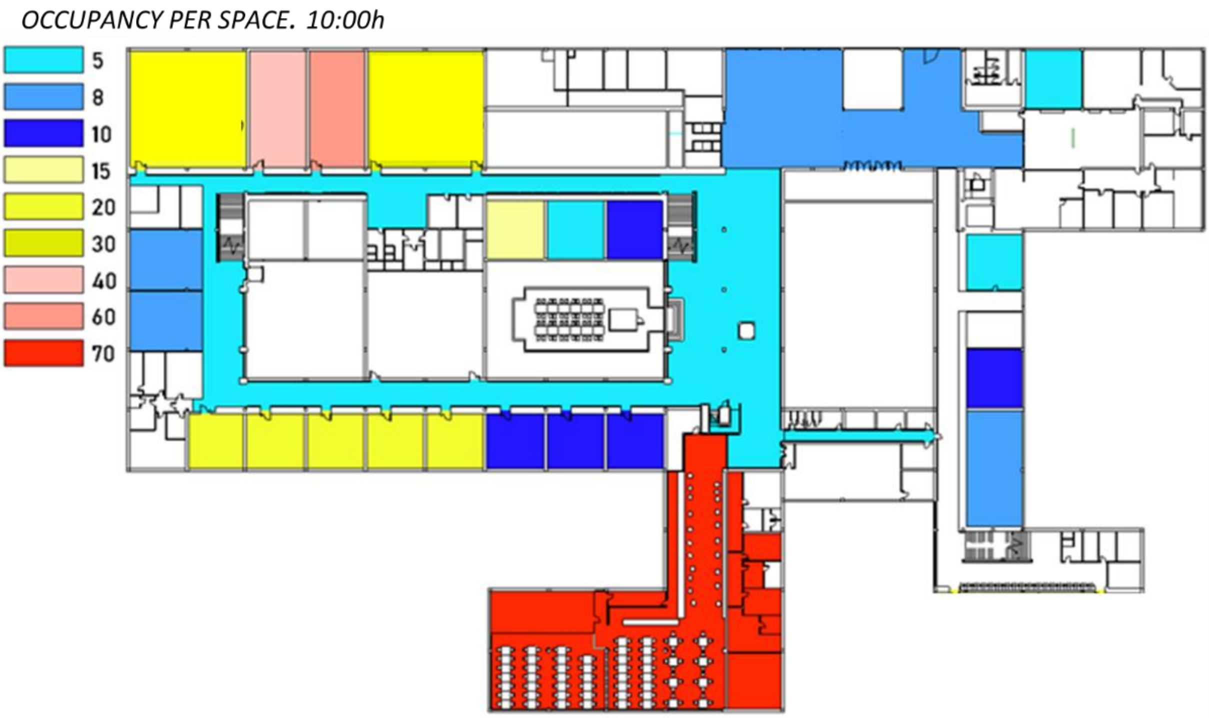

Figure 6. BIM model data output by real time occupation.

3.3. Inteligent Platform

Useful management techniques, even considering the COVID-19 context were developed and detailed in previous points. However, multiple commercial software programs were used to achieve those utilities. This fact implied that the user needs some technical BIM skills. Moreover, programming skills were needed to link different data structures. Thus, the research team faced multiple BIM implementations barriers enunciated by multiple researchers, as it is indicated in introduction point in this paper. It is not viable to ask for BIM formation or programming skills to all management staff or standard users of the building.

Therefore, to face this challenge, an intelligent platform was developed. The main purpose of this platform was to provide final users with all BIM-FM possibilities without any technical skills but just the use of internet or smart devices. Main functionalities of the intelligent platform are described in Figure 7. The whole system has been developed with Python, C++, HTML, CSS and Java Script techniques. In order to meet the objectives, not only Revit, Dynamo or Navisworks, typically known as BIM software, was needed. The intelligent platform was performed with Python programming language, while the sensors were performed by using C++ language. Additionally, the user visualization through internet was based on HTML, CSS and Java Script while SQL databases were used to collect all data information.

