Development of an Innovative Seat Reservation System for University Buildings Based on BIM Technology

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Abstract: The usefulness of building information modeling (BIM) for facilities management, although widely demonstrated, has not been extended to use management in university spaces. In public facilities with free access, it is uncommon to be able to check the availability of seats, which causes capacity problems. In addition, while several studies show that the use of BIM makes the graphic communication of useful information about buildings more attractive and intuitive for its users, there are still challenges regarding how to make it accessible to the public, taking into account their preferences. The purpose of this study is to demonstrate the benefits of implementing BIM in a real-time seat occupancy management system to enable reservations tailored to the user's needs by offering various means of consulting model information. The research method focuses on the utility model designed for a university library in Malaga, Spain. The results, based on data obtained from a survey, indicate that users positively assessed the quality of the information offered, showed great interest in its use, and also considered it comparatively superior to other reservation systems used. The Results and Discussion and Conclusions sections also show the potential of the system to control social distancing and energy expenditure.

Keywords: reservation system; building information modeling; facility management; university library; visualization

1. Introduction

The past few decades have seen a paradigm shift in the design, execution and maintenance of architecture, engineering and construction projects [1]. Both in the design-build process of new constructions and in the facility management of existing buildings [2], there is an evolution from 2D graphic representation using computer-aided design (CAD) to building information modeling (BIM) [3].

A BIM model of a building is a parametric digital representation of its physical and functional information, which allows an infinite number of applications throughout its useful life cycle [4]. In the literature, these are generally referred to as BIM dimensions: 3D (modeling), 4D (time), 5D (cost), 6D (operation), 7D (sustainability) and 8D (safety) [5]. While the usefulness of BIM in all these phases of a construction project has been proven, other more imaginative uses of this methodology are possible, such as those related to the collective and ubiquitous visualization of building information in real time applicable, for example, to emergency evacuation situations [6], real estate services [7] or

museum management [8]. Therefore, the exploration of new potentialities of BIM is the focus of the more recent publications [9] and the main motivation for this research.

Accordingly, this paper proposes a new utility model for real-time space occupancy management and analyzes the potential use of collaborative work tools under the BIM methodology to enhance reservation management and space availability monitoring systems. The proposal simultaneously considers user preferences as a critical factor to maximize use efficiency and offers an additional tool for the effective management of free-access public buildings. To this end, we study a pilot project for the occupancy management system of the main library of the University of Malaga (UMA), called Biblio-Smart. The results obtained, based on a survey, show that using BIM as a tool for the consultation and interactive visualization of information of interest for seat selection and reservation by the users of a free-entry facility results in greater user satisfaction by improving system efficiency.

Background

Today, a wide range of BIM viewers is available (BIM Vision, Tekla, Solibri, Navisworks, Dalux BIM Viewer, etc.). They are typically used for design reviews and interactive presentations, thus helping to communicate ideas and share information among the agents involved in a project, among other applications [10]. Thereby, a single data source, such as the interactive 3D model, becomes the common element of reference for understanding among interdisciplinary groups collaborating on the same project [11]. However, the use of BIM among professionals has not been extended to regular or potential users of buildings, who could also benefit from the public consultation of information of use to them [12]. On the other hand, most BIM viewers only provide a snapshot of the 3D model, and many of them are not enabled for real-time operations or visualization [13]. Moreover, most of these tools are based on checking the direct parametric information of a BIM model, which was previously represented as tables [14] or understood as a simple database [15], despite containing detailed parametric information. Few studies consider the model as a relational database specifically enabled to program functions that more efficiently automate the responses to queries or needs [16].

It should also be noted that, despite the demonstrated benefits of the application of BIM to built environments [17] and existing advances in the Internet of Things [18] and in new technologies for visualizing spatial information using virtual reality (VR) [19] or machine learning [20,21], these advances are not usually applied to reservation systems, in which it is also not customary to take into account the needs and preferences of the target audience. Moreover, they generally offer very little graphic information or specific data on available seats, which would enable a comparison of their characteristics and hence an informed choice. This point is particularly relevant given that studies have shown that the attractiveness of graphic information and its ease of interpretation significantly affect the motivation of the recipients to collaborate with the strategies designed for buildings [22]. Nevertheless, in most of the research on this subject, the term "efficiency" is approached from the viewpoint of energy and sustainability [23] in relation to the design, construction and maintenance of buildings and infrastructures [24] and not from the perspective of the efficiency of space use by its users [25]. It is precisely in the field of energy information visualization where it has been shown that the implementation of BIM information tools is more intuitive and more interesting for occupants compared with other techniques for representing consumption, such as tables and line and bar charts [26].

Some studies revealed that there are still gaps in the BIM literature in some fields [27]. In addition, after conducting an extensive search of the existing literature, to the best of the authors' knowledge, there is no precedent for reservation systems using the BIM methodology. Therefore, from the analysis carried out, it is identified that one of the gaps in state of the art is located precisely in the area of the use of BIM for the management of the use of buildings. Therefore, one of the objectives of this document is to bridge this gap

in knowledge so that the application of BIM for the improvement of reservation systems, developed in Biblio-Smart, opens the way to future lines of research on this topic for other academics. For this reason, it is only possible to compare the occupancy and reservation management system designed for Biblio-Smart (without including the extra functionalities provided by the query system based on data from the BIM model) with other published use control systems, as performed below.

Most are focused on transportation [28], workplaces [29], tourist accommodations [30], leisure places [31] and restaurant spaces [32]. However, the attention to the implementation of booking systems in free-entry spaces of institutional buildings [33], such as libraries [34], computer rooms, conference rooms [35] or teaching spaces [36], is limited.

The main problems raised by these studies are related to seat management at times of high demand [37]. This lack of anticipation of necessary control mechanisms, together with the scarcity of seats in certain periods, leads users to resort to the traditional reservation method of placing objects on seats as a sign of occupancy. These seats can remain empty for a large part of the day, causing inefficient use of space and generating unnecessary movements by potential occupants in search of a free seat [38].

Among the deficiencies of the existing commercial systems [39–41], it should be noted that most of the solutions are capable of indicating where there are free spaces, but they do not allow online reservations through the mobile devices of its potential users.

On the other hand, when analyzing the characteristics of patents that address the existing problem in terms of managing the use of libraries and study rooms, various types of deficiencies are identified, according to the technology used by each remote reservation system. Solutions based on Wi-Fi technology [42,43] have limitations in relation to accurate monitoring of the occupancy status of seats and do not identify a seat as free, even if the user is absent from his or her post, as long as he or she does not leave the library premises. There are solutions that require Z-Wave technology in the interaction of both the occupant's terminal as well as the one installed at the entrance of the library and in beacons arranged inside the room [44], with more versatile and simple systems being desirable. Other systems use a short-range communications beacon (Bluetooth) where, by means of an app, they detect the presence of the user in the venue through their mobile terminal and thus proceed to confirm the reservation of a previous place [45]. However, this last type of system is usually limited to managing the reservation and not to the occupation or release of the seat by the user once he or she is in the room. There are also systems that use imaging, laser or ultrasound technologies through force sensors, inductive sensors or CO_2 concentration meters to determine if the seats are occupied or vacant [46], which increases their price.

In short, current occupancy management systems, in general, are usually able to indicate the locations of available seats but, in general, do not offer online booking via the mobile devices of potential users, nor do they allow on-site occupancy management in real time. Consequently, these systems can be improved by using more economical and effective technologies that reduce their cost and increase their versatility [47].

From this comparative analysis, it can be deduced that there is a concern among the scientific community for designing a management system for the use of libraries and study rooms that resolves the gap mentioned above. For this reason, from the initial approach of this research, it is considered that combining efficiency, versatility and economy should be a fundamental objective of the Biblio-Smart occupancy management system.

In addition, this document aims to highlight the opportunities and future lines of research that open up when applying BIM to space use management systems. This combination opens up a wide range of reservation options associated with the information contained in the model. As will be seen later, it is not only possible to introduce parameters and algorithms related to the user's location preferences, as exemplified by the developed case study, but it also allows other options associated with the interests and needs of the managers and other agents involved in a building, such as (1) restrictions on

the use of the room for groups or specific activities, (2) identification and programming of dates and times for maintenance tasks or inventory, (3) sectorization of the facilities for their progressive and coordinated start-up with the allocation of positions in rooms by the system or (4) optimization of the occupation in case of the need to apply social distancing measures, among others.

This introduction concludes by showing that the possible relevance and impact that the application of BIM-based tools for the personalization of reservations could have in occupancy management systems has thus far not been addressed. To this end, it must be added that the capability of BIM to bring virtual knowledge of the building to non-specialist users has not been quantified and verified in the field of spatial information visualization. Therefore, the research questions to be explored, through the experimental device for seat reservations (Biblio-Smart), are related to the automatization of interoperability between user decisions and parametric information present in a BIM model for informed choices. The final scope of the proposed utility model is to transition from being a modern reservation management system to a seat control system that automates in real time its response to the state of occupation of seats and to the rest of the information that can be consulted in order to enable reservations based on the needs of the users, thus optimizing the existing public resources, in a more efficient and versatile way. Hence, this research is relevant.

2. Materials and Methods

The research method is presented through the Biblio-Smart case study, the pilot project proposed for the General Library of the UMA. In its development, a cascade model was followed with the following stages: (a) Analysis; (b) Design; (c) Implementation; (d) Verification; (e) Feedback.

In this section on materials and methods, the phases of analysis and design of the prototype will be presented, distinguishing between the requirements and research strategies established for the different parts that compose it: (1) the management and reservation system and (2) the system consultation based on data from the BIM model. It also includes the implementation design, verification and feedback phases of the Biblio-Smart system as a whole.

2.1. Analysis Phase

The methodological procedure used was exploratory and experimental research. Exploratory research aims to provide greater familiarity with the problem, helping to improve ideas or discover insights. Regarding the technical procedures, experimental research consists of a methodology to determine the object of study, select the variables capable of influencing it, define the control mechanisms and observe the result of the variables in said object.

The first phase of the research consisted of a review of the literature and allowed a better understanding of the research gaps, the most relevant studies published in recent years and the most used tools, which are summarized in the introduction section. Said review included articles, patents, dissertations, theses and books available in the Scopus bibliographic database, in the web search engine specialized in academic literature Google Scholar and in databases specialized in patents such as Espacenet, Interpat or Latipat. At the same time, exploratory research uncovered specific information about the practical implementation of the tools. In this case, commercial websites and discussion forums were the most relevant research sources, which resulted in the analysis of tutorials and the definition of practical criteria to support the use of the tools. This allowed to determine the proposed objectives and requirements.

As stated in the introduction, one of the main objectives of this research is to close the knowledge gap in the application of BIM to improve building use management systems. To do this, the following research questions are raised: (a) How to combine efficiency, versatility and economy in the development of an occupation management sys-

tem?; (b) To what extent can the application of the BIM methodology improve a reservation system according to the opinion of its users?. Therefore, the research hypothesis was as follows: The implementation in the General Library of the UMA of an efficient, versatile and economical reservation and occupancy management system which allows the consultation of interesting information for seat reservation, based on data from the BIM model of said space, will improve the use management of the building in the opinion of its regular users.

2.1.1. Hardware Analysis for the Occupancy and Reservation Management System

In order to achieve the proposed objectives, the following requirements were established that the hardware had to meet.