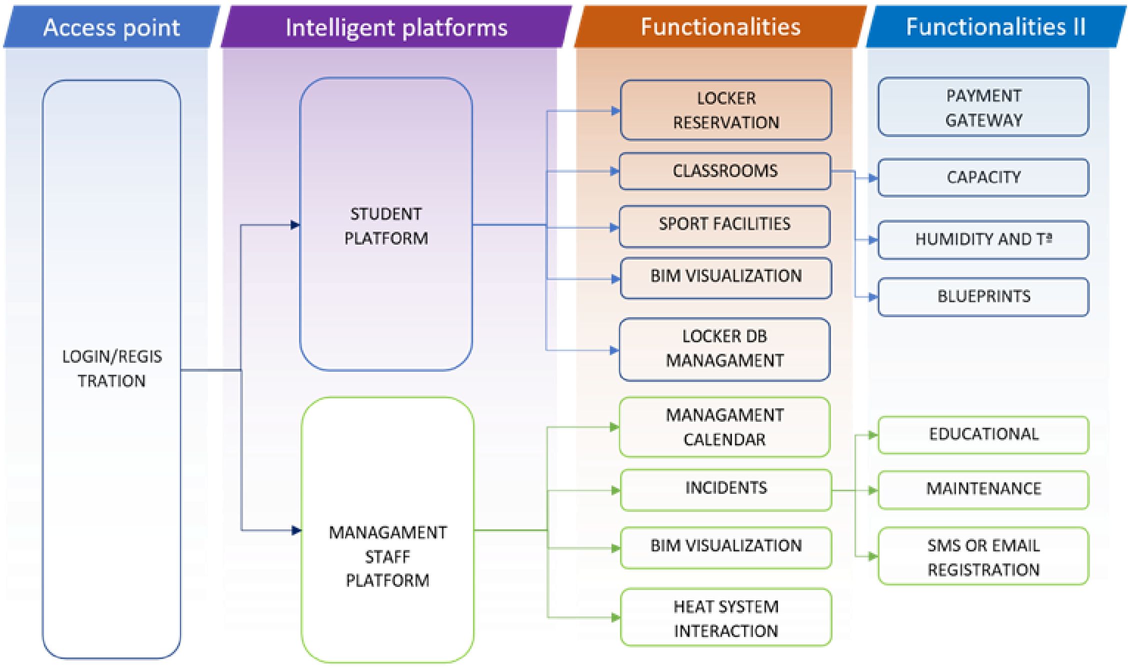

Figure 7. Intelligent platform functionalities.

Intelligent platform begins in the login form for all users. Once the user is registered in the platform, according to the privileges, the session will be redirected to one system or another. The first one is related to the student management system. Currently, five functionalities have been developed in this platform. Locker reservation provides the student with the possibility of locker reservation. Considering parameters as floor or the type of locker, the user is redirected to a payment gateway where any credit or debit card is accepted. When the process is over, a PDF is generated to be delivered to the management staff and receive the key. Regarding the classrooms, capacity, humidity and temperature can be detected and saved in a historical SQL database. Of course, an online BIM visualization environment is provided to the user, where students can navigate along the building.

If the user is catalogued as "management staff", the algorithm redirects the session to the management platform. A management calendar has been developed. This functionality provides the management staff with the possibility of placing common or specific events related to maintenance, cleaning, or subcontractors. In this way, the affected sector could check the event into the calendar or could be informed by e-mail or text messages to personal devices. An incident tool has been developed too. It consists in an online form where the user could insert manually any kind of incidence found along the building. This incidence could be registered while alerting message is sent through email or text messages to the management staff. This management is helped with a BIM visualization environment. In this case, the model hosts a higher LOI than the one in the case of students.

Moreover, in the last point of the management staff platform, a heating system interaction is provided. Using motherboard such as Arduino or ESP32, an interactive hardware has been developed. This links the information saved into the SQL database and the intelligent platform. The management staff can open or close the solenoid valve through internet with any device, or even, programming its aperture thanks to the management calendar developed.

4. Analysis and Results

Starting with the internal modelling focusing on management tasks, step by step, the model has been growing up holding even external spaces. Sports facilities, main roads or public transport system have been modelled too and new management techniques are currently being investigated. In Figure 8 the current state of the BIM model is showed.

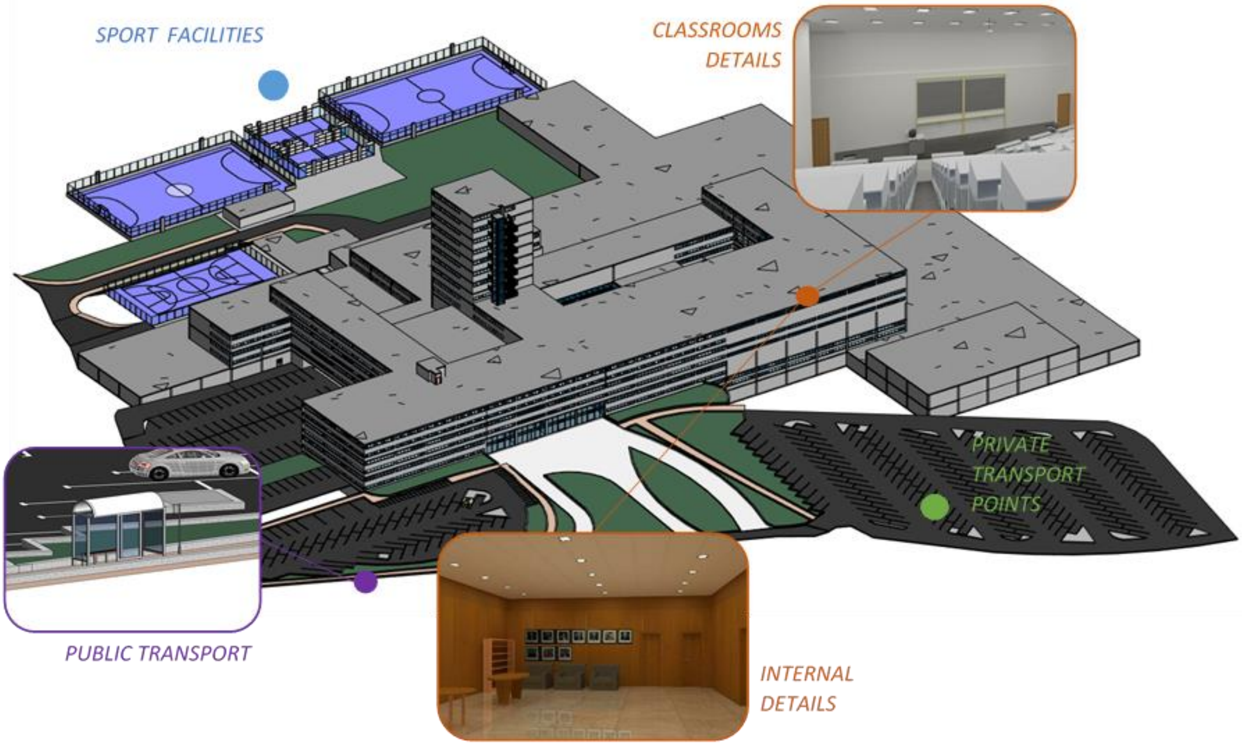

Figure 8. BIM model of the ETSICCP.