For saving costs, it was necessary to (1) contemplate a single device per table, which was shared by the six study stations grouped around it, (2) choose the most suitable type of low-cost and small-sized computer with a built-in power supply that was most suitable for the system and (3) design and manufacture, in a 3D printer with free software, the boxes that contain the hardware, with appropriate characteristics for public use.

To optimize the efficiency and versatility of the system, it was necessary to (1) include coded identifiers in each device that would visually indicate the occupancy status of each seat, (2) enable the recharging of the occupants' mobile devices and (3) enable two options for reservation from the users' smartphones—one online and the other on site—which would speed up the reservation process in person at the room.

2.1.2. Software Analysis for the Occupancy and Reservation Management System

The following requirements were established to be met by the software in order to accomplish the initial objectives.

To restrict the possibility of reserving seats to the UMA group, it was mandatory (1) that the reservation app be integrated into the institutional app of said university, to which only its members have access, and (2) to develop a hybrid reservation application based on web technologies (HTML, CSS or JavaScript) using an open-source Ionic Framework frontend software development kit (SDK), which allows one to develop applications for native iOS, Android and the web, from a single code base.

In order to guarantee the correct flow of use of the system, according to the conceptual scheme designed, it was necessary to (1) develop the web service hosted on a virtual server, (2) define the processes necessary for programming the app and (3) apply established protocols for coordination between the query system based on data from the BIM model and the occupancy and reservation management system.

To optimize the efficiency, versatility and economy of the system, it was necessary to (1) program the reservation app in Dynamic Universal Assembly Language (DUAL) (Wi-FI + other alternative technology) so that the Wi-FI of the library could be used by the smartphones of the occupants of the seats without this affecting the occupancy control system and (2) install a program on the computer of each device that reads the occupancy status and shows it by turning on the visual identifiers installed in the hardware.

The web service is hosted on a CentOs virtual server. This service is programmed with NodeJs, hosts a database and it is responsible for controlling the disconnection time to release the seats when the user is absent for a predefined time.

2.1.3. Analysis of the Query System Based on Data from the BIM Model

As was already explained, the design and operation of the consulting system has the objective of enabling the use by users of the library of tools typical of collaborative work between BIM project technicians, being useful for consulting information associated with the model and of interest for the choice of seat, so that it can be viewed interactively from the smartphones of UMA members through the query interface of the app developed to

manage reservations and thus offer them the option of an informed choice of seat based on a comparison of the characteristics between them.

In response to this objective, the following criteria were established to be met by the query system based on data from the BIM model.

To guarantee coordination between the parties and a correct connection and mutual data flow between both systems, it was necessary to (1) develop a BIM execution plan (BEP) that included the rules, tasks, milestones, procedures, technologies, level of information need (LOIN), etc. of the project, (2) install the necessary technological infrastructure to host the central model of the building and work collaboratively and (3) define the appropriate cloud platform that allowed the development of the applications and programming necessary to make the query available to users of the model information, among other elements.

For modeling the building, it was necessary to (1) previously compile the existing planimetry and carry out the pertinent data collection in situ and (2) follow the workflow of the BIM project, consisting of structuring the model, creating the development matrix, designing the parameterization strategy, creating the necessary planning tables and custom families, etc.

In order for the information of the BIM model to be properly consulted from the users' smartphones, it was necessary to select an appropriate information display system, identify and configure the deliverables and data of interest of the BIM model for seat reservation, define the exchange formats, configure and map the IFC parameters, specify the maximum weight of the native model file with its inserted families, define the view templates, thicknesses, materials, annotations and filters, configure the export of images and rendered videos, select the editing and programming software, design the graphical query interface for the app, elaborate on this interface, host in the cloud and create links to the app of files that can be consulted, etc.

2.1.4. Analysis for the Implementation of the Biblio-Smart Prototype

In the prototype development phase, the stages were defined to establish the necessary infrastructure for each of the two systems that made it up and were interconnected through the app developed for Biblio-Smart: (1) the reservation and management system for occupancy and (2) the query system based on data from the BIM model. These systems are described in detail in their corresponding subsections.

### 2.1.5. Analysis for the Verification of the Biblio-Smart Prototype

As a requirement of the evaluation phase of the prototype, its transparency was established regarding the data collection and analysis process, as can be seen in the link available in the data availability statement of this document. The verification of the hypothesis had a quantitative approach of observation through a questionnaire and description and analysis of a case that deserved interest for research in the field of universities. Research of this type focused on a case study had an exploratory and descriptive function [48]. Therefore, it fit perfectly into the methodological strategy established to achieve the proposed objectives.

2.2. Design Phase

Secondly, we proceeded to define and test the tools. In this phase, the main objective was to determine the technologies, tools and equipment necessary to create the prototype of the system. As a product of the literature review indicated in the previous phase, the defined requirements guided the procedures adopted.

As shown in Figure 1, the conceptual design of the Biblio-Smart prototype consisted of two parts interconnected with the institutional application (app) of the UMA through a virtual server, by which users interacted from their mobile devices with (1) an occupancy and reservation management system, made up of a hardware prototype and three

software applications which controlled it, and (2) a consultation system based on data from the BIM model, which allowed personalized seat reservations to be made through the application.
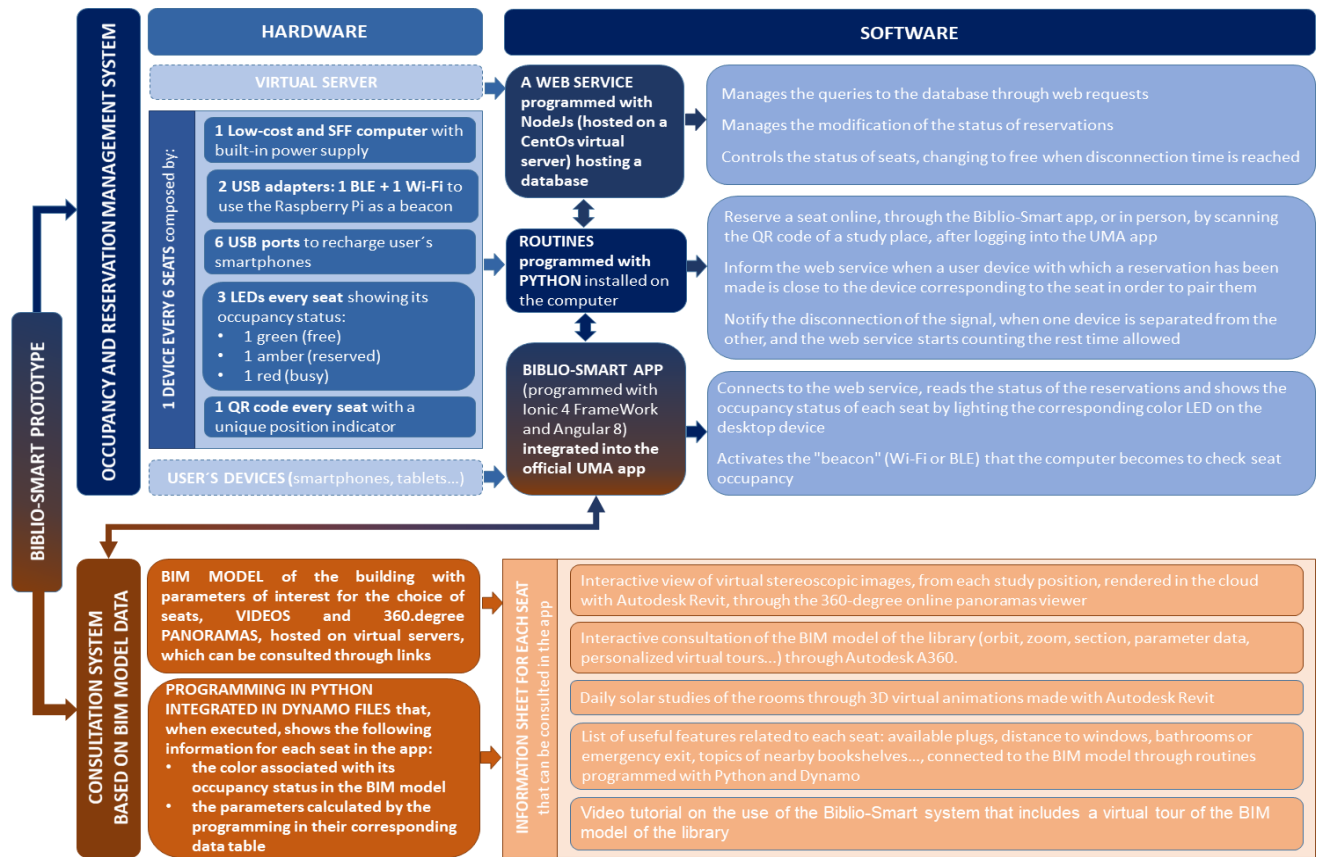
Figure 1. Diagram of the Biblio-Smart prototype components and the functions managed by each one.

2.2.1. Hardware Design for the Occupancy and Reservation Management System

Based on the criteria established in the analysis phase, one device per table was projected, covering six study stations. Thus, each of them was designed to connect the mobile phones of six students to the reservation and seat management system.

The hardware prototype was a device designed to contain a low-cost, small form factor (SFF) computer with a built-in power supply, 6 universal serial bus (USB) chargers for mobile recharging and 18 light-emitting diodes (LEDs), which indicated the different occupancy statuses of the 6 workstations it served: free (green), reserved (amber) and occupied (red). In addition, each seat included a quick response (QR) code, which contained a unique indicator to identify the seat location and also served to enable face-to-face reservation by scanning the QR code.

The support box contained a Raspberry PI, which is a computer the size of a credit card. It consisted of a motherboard that supported different components of a computer to which, through its ports and inputs, peripheral devices could be connected, and a connection to the network could be established through the Ethernet port. It also had an SD slot that allowed installation, by means of a microSD card, of free operating systems.

The SFF computer case layout, with its holes for the power supply, USB charging ports and LEDs, was designed in 3D using AutoCAD software. The 3D printing of the case was performed with Cura slicing software to convert the 3D CAD model into a G-code file, which provided the necessary instructions to the 3D printer. Cura software was chosen as it is free, open source, easy to use, supports different file formats (STL,

OBJ, X3D and 3MF) and is compatible with the most common operating systems (Windows, Mac and Linux). Each case, measuring 140 × 80 × 110 mm, was printed with an Ultimaker 2+ printer using Ultimaker PC (polycarbonate) material, which gave the molded parts strength, resistance and dimensional stability at high temperatures, making them ideal for this functional prototype.

2.2.2. Software Design for the Occupancy and Reservation Management System

According to the identified requirements, software was designed in which the web service was hosted on a CentOs virtual server. This service was programmed with NodeJs and also hosted a database. It was responsible for controlling the disconnection time to release the seats when the user was absent for a predefined time.

Python code was in charge of connecting with the web service, reading the status of the reservations and displaying them by turning on the hardware LEDs. It also turned the computer into a beacon generator, which was programmed in DUAL to be used for Wi-Fi and Bluetooth Low Energy (BLE) connections.

The app installed on the mobile device was responsible for reserving a seat, both remotely and in person by scanning the QR code on a specific seat. This application locates the beacon generated by the hardware device and informs the web service whether or not the device is near the workstation. Likewise, it also sends a beacon loss signal when the seat is vacated, initiating the web service to begin counting the time until the established maximum break period before changing the seat status back to available.

The app, programmed with Ionic 4 FrameWork and Angular 8, was designed so that it could be integrated into a superior application (the UMA institutional app), offering greater scalability.