As it is indicated in Figure 8, not only internal spaces were modelled with high LOI but also the external environment. Future implementations of public transport information with the developed intelligent platform are being the center of research at the time of writing.

With an important volume of information hosted by the BIM model, a locker reservation system, rooms' main characteristics management or educational scheduling were the firsts management systems elaborated. Additionally, the intelligent platform took shape and implemented new management tasks.

Regarding the locker reservation, Dynamo programming was selected. Thanks to it, a complete digitalization of the process was carried out, and the reservation process was developed linking a worksheet with BIM through Dynamo.

One of the conclusions obtained was that it was possible to reach the total synchronization of all the degree schedules along the infrastructure with the BIM model. The complete digitalization of the schedules was carried out inserting it into worksheets databases. The next step was linking those databases to different space and space properties. In Figure 9, the results of implementing the schedules and databases into the BIM model are shown. As can be seen, the BIM model reflects the actual occupied zones through daily schedule. The color code shows to what degree belongs the lecture on course at the classroom.

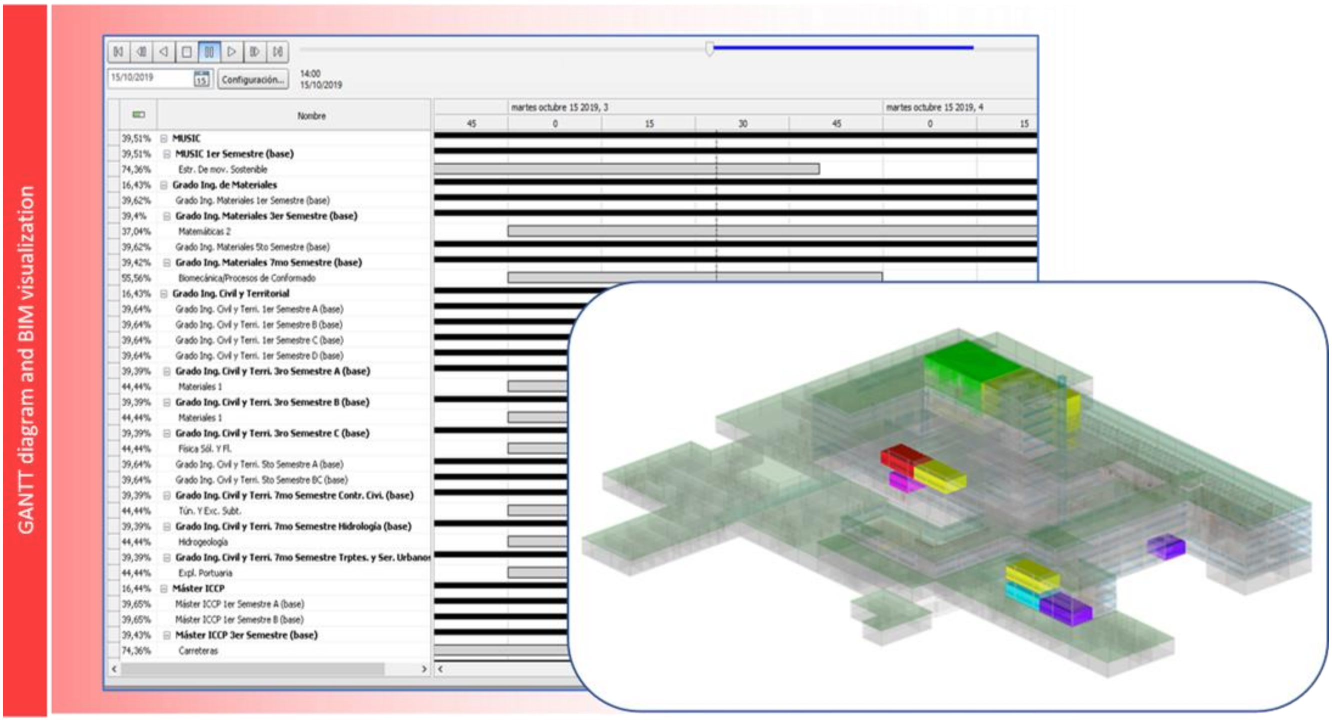

Figure 9. Educational Scheduling linked with BIM model.

Regarding the COVID-19 pandemic situation, the management system helped identifying the possibilities for this academic year. Detailed information was provided to the managing staff. In addition, internal movements along the building were registered through the O-DM's [26]. Moreover, the perspective of the COVID-19 framework opened new research lines focused the project into sensorization techniques, considering parameters not studied until this point. The level of CO_2 or counting systems are among the possibilities of the self-developed sensors.

The management techniques described in the paper, locker reservation, scheduling visualization and COVID-19 management system, provide the management staff with the initial steps to achieve the smart campus concept. Those management techniques reduced considerably the paper format. However, multiple skills of different kinds of software where needed to make the best use of the management system. This fact was the origin of the idea of developing an intelligent platform for all the users of the building.

The intelligent platform is continuously growing. Each day, new management techniques or improvements of already existing management tasks are developed. The intelligent platform hosts the use of multiple programming languages. It must be considered that the intelligent platform is accessible through internet, so not only filtering or searching algorithms were completed but also security and identification process have been evolved.

Some of the most significant results of the application of the intelligent platform were the reduction of time on management tasks and the operation and maintenance costs. It links multiple management tasks, independently of its data nature. Spreadsheet, images, graphs, or different data formats could be easily linked with the platform, either exporting or importing way. Alert systems through text message or e-mail or prediction of possible failure of the elements were developed and implemented recently. Figure 10 shows login access and Figure 11 is related to management staff platform.

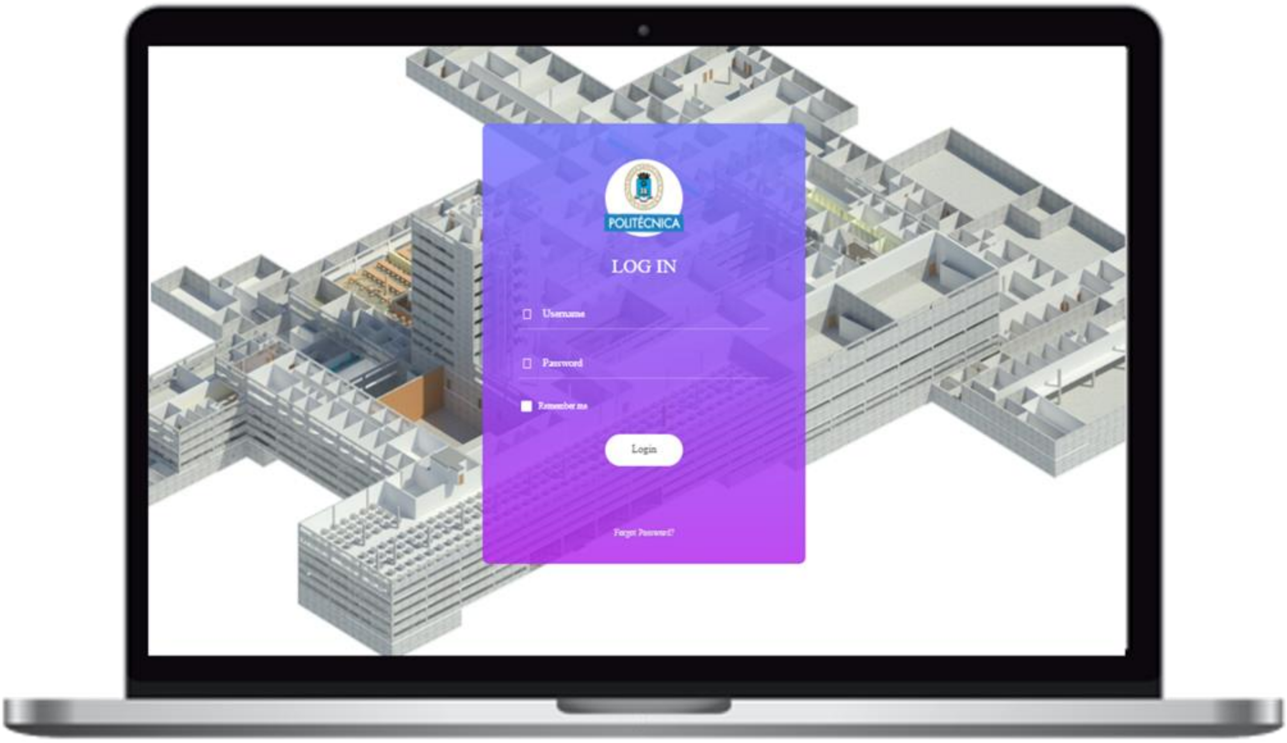

Figure 10. Intelligent platform login.

Figure 11. Intelligent platform. Management staff.

Additionally, IoT technologies were implemented. The intelligent platform plays a key-role in this system. With it, multiple sensor analysis could be implemented. All sensor measures could be studied by a single platform providing the possibility to interact with the infrastructure with BIM parameter such as capacity, distance or material, or even other live parameters as occupancy, temperature, humidity or level of CO_2.

While the implementation process was studied, it concerned us about the massive commercial software in the marketplace. However, a single platform with no possibility of interaction was the only solution. Considering the management needs related to ETSICCP, heat systems stand out over other systems. A heat system with no division properties causes important costs on the monthly gas billing. Hence, a new sensor integrated with the intelligent platform was developed. The hardware is based on a ESP32 motherboard and a Solenoid valve. The programming code links the hardware with the platform and its activation depends on the developed algorithms provided to the management staff. Hardware and a solenoid valve are shown in Figure 12. While intelligent management cloud platform is based on Python language, the sensors were based on C++ programming language. The intelligent platform connects each sensor through the internet. ESP32 motherboard connects to an internet domain where data is sent and received. Solenoid valve diameter varies considering the piper sector where it is installed.

The heating system designed in the 1960s was based on a central heating system. However, such a system can only be working or stopped. This implies that, occasionally, the whole building must be heated up for the only use of several rooms. This supposes an additional consumption of combustible and an inefficient use of the resources. The single automation sensors developed permit opening or closing the heating system of each of the classrooms or areas. The intelligent platform hosts this possibility working as a prototype. Even though the full implementation in all the spaces depends on new investments of the ETSICCP, this study has shown that relatively cheap components and self-designed sensors permit doing so in any building with these characteristics.