2.2.3. Design of the Consultation System Based on Data from the BIM Model

The definitions of the structure and relationship between elements, described in this section, respond to the requirements and conceptual design set forth above.

First, a specific project plan was designed with its corresponding BEP, in which the bases, rules and internal norms of the project to be developed under the BIM methodology were defined so that all the agents involved could perform coordinated and consistent work.

At the same time the information display system was selected. For this, the following were evaluated: (1) the large amount of graphic and non-graphic information that the shared 3D digital representation of the BIM model was capable of containing and (2) the visualization tools available for it. Finally, the decision was made to use the Revit application programming interface in the integrated BIM spatial visualization approach developed in this document.

Second, the data were collected for BIM modeling of the necessary elements of the constructed building with the appropriate LOIN for this purpose, such as the building envelope and public interior spaces, including the furniture, structure and exposed installations.

Next, the technological infrastructure was configured to be able to work collaboratively, enabling a server to host the central BIM model, and to have Revit Server installed.

Subsequently, the central model was created according to the BEP in terms of organization of the project browser and creation of the view templates necessary for the initial phase of the project's architectural model, to which the project files were linked. After this, the reference model was created, levels and grids were defined, and the central architecture model was built according to the LOIN defined in the BEP, starting with default elements that became progressively more detailed in certain areas (layers, thicknesses, properties, materials, finishes, etc.). Later, the necessary view files were generated to reflect, through labels, the legends collected in the annotation file.

Once the custom families for each modeling phase were created, in their corresponding LOIN, a series of necessary parameters was inserted to refer to them in the

programming of the plugins created to be applied to the BIM model. For example, the default parameter "subject" was added to the shelves to indicate the subjects of the books for each instance of this type of family. Thus, these data appeared among the properties of any shelf item selected by the user in A360 and were reflected in the data summary table of each seat within the item "subjects of books of nearby shelves".

Materials were also assigned to the finishes of the visible elements in public areas to make them look as realistic as possible. This was shown when rendering the necessary views and made the final editing process of the walkthrough video easier. By inserting the Revit model with the material parameters nested in each family, the Lumion software automatically recognized them.

In addition, the project was organized through tasks that facilitated and expedited the processing of information embedded in the model, such as (1) organization of the project elements into subprojects according to the BEP, allowing the creation of faster filters and speeding up the exchange of information, (2) the creation of planning tables and (3) the creation and application of new view templates to the model to highlight the desired aspects in each view of the application, as can be seen in Figure 2.
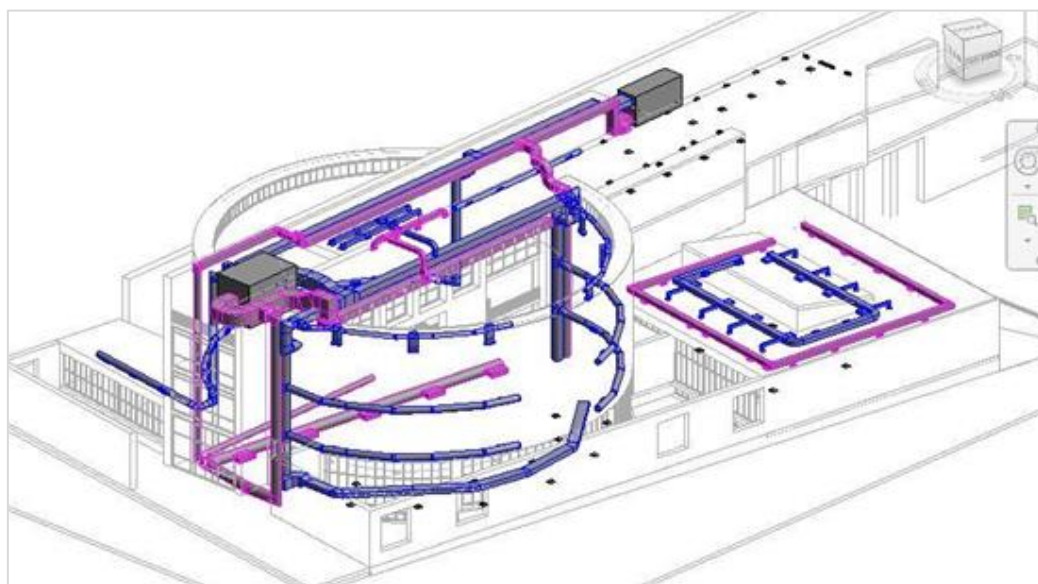
Figure 2. A 3D view of the air conditioning and lighting installations highlighted, through the application of view templates, with respect to the architectural and structural elements of the model.

At this point in the project, scripts were created that simulated the building's occupancy situation in order to carry out performance tests on the connection methodology between the query system and the reservation system. These tests were conducted by executing a Python script integrated in Dynamo files, which incorporated functions to modify the visualization of graphics in the Revit model, to facilitate understanding of the occupancy, similar to that shown in Figure 3.

Dynamo is a graphical programming interface that allows customization of the building information workflow, broadening the capabilities of BIM models. In this case, this tool was essential for developing a "live" model that would allow interaction with the virtual building, depending on the variation in some of its parameters. In addition, Dynamo enables the immediate visualization of these changes graphically in the same model, which facilitates their understanding. In this way, it is shown that by combining the appropriate parameters, variables and operations, the model could respond instantly to the use of the application, displaying the information in the interface of the app to which it was connected.

(**a**)

(**b**)

(**c**)
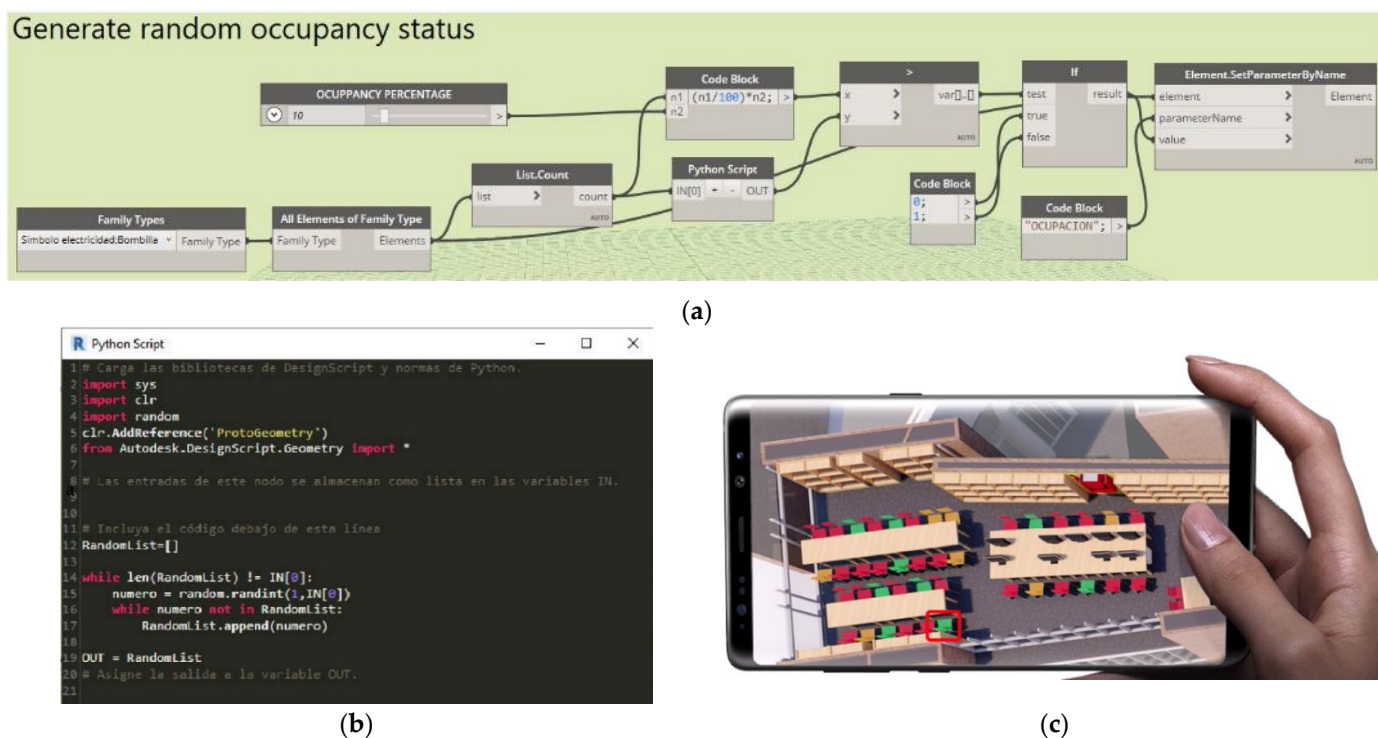
Figure 3. Example of a visual programming definition in which custom algorithms are created (**a**) using Dynamo and (**b**) with the help of Python scripts, which automates (**c**) the graphic display of changes in the occupancy status of seats by applying filters of color, thus providing said information as parameters to the Revit model and rendering them able to be displayed in the app interface.

In parallel to all of this, the data of interest to the BIM model for seat reservations were determined, and the graphic query interface for the Biblio-Smat app (Supplementary Materials S1). Consequently, prior to linking to the "information sheet" of each seat, it was necessary to perform the following tasks:

(1) Generate 360-degree rendered panoramas that could be observed from each seat, such as the one in Figure 4, offering the user an immersive experience through the free rotation of the model from that fixed point, which facilitates understanding of the spatial information of the environment. The stereoscopic image, in png file format, was rendered in cloud using A360, choosing the stereopanorama or 360-degree view option, and was visible in the application through its URL link (Supplementary Materials S2).


(**a**)

(**b**)
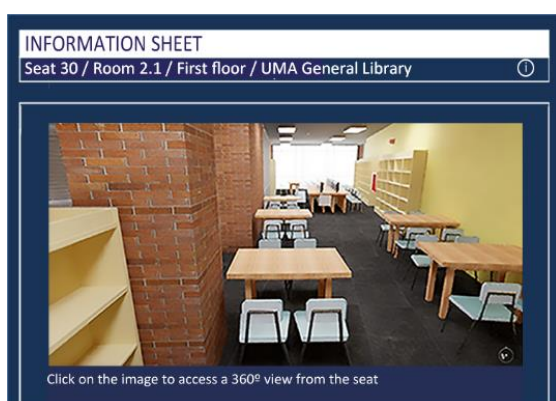
Figure 4. Link to the online 360-degree image viewer from the app's query interface (Supplementary Materials S2) (**a**) and stereoscopic image created with Revit in A360 (**b**).

(2) Upload the library building rvt file to Autodesk A360, which converts it into a lighter format for online viewing through its link to the system app from the mobile devices of users with Android or iOS operating systems. To accomplish this, an A360 free account was used, which allows a model with up to 5 GB of storage to be shared publicly and free of charge, so that all users could use the A360 BIM model consultation services. These features included pan and zoom, orbit, explode, perform component search, query element properties, perform user-customized virtual tours, select from a list of linked view planes to display, such as the floors of the building with their legends (Figure 5), section (Figure 6), as well as other utilities to examine the virtual building in more detail (Supplementary Materials S3).