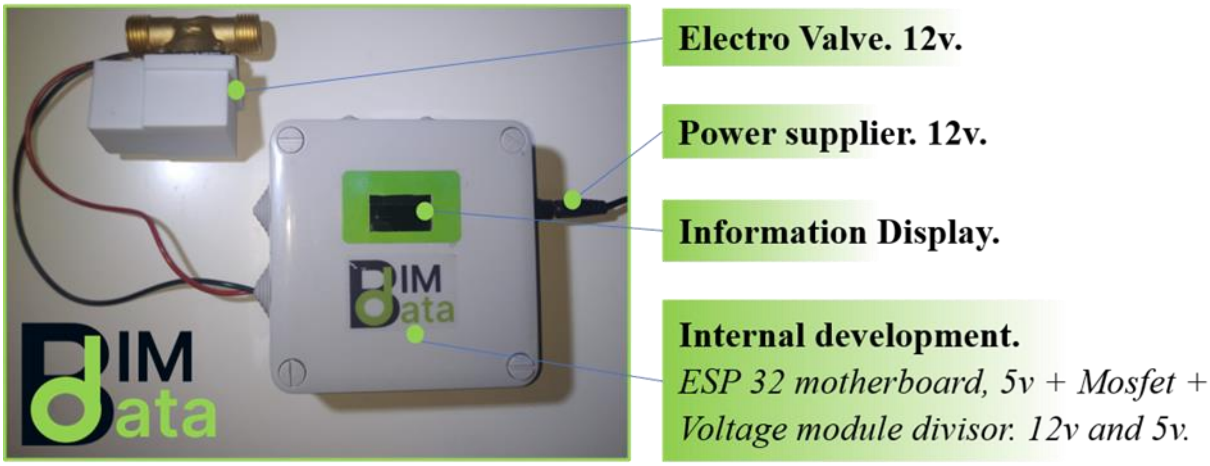

Figure 12. Hardware developed. BIM DATA SL.

The synchronization of hardware with the intelligent platform can provide the ETSICCP with an important cost reduction from gas consumption for the heating system. Moreover, this hardware installation brings the possibility of dividing and sectorizing all the heating systems. Each sector could be analyzed by the intelligent platform with its own parameters of temperature, humidity or occupancy. The reason of developing this was the nature and structure of the heating system, which is nowadays is a single system with no sectorization along the 40,000 m^2 of the building. This fact means a high loss of energy because of low occupancy rates; however, the heat system must be switched on to affect the busiest areas and, consequently, affecting also areas with no occupation.

A space analysis consumption was developed thanks to the BIM model of the infrastructure. Volume and area were collected in Table 4. Moreover, using energy billing of the year 2018, all average gas energy consumption and its cost has been detailed in Figure 13.

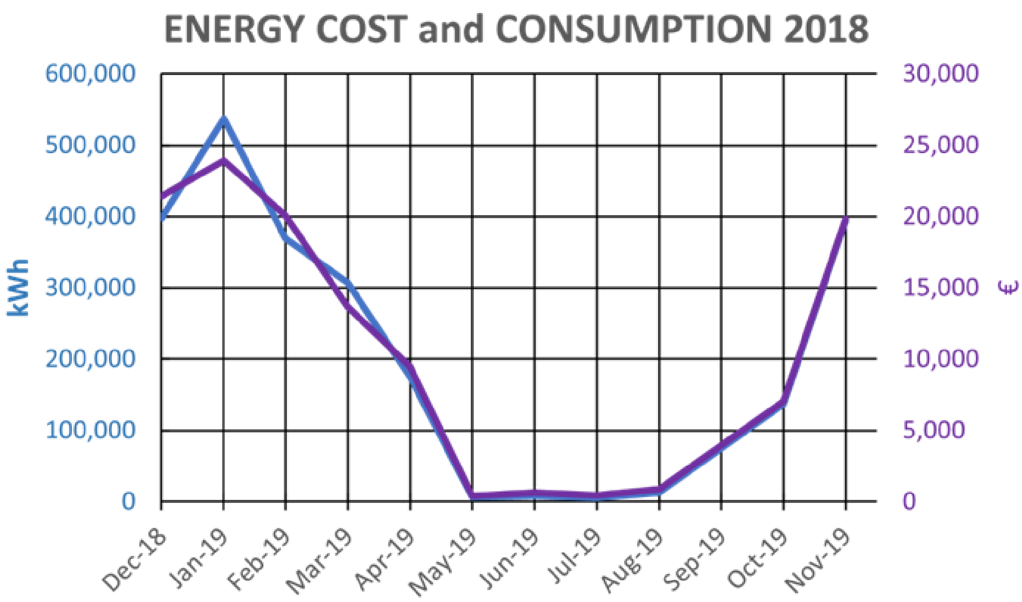

Figure 13. Energy cost and consumption of 2018.

Given that current gas infrastructure system has no sectorization, the need to use just one space of the infrastructure entails switching on the heat system for all the building. Thus, applying sensors synchronized with an intelligent platform could significantly reduce the energy consumption.

Data consumption and cost assume a complete occupancy of all spaces from 7:00 to 22:00. However, occupation rates vary every semester, day of the week and hour. Occupation rates considering the whole year are approximately 50%, consequently economic and energy savings could be improved considerably.

With a total consumption of 2,2352,276.00 kWh and approximately 120,000.00 € as annual cost, the entire infrastructure has a total volume of 95,699.26 m^3. Energy consumption per m^3 is 24.58 and economic cost per m^3 is 1.23, as it is indicated in Table 4.

Table 4. Global Infrastructure parameters.

Total Annual Consumption (kWh)	Total Annual Cost (€)	Total Volume (m^3)	Consumption/m^3	Cost/m^3
2,352,276.00	117,766.42	95,699.26	24.58	1.23

Consumption or cost per m^3 of infrastructure volume was possible given the model of all the infrastructure spaces. Total energy analysis of the infrastructure was developed. Main spaces resulted in terms of consumption and cost savings are attached in Figures 14 and 15. The spaces detailed in both Figures 14 and 15 are highlighted in Figure 16a,b.