(**a**)   (**b**)
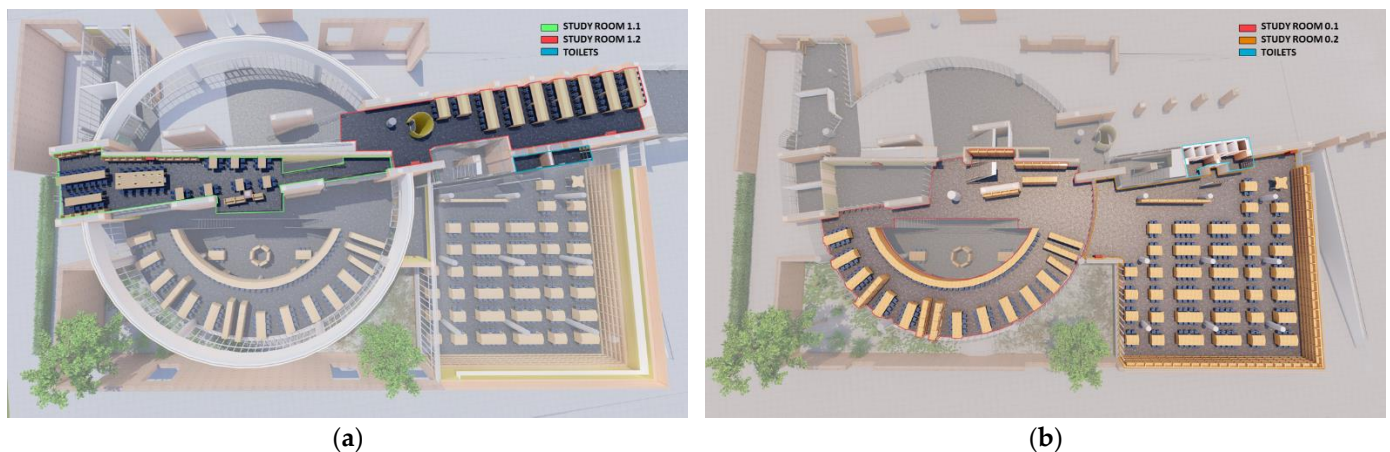
Figure 5. Views rendered with Lumion of the first floor (**a**) and ground floor (**b**) of the General Library of the UMA, available by clicking the option "show images uploaded to A360".

(**a**)   (**b**)
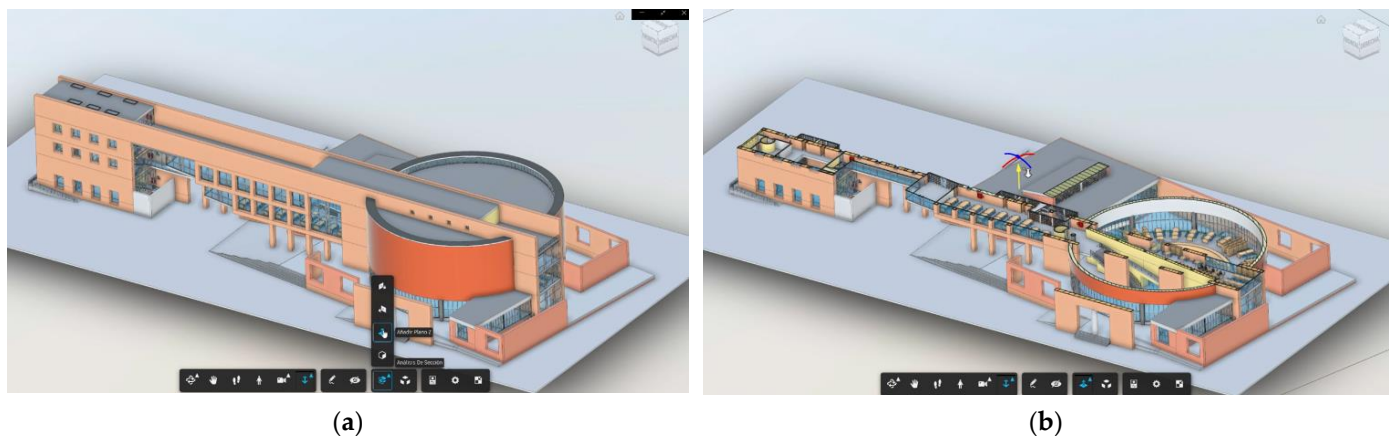
Figure 6. The 3D views of the full model (**a**) and a horizontal section (**b**) using one of the A360 tools.

(3) Prepare cloud hosting and linking to the app of the solar analysis videos for one day of each month of the year in the room where the consulted seat is located (Supplementary Materials S4). This allows the user to check the time of day during which the sun's rays fall on the seats inside the room on the date the user intends to occupy a seat in the library, which helps the user decide which seat to reserve, as can be seen in the frames from the video in Figure 7.

To carry out the solar analysis of one day of each month, we first located true north in the project, and then a 3D view of the interior of the room was selected from its windows with shadows activated. Then, it was previewed, saved and exported in video format so that it could be hosted on the cloud and its URL linked to the corresponding month icon in the app's query interface.

(**a**)　　　　　　　　　　　　　　　　　　　　　　　　　　(**b**)

Figure 7. Two frames from one of the daylight simulation videos, showing the evolution of the sun's rays inside the library's study room through the 15th of January.

(4) Link to the summary table of the data of interest for each seat for seat selection of a position, which are automatically extracted from the parameters entered for each seat family in the BIM model and from the functions, programmed for this using Python and Dynamo, in a manner similar to that shown in Figure 4. In this case, however, the parameters entered into each of the personalized family of seats were "plug availability", "distance to the nearest window", "distance to the nearest toilet", "distance to nearest evacuation exit" and "subjects of books on nearest shelves". Thus, each function programmed with Dynamo automates one of the necessary calculation formulas so that the data for these parameters are auto-filled in the properties for each instance of that type of family. Next, a planning table was generated for each seat with its calculated parameters, and through Python, they were linked to the query interface of the app.

(5) Prepare a video tutorial on the use of Biblio-Smart (Supplementary Materials S5) and rendered videos of virtual tours of the BIM model of the building using Lumion software (Figure 8). Subsequently, these videos were edited with Filmora software to merge them into one, including text and audio so that the resulting video, linked to the app's consultation interface, allowed any member of the UMA to intuitively learn to use all system options designed. The video was also intended to help new users (first-year students, exchange students, people on stay, research, etc.) to familiarize themselves with the UMA facilities before visiting them. This option may be useful to them in deciding which library to use once the prototype is implemented in the rest of the libraries on the UMA campuses.

(**a**)　　　　　　　　　　　　　　　　　　　　　　　　　　(**b**)

Figure 8. Frames of the virtual tour of the BIM model, included in the video tutorial of the system. (a) View of rooms on the ground floor and basement, (b) View of first floor room.

2.2.4. Design for the Implementation of the Biblio-Smart Prototype

The reservation procedure comprises the following steps, as shown in Figure 9 (Supplementary Materials S5). UMA members, after logging in to the university app on

their smartphones and accessing the "Services" option of "Reserve a seat in the library", will see a drop-down menu of the campus libraries in which this system is implemented. By selecting a library, they can check the occupancy status of each seat (green = free, amber = reserved and red = occupied). Next, after clicking on any of those shown in green, two options are offered: (1) "Reserve a seat" or (2) "Consult seat information", which allows them to compare seat data with those of other free study stations and choose the one that best suits their needs, thus customizing the reservation system. This option integrates all the previously described information tools linked to BIM model data.

After comparing the data and choosing the desired seat or without having previously used the query option, users can click on the "Reserve seat" option, and it will appear as reserved (amber) both in the application's occupancy map and on the LED of the device. Immediately afterward, the app sends a confirmation to the corresponding UMA email with the reservation data: name and surname, seat number, library and room where the seat is located and the time limit to occupy it. Once students approach the reserved study station, the occupancy management system verifies their identities, pairs with their smartphones and displays the seat as occupied (red) on the interface and on its corresponding LEDs. Similarly, the system also controls the disconnection time to free up seats when users are absent from their seats for longer than the scheduled break time.

(a) **(b)**
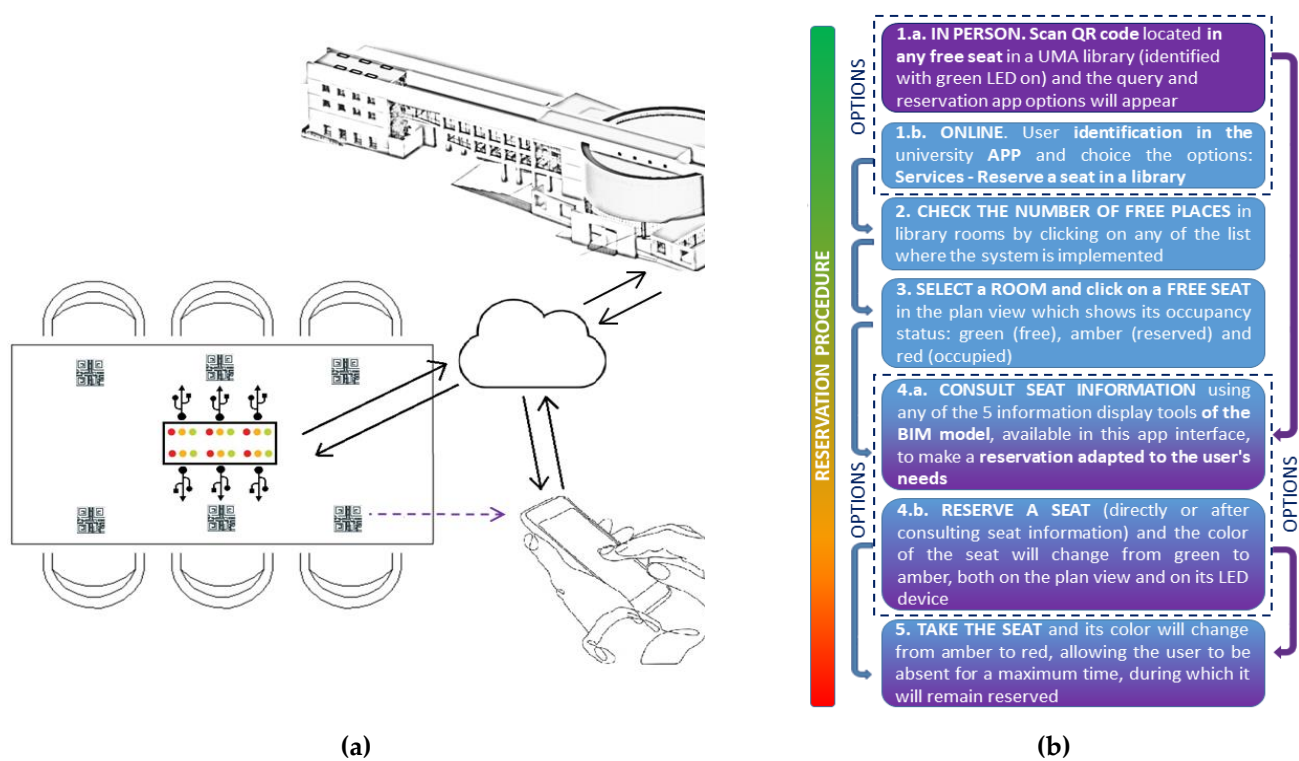
Figure 9. Diagram of the reservation procedure and system communication flows. Clockwise, we have (**a**) the cloud-hosted BIM model, (**b**) the user's smartphone with the UMA app.

As an alternative to booking online, the option of booking in person is also possible. To accomplish this, UMA members must scan with their smartphones, using the QR code reader of the UMA app, the unique identifier of any free seat in the library where they are currently located, which will have its corresponding green LED on the device. This step identifies the potential occupant and the seat, and this allows users to reserve it and sit directly if they do not want to consult any information about the study stations.

2.2.5. Biblio-Smart Prototype Verification Design

The presentation and analysis of the results to respond to the research objective were carried out based on the consideration that the Biblio-Smart system could be measured based on the assessments that the users themselves made regarding its quality, interest and comparison with other reservation systems used. From here, an analytical strategy articulated in two phases was followed. First, by means of univariate and bivariate analyses, the evaluations carried out on a total of 27 indicators were described. Secondly, it was desired to to find out, through exploratory factor analysis, if this type of evaluation would constitute factors and how, if so, they would contribute to understanding the evaluations that users made of the Biblio-Smart system.

The survey sought to collect the opinions of the respondents by obtaining indicators of the six dimensions of greatest importance to instrumentalize the concept "Evaluation of the Biblio-Smart system for seat reservation according to members of the UMA, regular users of the library where the prototype was developed".

The survey was undertaken through a structured online questionnaire with 40 questions designed using the Google Forms tool, with 5 questions about the profile of the respondents (gender, age, verification of belonging to the population of interest, branch of study and degree course), 5 questions about the use of the UMA libraries, 3 questions related to previous experience in the use of online reservation systems and the opinion on their efficiency and 27 questions to evaluate the Biblio-Smart reservation system.

The design of the operationalization of the concept, the questionnaire and the analysis of results were validated by experts from the Sociological Practice Research Committee of the Spanish Federation of Sociology. As a validation indicator, a test or pretest of the questionnaire was administered to a group of 24 students. In addition to being able to estimate the completion time, this phase made it possible to clarify the content of certain questions and improve their wording for faster reading and to avoid drop-outs by potential respondents.

An online web-based questionnaire through Google Forms was chosen to be used for the following reasons: (1) it was an economical means of obtaining the primary information, (2) it had a responsive design, which enabled proper visualization on any device, (3) it corrected possible interviewer biases, (4) it provided access to the entire universe under study through the emails of all students enrolled at the UMA, (5) its ease of access and short completion time (10 min) encouraged student participation and (6) it guaranteed anonymity, thus achieving a higher participation rate.

The link to the online questionnaire, accessible for 6 months, was disseminated through websites, institutional social networks, virtual campus thematic forums and emails with the collaboration of UMA staff and official services.

The target population of the survey was limited to "UMA members who regularly use individual study stations in the rooms of its General Library", given that this was the public and the environment for which the prototype of the Biblio-Smart system was designed. A field study was conducted, and the target population was determined to be 1200 individuals (N). Thus, the minimum sample size necessary to obtain statistically significant results, depending on the number of study subjects, was between 20% and 30% of the total population.

The criteria for operationalizing variables are set out below. To evaluate the Biblio-Smart seat reservation system, quantitative research was carried out based on the measurement of the dimensions "Quality of the Biblio-Smart seat reservation system", "Interest in the consultation information for reservations offered by Biblio-Smart" and "Comparison of Biblio-Smart with other reservation systems used". The subjective and comparative quality indicators selected were based on the most significant quality variables raised by experts in the field (summarized in Table 1), such as usefulness [49], suitability for use [50], attractiveness [51], excellence [52,53], user satisfaction [49,50,54,55], effectiveness [56], efficiency [56], compliance with requirements [56–58], affordability [49] or comparative superiority [51], among others.

Table 1. Subjective and comparative quality indicators according to the experts, on which some selected subdimensions were based to operationalize the analyzed concept.

Author	Year	Indicator	Concept of Quality According to Its Indicator
American Society for Quality Control (ASQC)	1974	User satisfaction	Quality is the set of functions and characteristics of a product, process or service that gives it the necessary capacity to **satisfy** the **needs of** a certain **user**.
Crosby	1996	Compliance with requirements	Quality is **compliance with** precise standards and **requirements**.
Harvey and Green	1993	Excellence	Quality is assimilated to something distinctive or exceptional, associating it with **excellence**, in the sense of exceeding high standards, highlighting the difficulty of achieving them.
International Standar Organization (ISO)-ISO Standard N° 8402:1994	1974	User satisfaction	Quality is the set of characteristics of an entity that gives it the ability to **satisfy** stated or implied **needs**.
International Standar Organization (ISO)-ISO Standard N° 9000:2005	2005	Compliance with requirements	Quality is the degree to which a set of inherent characteristics **meets requirements**.
Ishikawa	1988	Usefulness Affordability Use satisfaction	Working in quality consists of designing, producing and serving a product or service that is **useful**, as **economical** as possible and always **satisfactory** for the user.
Juran	1993	Suitability for use User satisfaction	Quality is the **suitability for use**, **satisfying** the **needs** of the client.
Peters and Waterman	1984	Excellence	**Excellence** is quality at the level of exceptionality.
Taguchi	1986	Attractiveness Comparative superiority	Quality products must be **attractive** to the customer and **better than those of the competition**.
Valls	2007	Compliance with requirements Effectiveness Efficiency	To achieve quality, a series of **requirements** demanded by the client must be **met** as **efficiently** as possible while prioritizing **effectiveness** in achieving said objective.

This strategy made it possible to evaluate the three main dimensions, the indicators of which covered the most important subdimensions and were considered as observable manifestations of these characteristics of interest, which could be evaluated for improvement. These indicators were compared with dimension 1, associated with the "Sociodemographic profile of the respondents". Crucial factors for the validation of their answers were their experience in the use of libraries—included in dimension 2, "Usability of UMA libraries"—and in the use of other online seat reservation systems, included in dimension 3, "Previous experience using online reservation systems", allowing a comparative evaluation of the new system designed for the case study.

For the first three dimensions, direct, closed, simple or multiple-choice questions were used and in the fourth, fifth and sixth dimensions. Questions with a Likert-type scale with five preconfigured measurement levels were used with an intermediate neutral element. The Likert scale was considered the most appropriate for understanding the opinions and attitudes of the respondents in relation to the concept operationalized in

those dimensions of the research, as it allowed us to determine the degree of agreement, with the affirmative sentences stated as indicators. The data supporting the findings of this study (survey questions and answers, etc.) were deposited in an institutional repository and published openly with the DOI indicated in the data availability statement.

The dimensions, subdimensions and indicators of the operationalization proposal are summarized in Table 2.

Table 2. Proposed operationalization of the concept "Evaluation of the Biblio-Smart system for seat reservation according to members of the UMA, regular users of the library where the prototype was developed".

Dimensions	Subdimensions	Indicators
1. PROFILE of questionnaire respondents	Gender	1. What is your gender?
	Age	2. What age range do you fall under?
	Verification of belonging to the study population	3. Are you a member of the UMA and a regular user of the General Library?
	Branch of study	4. In which of the following schools or faculties do you study?
	Degree course	5. What is the highest course you are enrolled in?
2. USABILITY of UMA libraries	Library use	6. Do you ever use library seating?
	Most used library	7. If you answered "yes" to the previous question, please indicate which library you use most often.
	Frequency of use outside exam periods	8. How often do you use library seating outside of exam periods?
	Frequency of use during exam periods	9. How often do you use seating in any of the libraries during exam periods?
	Availability of seats during exam periods	10. Do you usually find it difficult to find an available seat in the library you would like to use during exam periods?
3. PREVIOUS EXPERIENCE using online reservation systems	Previous experience using online reservation systems	11. Have you ever used an online seat reservation system in any type of space (library, cinema, etc.) before?
	Types of spaces in which online reservation systems have been used	12. If you answered "yes" to the previous question, please indicate in which types of spaces you have used reservation systems (multiple answers possible).
	Opinion on the effectiveness of online reservation systems vs. reserving with objects	13. Do you think that online reservation systems are more effective than placing an object on the seat as a sign of occupancy?
4. QUALITY of the Biblio-Smart seat reservation system	Usefulness	14. It is useful for the user.
	Suitability for use	15. It is suitable for use (choice of seat to be reserved).
	Attractiveness	16. It is attractive for optional consultation.
	Excellence	17. It is a mark of excellence for the institution that offers it because it is based on high standards.
	User satisfaction	18. It meets the needs and the requirements of the user.
5. INTEREST in the consultation information for reservations offered by Biblio-Smart	2D and 3D views of the BIM model	19. Visualization of the 2D and 3D views of the virtual model.
	Real-time color codification of seat occupancy	20. Real-time color-coded visualization of seat occupancy (red = occupied, amber = reserved and green = free).
	Summary table of data of interest for the reservation linked to the BIM parameters of each seat	21. Consultation of data of interest for the reservation in the summary table of each seat, such as availability of power outlets, distance to bathrooms or subjects of nearby shelves.
	Daylight simulation videos extracted from the BIM model	22. Visualization of the daily changes in sunlight exposure for the seats available in daylight simulation videos with date and time.
	360-degree interactive panoramas of the BIM model from each seat.	23. Using 360-degree interactive panoramas to see virtual representations of the virtual model from each seat.
	Interaction in A360 with the virtual reality of the BIM model of the building.	24. Interactive virtual reality visualization of the building in A360 that offers the possibility of orbiting it, enlarging it, sectioning it, creating personalized tours, etc.
	Consultation of the properties of the BIM model elements in A360.	25. Personalized query of the properties of the virtual model elements in A360, such as the characteristics of each seat or the subjects of the shelves.
	Explanatory video of the system with a virtual tour of the BIM model included.	26. Visualization of the explanatory video of how to use the system and an overview of the library, showing a virtual tour of the building.

	Relative quality	27. Its quality is better.
6. COMPARISON of Biblio-Smart with respect to other reservation systems used	Relative interest	28. The degree of interest it arouses is higher.
	Relative efficiency	29. It has greater efficiency (relation between the result achieved and the resources used).
	Relative effectiveness	30. It has greater effectiveness (ability to achieve the expected effect or result).
	Relative functionality	31. It has greater functionality (characteristics that make something practical).
	Relative ease of understanding	32. It is easier to understand.
	Relative attractiveness	33 It is more attractive (quality of pleasing or attracting attention).
	Relative innovation	34. It has a higher degree of innovation (action of changing things by introducing something new).
	Relative motivation	35. Motivation for optional consultations is greater.
	Relative versatility of use	36. It is more versatile to use (for building management, virtual tours, etc.).
	Relative adaptability	37. Its adaptability to other types of spaces or to changes in requirements (such as not offering reserved seating less than 1.5 m apart) is greater.
	Relative personalization	38. It has greater personalization and consideration of the diversity of user needs (personalized queries, interactive 360-degree tours and views and specific data on seats).
	Relative completeness	39. Its completeness (quality of being complete) is greater.
	Relative overall satisfaction	40. Overall satisfaction with it is higher.

After grouping the questions according to the dimensions and subdimensions defined in the concept operationalization proposal table, the data obtained were analyzed with the SPSS program and can be consulted in the results section.

Once these results were obtained, a comparison was made of the mean values obtained in each of the main subdimensions analyzed to evaluate the system (quality, interest and comparison). With these scores, the mean value of each dimension was calculated on a Likert scale from 1 to 5, and in this way, they could be compared with each other and obtain a global vision of the opinion of those surveyed about the Biblio-Smart system.

Next, through graphs, the entire variation range was analyzed from the minimum to the maximum, with the probable variation range and a typical value of each of the three main dimensions analyzed, in addition to their quartiles. This allowed identifying the mean values and the dispersion of the data set, including the signs of asymmetry. Moreover, with these data, the variance and standard deviation of the three main variables were calculated.