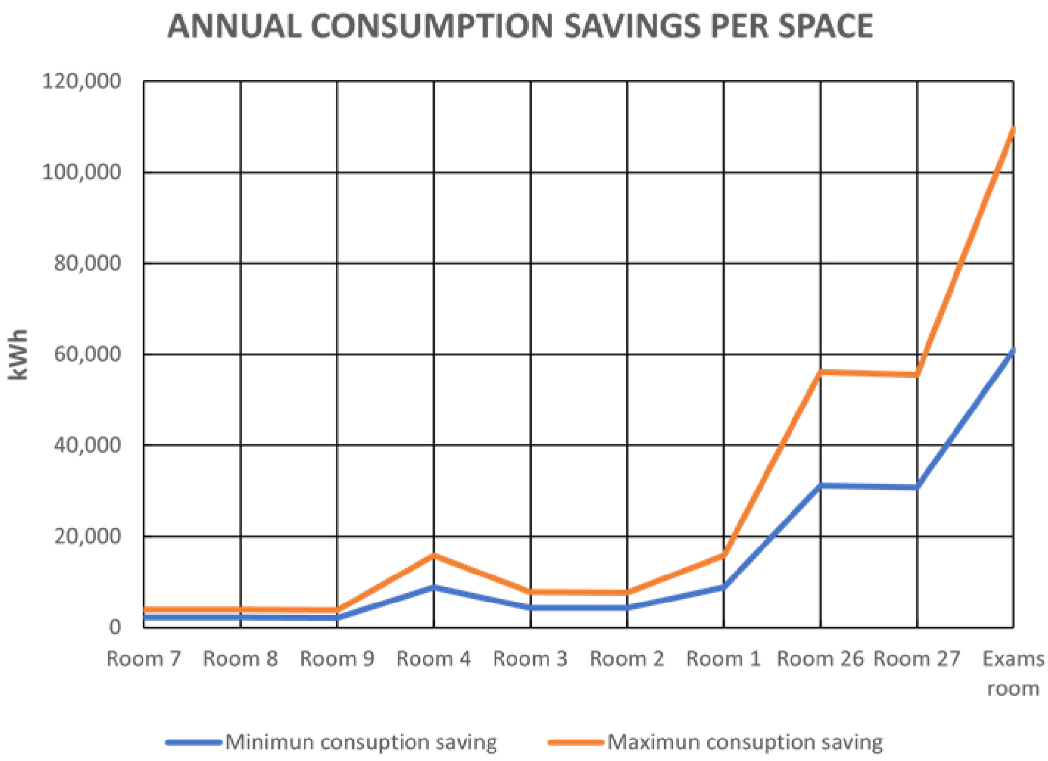

Figure 14. Annual consumption savings per space.

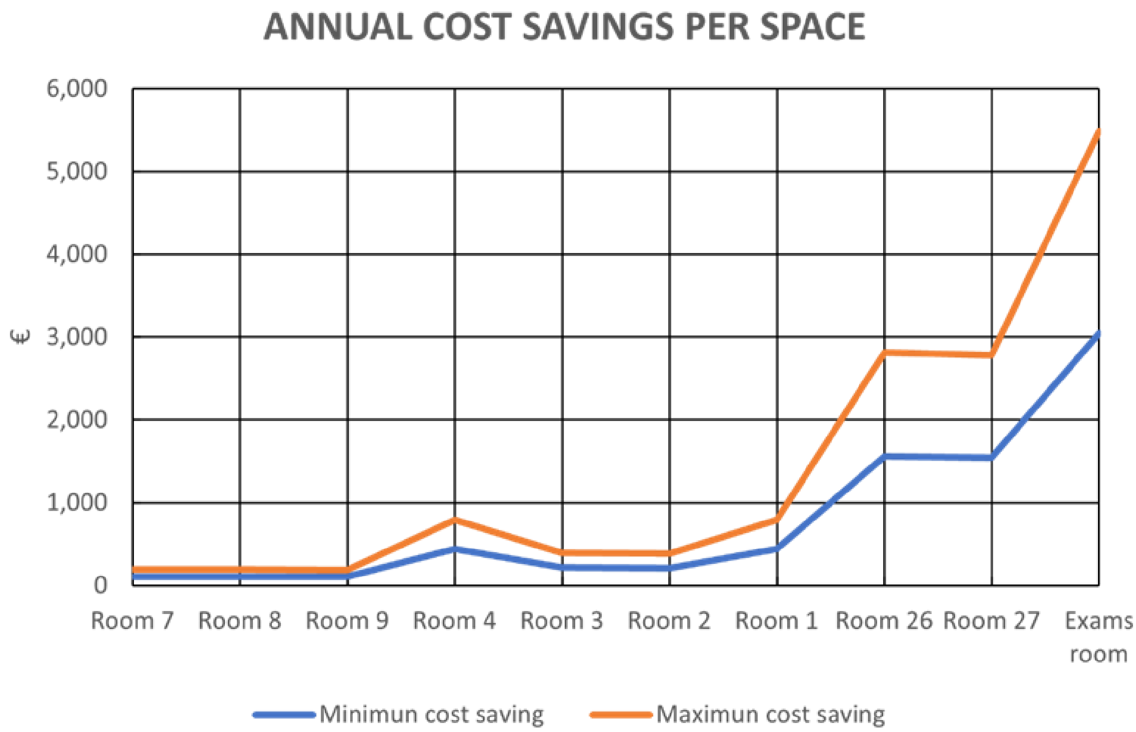

Figure 15. Annual cost savings per space.