As noted previously, the initial analysis strategy in this work had an exploratory and descriptive function, presented through univariate and bivariate analyses, which was complemented by exploratory factorial analysis, which made it possible to identify the factors that configured the uses and utilities of the Biblio-Smart seat reservation system and confirm the proposed theoretical model with the results obtained.

2.2.6. Biblio-Smart Prototype Feedback Design

Finally, a discussion and conclusions phase is designed by presenting the most outstanding results of the research, the limitations detected, the researchers' perception of the challenges and benefits to support the improvement of the application and the possibilities expansion of the system for future studies.

3. Results

This section presents the results of implementing and evaluating the Biblio-Smart prototype.

3.1. Results of Implementing the Biblio-Smart Prototype

As a result of the development of the Biblio-Smart prototype, Figure 10 shows the app interface that appeared when a user selected the option "check seat information" (Supplementary Materials S1). Clockwise in the figure are (1) a link to the BIM model on Autodesk A360, a central workspace in the cloud for projects, allowing users to interact with the library building and view the parameters of any element in the model BIM (Supplementary Materials S2), (2) links to the videos of the monthly solar analysis of the interior of the room where the selected seat was located to check the hours during which the sun hit the seats next to the windows (Supplementary Materials S3), (3) a link to the video tutorial for the use of the system, which includes a virtual tour of the library for new users (Supplementary Materials S4), (4) a data summary table of interest for booking, connected with the BIM model, and (5) a spherical image that allowed the user to rotate the rendered scene 360 degrees around the selected seat on the screen via a link to its URL (Supplementary Materials S5).

Figure 10. Biblio-Smart app interface designed to consult information of interest for the reservation from BIM model data, with its expanded options and icons of the file format or tool used.

It should be noted that the use of the BIM model as a relational database, as used in this case study, opens the door to multiple configuration options for the reservation system with a different approach than the informed choice of seat for online reservation by users, as was already mentioned in the introduction. To verify the simplicity of the approach, we present here an experiment in which, hypothetically, other restrictions associated, in this case, with requirements of the building manager to guarantee compliance with the regulation of use were imposed on the developed system.

Let us take as an example the situation experienced during the course of the COVID-19 pandemic, when the need was detected for the distribution of occupiable seats to meet social distancing restrictions and comply with the health regulations in force at any given time. Within the framework of this situation, this research experimented with the possibility of offering, through the reservation app, a dynamic occupancy model based on compliance with current separation distance restrictions. Thus, for example, all seats were initially shown as free, and each time a user reserved a seat, the programming

recalculated the optimal configuration of available study stations that met the condition of being at a distance greater than 1.5 m from the newly reserved seat and those already occupied, as required by Spanish regulations. This information was provided as parameters to the Revit model, which was automated to graphically display parametric changes through filters, as shown in Figure 11. New custom algorithms were created using Dynamo with the help of Python scripts which fulfilled social distancing restrictions such that they were adaptable to compliance with current regulations.

(**a**)   (**b**)
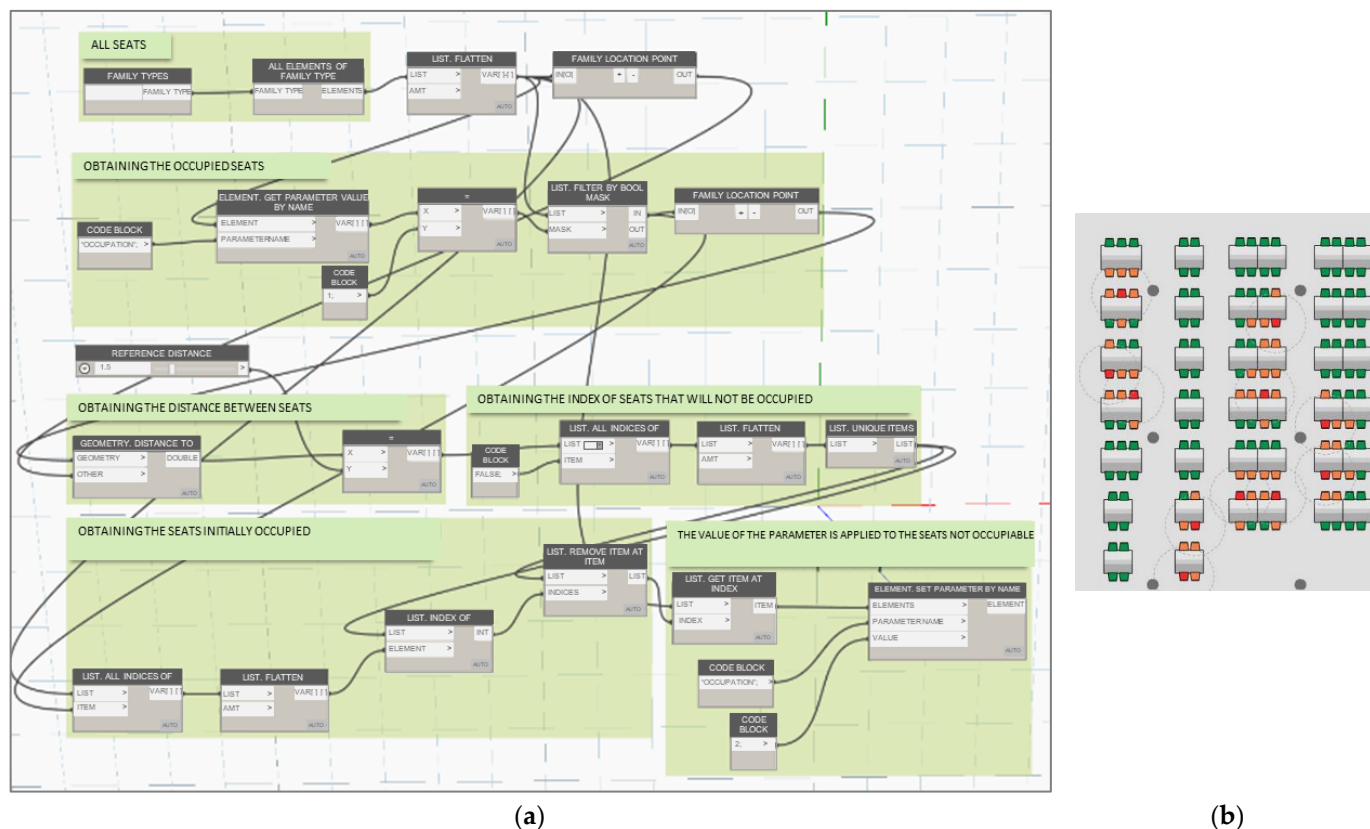
Figure 11. (**a**) Example of programming with Dynamo to simulate the optimal occupancy of seats complying with the social distancing regulations during the pandemic and (**b**) floor plan view of the occupancy status complying with the programmed distance restriction between users, indicated by 1.5-m radius circumferences over the occupied seats.

The consideration of the model as a relational database was based on the fact that the information related to the distance between the seats was already intrinsically contained in the model, as can be seen in the example contained in the video provided as a supplementary material (Supplementary Materials S6). However, since there was no parameter for each seat element that showed the distance between them, this also had to be calculated. Therefore, the first step was to determine which of the hundreds of possible seating options that met this distance specification offered the maximum possible seating capacity. Once the optimal distribution was chosen, this information from the model was linked to the system application so that the app only offered those seats as available for reservation (green) and showed the rest as not available (amber).

In this way, the potential of the parameterization offered by BIM for occupancy control systems was tested, given its versatility and adaptation to each specific case, establishing different types of restrictions using a similar methodology.

3.2. Results of Evaluating the Biblio-Smart Prototype

This section presents the most relevant results of the analyses carried out to evaluate the Biblio-Smart protopype.

3.2.1. Population and Sample

Table 3 shows the distribution of the percentages of responses to the questionnaire, according to the branches of knowledge that make up the UMA's study offerings, in relation to the number of students enrolled in each branch and the total number of students enrolled in UMA degree programs. As can be seen, sample responses were obtained from undergraduate students and regular users of the UMA General Library from each branch of knowledge and with a reasonable percentage in each of them.

Table 3. Percentage of responses to the survey according to percentage of enrolled students in each branch of knowledge at the University of Malaga (UMA).

| Branch of Knowledge	UMA Faculty or School	Number of Students Enrolled in UMA Degrees	% Enrolled in Degrees Compared to Total by Branch	% Responses to Survey by Branch
Arts and Humanities	Faculty of Fine Arts	392	11.6	12.4
	Faculty of Philosophy and Letters	3154		
Social and Labor Sciences	Faculty of Communication Sciences	1647	46.2	24.4
	Faculty of Education Sciences	2930		
	Faculty of Economics and Business Sciences	3330		
	Faculty of Commerce and Management	1568		
	Faculty of Law	1982		
	Faculty of Social and Labor Sciences	1892		
	Faculty of Tourism	779		
Health Sciences	Faculty of Health Sciences	1375	12.9	24.9
	Faculty of Medicine	1087		
	Faculty of Psychology and Speech Therapy	1491		
Sciences	Faculty of Sciences	2330	7.6	17.1
Engineering and Architecture	School of Industrial Engineering	3705	21.7	21.2
	Higher Technical School of Architecture	437		
	Higher Technical School of Telecommunications Engineering	1057		
	Higher Technical School of Computer Engineering	1448		
Totals	**17**	**30,604**	**100.0**	**100.0**

As already stated in the section on evaluation methodology, the survey's target population was limited to "UMA members who regularly use seats in the study rooms of its General Library", composed of 1200 individuals (N). On the other hand, the minimum sample size to obtain statistically significant results, depending on the number of study subjects, had to be between 20% and 30% of the target population.

In this case, 242 complete responses were obtained, corresponding to members of the study group who voluntarily responded to the survey. Therefore, the sample was representative, since it corresponded to 20.17% of the total population of interest, which allowed results to be generalized.

3.2.2. Profile of Questionnaire Respondents

To contextualize the results obtained, the basic profile of the participants is presented in Figure 12. The questionnaire was answered in its entirety by UMA students and regular users of the General Library to a greater extent by women (66.5%) than by men (33.5%). A total of 69.7% of the participants were between 18 and 22 years of age, and the majority were in their first (33.6%) or second year (22.0%) of their degree programs. As

displayed in the following chart, participation by women was higher in the branches that tended to be female-dominated in health sciences and arts and humanities.
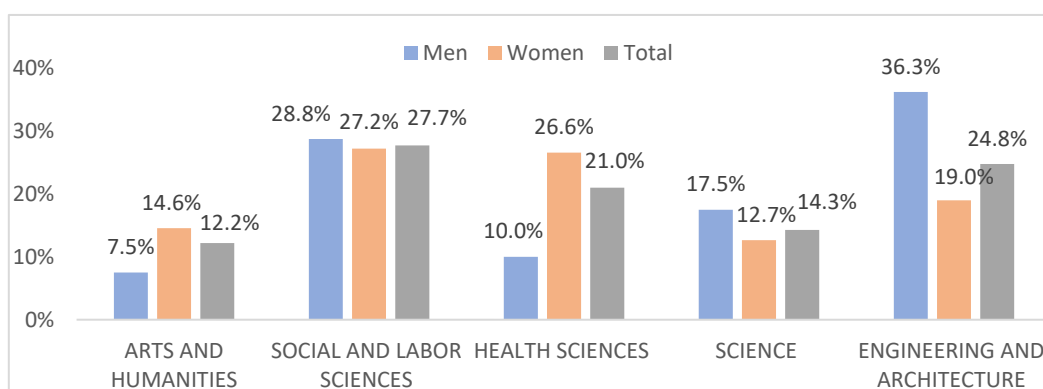
Figure 12. Percentages of answers obtained according to branch of study and gender.

3.2.3. Usability of UMA Libraries

As can be deduced from Table 4, the frequency of use of UMA libraries was influenced by the exam variable. Accordingly, while outside of exam periods, 42.3% of those surveyed used reading posts in UMA libraries only a few times each term, while during exam periods, half of them (49.8%) did so almost every day.

Therefore, most of the students consulted (78.7%) stated that they had difficulties finding available seats in the UMA libraries at exam time, as indicated in Table 4. The degree of difficulty in finding available seats during exam periods was high in all the UMA libraries and was 88.6% in the General Library.

Table 4. Difficulty in reserving a seat during exam periods according to the most commonly used UMA libraries.

Name of the Library	Yes	No
General Library	**88.6%**	**11.4%**
Humanities Library	84.6%	15.4%
Computer Science and Telecommunications Library	92.9%	7.1%
Industrial Engineering Library	87.5%	12.5%
Medicine Library	90.9%	9.1%
Tourism Library	50.0%	50.0%
Architecture and Fine Arts Library	58.8%	41.2%
Science Library	91.2%	8.8%
Communication Sciences Library	100.0%	0.0%
Education Sciences and Psychology Library	88.9%	11.1%
Economics and Business Sciences Library	68.0%	32.0%
Law Library	100.0%	0.0%
Social and Labor Sciences Library	75.0%	25.0%
Total	**78.7%**	**21.3%**

3.2.4. Previous Experience Using Online Reservation Systems

Contrary to expectations, 36.9% of the university students had never used an online seat reservation system in any space (cinema, airplane, etc.), as shown in Figure 13. Of these, almost all were between 18 and 22 years (62.9%), compared with those aged 23 to 27 years (24.7%).
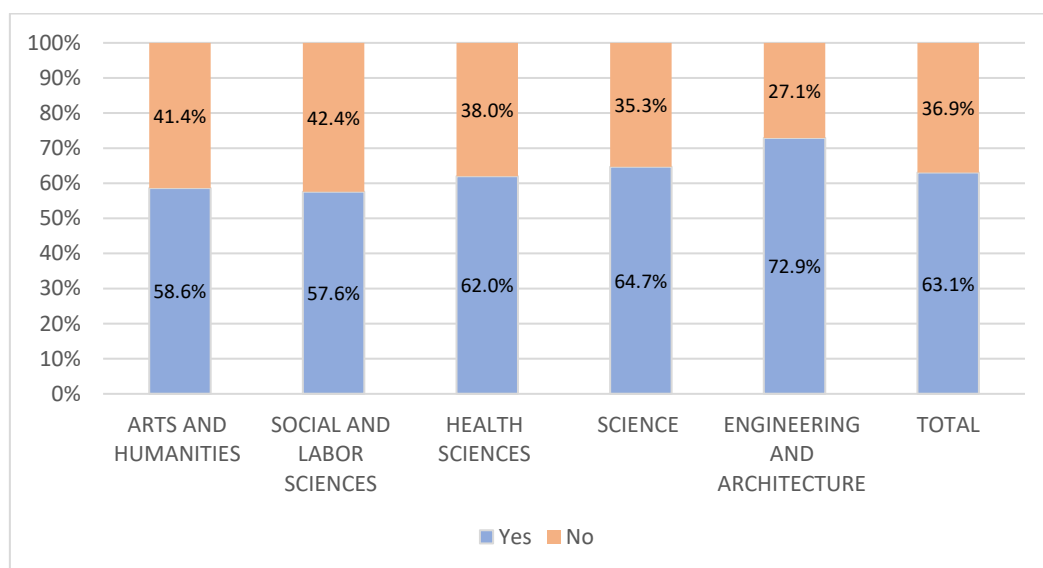
Figure 13. Percentage of use of an online seat reservation system according to branch of study.

Among the students who had used some type of online seat reservation system (63.1%), a large majority (88.3%) considered it more effective than placing objects on the seats to indicate occupancy. The spaces with seat reservation systems most used by university students were cinemas, theaters, auditoriums and other similar venues (82.1%) as well as public transport (80.8%), followed by restaurants (44.9%) and sports stadiums (28.8%), with libraries or study rooms in second-to-last place (17.3%), only ahead of meeting rooms and coworking spaces (9%).

3.2.5. Quality of the Biblio-Smart Prototype

An elevated percentage of the students surveyed positively assessed the information provided by the Biblio-Smart prototype. More than 70% believed that it was useful for the user, suitable for the choice of seat to be reserved, pleasing to consult, a mark of excellence for the institution that offers it, and that it met the needs and requirements of the user. Figure 14 illustrates this positive evaluation, with special emphasis on the suitability of the system for choosing the seat to be reserved (85.7) and the usefulness for the user (84.9%).
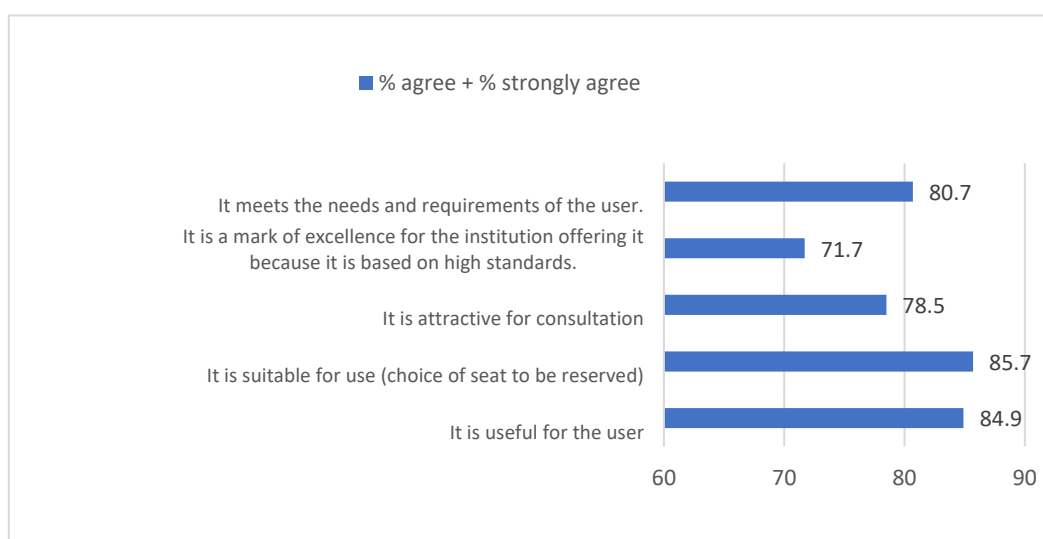
Figure 14. Assessment of the quality of the Biblio-Smart prototype.

3.2.6. Interest in the Consultation Information for Reservations Offered by Biblio-Smart

Concerning the assessment of the interest shown in the Biblio-Smart consultation options, the results obtained were positive, as illustrated in Figure 15. Overall, more than 60% of those surveyed in the eight proposed indicators considered them to be interesting or very interesting. Of these, the most highly rated indicators were the real-time color-coded display of seat occupancy (90.7%) and the visualization of information of interest for choosing a seat, which was associated with each seat (90.3%).
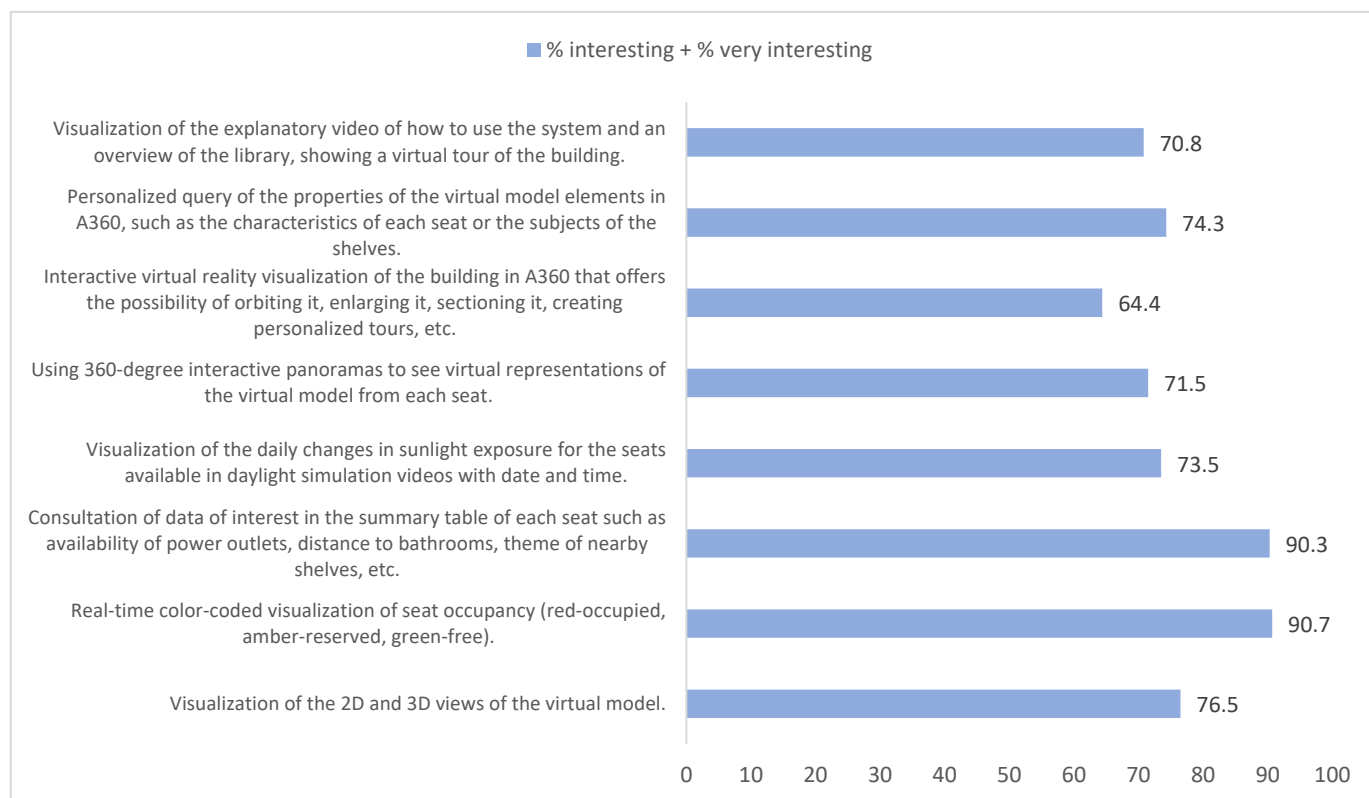
Figure 15. Degree of interest in the visual information offered by Biblio-Smart applying BIM.

3.2.7. Comparison of Biblio-Smart with Other Reservation Systems Used

The evaluation of the characteristics of the information displayed by the Biblio-Smart seat reservation system was conducted using a list of 14 statements on a scale from 1 (strongly disagree) to 5 (strongly agree). As indicated in Table 5, all received a very positive assessments (between 3.86 and 4.23) by the respondents.

Table 5. Comparative assessment of Biblio-Smart compared with other reservation systems used.