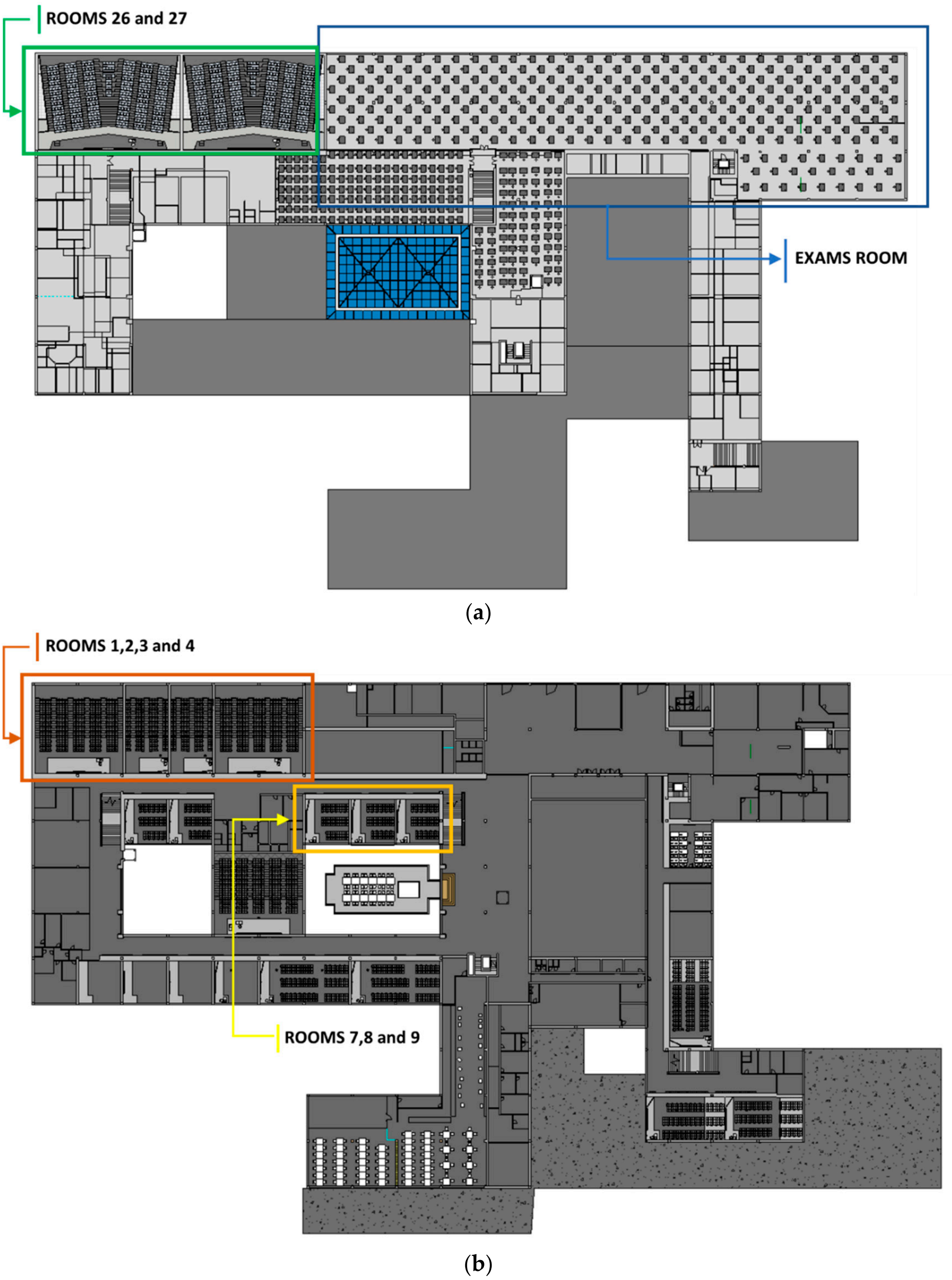

Figure 16. (**a**) Location of rooms 26, 27 and exams room. (**b**) Location of rooms 1 to 4 and 7 to 9.

Occupation rates vary from 50% to even less than 10% in specific spaces. That hypothesis provides the maximum and minimum occupation rate and, therefore, economic and consumption savings. In terms of consumption, only the exam room could provide a maximum saving of 109,644.49 kWh each year. Turning it into economic parameters, it could provide a maximum saving of more than 5000 €. Other main spaces such as Room 26 and 27 could provide a total consumption saving of 56,172.12 kWh and a total economic saving of 2812.25 € for each one. Following this analysis, if this research were applied to the whole infrastructure, affecting all spaces, a total saving of 418,928.40 of kWh and 20,963.70 € (17.8% reduction) could be reached in one year period, as it is shown in Figure 17.

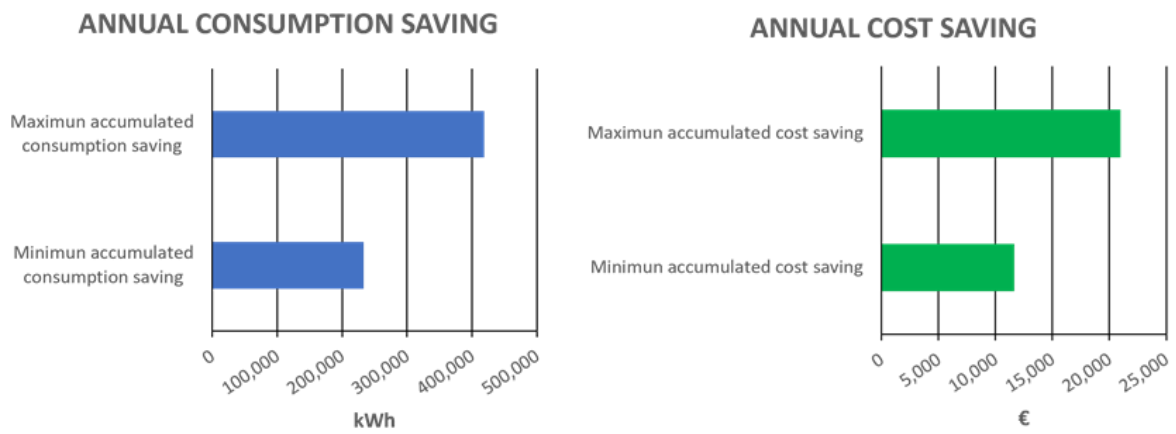

Figure 17. Annual consumption and cost savings.

5. Discussion

This paper shows some possibilities of new developments in BIM, FM, IoT, Big Data, etc. that together with programming and modelling can serve to improve the efficiency of large public buildings that were built without sustainability and efficiency concepts. In such a sense, ETSICCP has served as an example to show how with low investments it is possible to transform such types of buildings into smart and sustainable buildings. The advances shown in this study suppose a step forward in the possibilities of enhancement in the management of public buildings such as hospitals, educational institutions, libraries, etc. without large investments.

This paper is based on the process related to the transformation of the ETSICCP into a Smart Campus concept, unifying standard technologies linked with that terminology and new outstanding techniques such as BIM. The detailed process in the paper gives the idea of the project research magnitude. Not only have pure management barriers been detected, also many technical aspects associated with programming were faced. Moreover, each new technology to be implemented in the project caused new important barriers to overpass. The whole paper details step by step different phases referred to transform a traditional management system into a modern smart and sustainable system.

According to references in the introduction [2,3], FM management demands a high percentage of budgets, especially in universities, where most publications applied BIM on construction or FM linked with other technologies such as RFID, IoT or Big Data. This system holds all of them as one. Thus, reducing cost and time spent, providing detailed infrastructure graphical environment and reducing energy consumption.

Thanks to the evolved management system, the BIM technology profits could be accessible to all infrastructure users and visitors. Based on BIM research [17,32–38], the most important barriers of BIM implementation are the skills needed, the initial investment and the data interoperability. The intelligent platform with the implementation of the BIM technology accessible through internet permit lowering these problems. It should also be mentioned that it permits accessing from any smart device. No BIM skills are needed to its usage nor highly cost hardware required. Different data nature of management or educational tasks are saved in external SQL databases. With this framework, the user could link any kind of information, use the BIM model as a graphical environment and interact with the mechanical equipment along the building.

The project sought to transform the traditional management methodology into a smart management system. The process demands not only a mind transformation, also demands an actualization of building systems, like heating, air-conditioning or electricity. Nevertheless, a total refurbishment is not viable in complex existing building such as the ETSICCP infrastructure. As an alternative, hardware development was carried out and linked with intelligent platform. Affecting initially to heating system, a solenoid valve associated to the intelligent platform by a motherboard permit dividing the heat system, significantly reducing the energy consumption installed over the 1960s decade.

Multiple new research lines have begun being studied by this project: interaction with more data, nature parameters inside the building or external parameters such as traffic density and public transport are planned as future implementations. Given that the starting point was a total traditional campus, ETSICCP is now closer to a smart infrastructure management.

In order to extend this experience to other buildings with analogous characteristics, certain considerations must be taken into account. As a long-term project with complex phases such as modelling, programming or data structure, there are some limitations regarding each one. On the one hand, in terms of modelling, it is recommended to start from previous CAD information as accurate as possible. If this is not possible, an initial scanning to obtain a point cloud of the building should be considered as the first step to start the modelling process. On the other hand, regarding data structure and programming, it is important to understand the management techniques in use at the initial steps of the project. If there is no collaboration between the management staff and the research team, the intelligent platform would become limited, with the risk of developing a useless tool. Moreover, this project involves significant programming skills. There are no commercial templates or techniques that can host a complete management link to IoT, Big Data or BIM visualization. Given this complex context, the methodology followed in this study took best use of BIM formation, FM knowledge and important programming skills in order to achieve a specific intelligent management system for the ETSICCP. Existing commercial BIM platforms offer standardized solutions for general purposes. Nevertheless, implementing real-time data through sensors could be a difficult task due to commercial restrictions. This research is based on self-developed systems with no commercial implementations. Other stages such as the most basic BIM modelling of FM tasks could be implementable through commercial BIM platforms. Hence, the paper provides all the steps to transform a traditional university building into a Smart Campus. The project details BIM modelling, FM and programming implications applicable to any other traditional University Campus worldwide

6. Conclusions

Based on the results of this study, BIM-based FM has shown to be of great interest not only for new developments and constructions but also in order to update outdated and inefficient large buildings. In such a sense, based on the scope of this paper, the following conclusions can be drawn:

- The use of a three-dimensional information model as the center of the management combined with an internet platform permits both the users and the managing staff the use of this system without previous education in BIM.
- The system permits the link of the model with databases and real time information that can serve to make decisions.
- The development of sensors that are connected to the BIM-FM managing system permit monitoring any of the parameters that can be programmed: occupancy, CO_2, temperature, humidity, etc.
- The system and sensors developed can significantly improve the efficiency of the heating systems in large buildings with non-smart installations.
- The new technologies applied, as well as the programming developed in this research, permit transforming older buildings into smart and efficient buildings with low degrees of investment which can be of great interest for university buildings.

This paper shows relevant advances in the combined use and development of technologies such as BIM, FM, IoT, Big Data, etc. The significance of the research relies on the use of an intelligent platform that enables the use of such technologies without previous training and transforming an outdated large building into a more efficient and sustainable one and without large investments. The implementation of the self-design platform and sensors have shown to be suitable for many large public buildings that share the same issues. As shown in this paper, this could involve significant reductions on the energy consumption. This could be of great interest also in terms of the reduction of pollution in large cities with the real-time control of the central heating systems that were typically installed in the 20th century in this type of buildings.

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