Statements	% Agree + % Strongly Agree
Its quality is better.	71.2%
The degree of interest it arouses is higher.	76.8%
It has greater efficiency (relation between the result achieved and the resources used).	65.3%
It has greater effectiveness (ability to achieve the expected effect or result).	68.1%
It has greater functionality (characteristics that make something practical).	75.1%
It is easier to understand.	66.0%
It is more attractive (qualities that are pleasing or attract attention).	78.2%
It has a higher degree of innovation (the action of changing things by introducing something new).	83.2%

Motivation for optional consultation is greater.	77.6%
It is more versatile to use (ability to adapt quickly and easily to different functions).	76.3%
Its adaptability to other types of spaces or to changes in requirements (such as not offering reserved seating less than 1.5 m apart) is greater.	78.1%
It has greater personalization and consideration of the diversity of user needs (offering personalized consultations, interactive 360-degree tours and views and specific data for each seat).	75.8%
Its completeness (quality of being complete) is greater.	78.1%
Overall satisfaction with it is higher.	75.9%

Based on the above considerations, four characteristics can be highlighted as receiving particularly high ratings: degree of innovation was the most appreciated aspect (83.2%), followed by attractiveness (78.2%), adaptability to other types of spaces or changes in requirements (78.1%) and completeness (78.1%), all of which were superior to similar applications. Furthermore, as reflected in Table A5, 75.9% of those surveyed agreed or strongly agreed that overall satisfaction with the Biblio-Smart reservation system was greater than that with other systems used.

3.2.8. Comparison between the Mean Values of the Main Subdimensions for the Evaluation of the System, Considering Their Standard Deviations

Table 6 shows a comparison of the mean values obtained in each of the main subdimensions analyzed to evaluate the system. With these scores, the mean value of each dimension was calculated on a Likert scale from 1 to 5, and in this way, they could be compared with each other, and an overall view of the respondents' opinions of the Biblio-Smart system could be obtained.

Table 6. Comparison of mean values obtained in each indicator and in each of the three main dimensions analyzed.

Dimensions	Subdimension	Average of Indicators	Average of Dimensions
QUALITY of the Biblio-Smart seat reservation system (1 = totally disagree and 5 = totally agree)	Usefulness	4.30	**4.18**
	Suitability for use	4.26	
	Attractiveness	4.12	
	Excellence	4.04	
	User satisfaction	4.18	
INTEREST in the consultation information for reservations offered by Biblio-Smart (1 = very uninteresting and 5 = very interesting)	2D and 3D views of the BIM model	4.09	**4.16**
	Real-time color codification of seat occupancy	4.55	
	Summary table of data of interest for the reservation linked to the BIM parameters of each seat	4.54	
	Daylight simulation videos extracted from the BIM model	4.14	
	360-degree interactive panoramas of the BIM model from each seat	4.19	
	Interaction in A360 with the virtual reality of the BIM model of the building	3.76	
	Consultation of the properties of the BIM model elements in A360	4.03	
	Explanatory video of the system with a virtual tour of the BIM model included	3.,96	
COMPARISON of Biblio-Smart with other reservation	Relative quality	3.95	**4.04**
	Relative interest	4.09	
	Relative efficiency	3.86	

systems used		
(1 = totally disagree	Relative effectiveness	3.93
and 5 = totally agree)	Relative functionality	4.06
	Relative ease of understanding	3.87
	Relative attractiveness	4.10
	Relative innovation	4.23
	Relative motivation	4.07
	Relative versatility of use	4.07
	Relative adaptability	4.10
	Relative personalization	4.07
	Relative completeness	4.13
	Relative overall satisfaction	4.09

Thus, the analysis of the average scores obtained shows that the respondents assessed the quality of the Biblio-Smart system positively (an average of 4.18 out of 5), they showed great interest in the information it offered (an average of 4.16 out of 5), and they considered it comparatively superior to the other reservation systems used (an average of 4.04 out of 5).

Next, the box plots in Figure 16 show the entire range of variation from the minimum to the maximum, the probable range of variation and a typical value for each of the three main dimensions analyzed. Thus, each of the three boxes visually represents the data corresponding to the minimum, the first quartile, the median (second quartile), the third quartile and the maximum in ascending order. This makes it possible to quickly and easily identify the mean values as well as the spread of the data set, including signs of skewness.
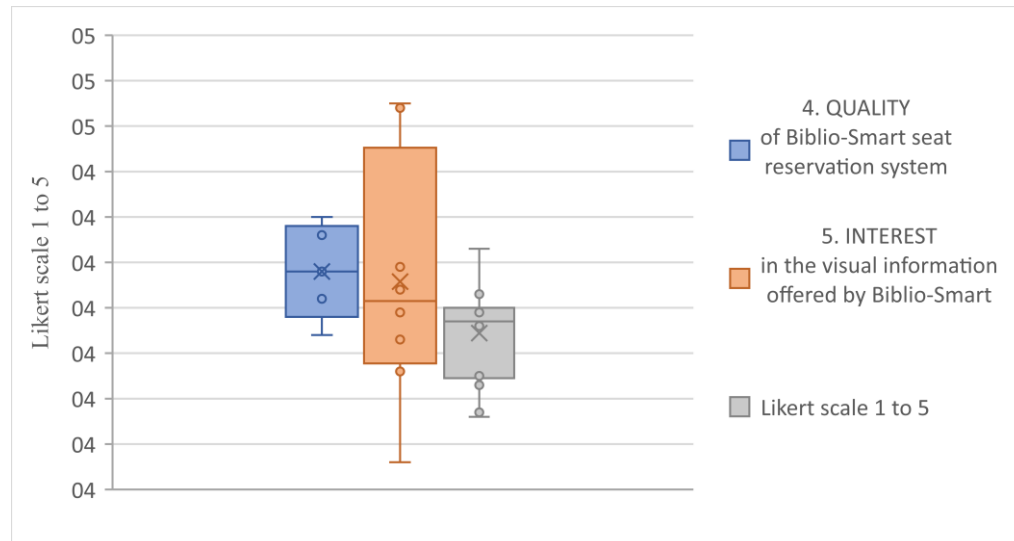
Figure 16. Comparative box plots of data of interest on the three main dimensions analyzed (minimum, first quartile, median, third quartile, maximum, etc).

With the data obtained, the variance ($\Sigma\,(\chi - \mu)2/N$) and the standard deviation (σ) of the three main variables were calculated using the following formula, where x is the data obtained in each subdimension, μ is its arithmetic mean and N is the amount of data:

$$\sigma = \sqrt{\frac{\Sigma\,[x - \mu]^2}{N}}$$

As can be seen in Table 7, in the three dimensions analyzed, the standard deviation and the variance data were very low, which indicates that the values were close to each

other and close to the mean. Among the three variables, the responses to "interest in the information for reservations offered by Biblio-Smart" had the highest dispersion value (0.25), although their difference with respect to the other two variables did not exceed 0.16 points in the standard deviation or 0.05 points in the variance, which is not relevant due to the lack of concentration of the observations around the mean.

Table 7. Summary of indicators of the three variables analyzed, including their standard deviations.

	Quality of the Biblio-Smart Seat Reservation System	Interest in the Consultation Information for Reservations Offered by Biblio-Smart	Comparison of Biblio-Smart with Other Reservation Systems Used
MEAN	**4.18**	**4.16**	**4.04**
Minimum	4.04	3.76	3.86
First quartile	4.08	3.98	3.95
Median	4.18	4.12	4.07
Third quartile	4.28	4.45	4.10
Maximum	4.30	4.55	4.13
Variance	0.01	0.06	0.01
STANDARD DEVIATION	**0.09**	**0.25**	**0.10**

In summary, the results of validating the method showed quite similar mean scores, which evaluated the system as having a score always higher than 3.75 out of 5 and a low deviation in the responses from their mean or expected values. This indicates that the Biblio-Smart reservation system was rated as outstanding by a representative sample of the population and that this result was consistent.

3.2.9. Exploratory Factor Analysis

The objective of this section is to explore whether the instrument used allows us to differentiate between different evaluations of the Biblio-Smart system and, if so, whether it can be said to manifest itself differently depending on the COMPARISON, INTEREST and QUALITY dimensions. To accomplish this, with the 27 items of the survey referring to these three dimensions, an exploratory factorial analysis of the principal components with varimax rotation was carried out with the SPSS program, resulting in an optimal model with 72.61% explained variance.

The Kaiser–Meyer–Olkin (KMO) sample adequacy test obtained a value greater than 0.9, so it can be said that the data matrix was quite appropriate for factoring. In addition, as shown in Table 8, the significance test of the Bartlett sphericity test was significant (0.000).

Table 8. KMO and Bartlett tests.

Kaiser–Meyer–Olkin Measure of Sample Adequacy		0.934
Bartlett's sphericity test	Approximate chi-squared	4333.660
	Gl	351
	Sig.	0.000

Table 9 shows the four factors detected by the analysis that met the criteria of having eigenvalues or eigenvalues greater than unity. The four factors, as already indicated, explained 72.61% of the variance, with the first being the most important (51.91%) and precisely the factor that grouped all the indicators of the COMPARISON dimension of Biblio-Smart with the other reservation systems used.

Table 9. Total explained variance.

Factor	Initial Eigenvalues			Sums of the Squared Loadings of the Extraction		
	Total	% Variance	% Accumulated	Total	% Variance	% Accumulated
1	14.017	51.914	51.914	14.,017	51.910	51.914
2	2.727	10.099	62.013	2.727	10.100	62.013
3	1.640	6.073	68.086	1.640	6.070	68.086
4	1.222	4.524	72.610	1.222	4.520	72.610

The results in this table came from the principal component analysis extraction method.

Table 10 shows the component matrix that reports on the unique contribution of each item to the corresponding factor. To obtain it, it was decided to apply a varimax rotation, since it usually provides good convergence and easily interpretable factorial solutions [59].

Table 10. Matrix of rotated components.

Factors and Items	1	2	3	4
	Comparison	Interest A	Quality	Interest B
4a. Usefulness	0.439	0.156	**0.710**	0.258
4b. Suitability for use	0.350	0.148	**0.763**	0.192
4c. Attractiveness	0.470	0.240	**0.668**	0.120
4d. Excellence	0.412	0.194	**0.713**	0.009
4e. User satisfaction	0.399	0.120	**0.752**	−0.080
5a. 2D and 3D views of the BIM model	0.315	**0.641**	0.193	0.193
5b. Real-time color codification of seat occupancy	0.138	0.241	0.043	**0.832**
5c. Summary table of data of interest for the reservation linked to the BIM parameters of each seat	0.060	0.050	0.145	**0.879**
5d. Daylight simulation videos extracted from the BIM model	0.173	**0.779**	0.069	0.072
5e. 360-degree interactive panoramas of the BIM model from each seat	0.322	**0.804**	0.121	0.046
5f. Interaction in A360 with the virtual reality of the BIM model of the building	0.147	**0.895**	0.054	−0.034
5g. Consultation of the properties of the BIM model elements in A360	0.161	**0.798**	0.095	0.155
5h. Explanatory video of the system with a virtual tour of the BIM model	0.164	**0.679**	0.216	0.061
6a. Relative quality	**0.793**	0.275	0.207	0.081
6b. Relative interest	**0.721**	0.220	0.347	0.111
6c. Relative efficiency	**0.765**	0.262	0.224	−0.045
6d. Relative effectiveness	**0.808**	0.160	0.205	0.076
6e. Relative functionality	**0.789**	0.251	0.191	0.099
6f. Relative ease of understanding	**0.766**	0.297	0.116	−0.030
6g. Relative attractiveness	**0.774**	0.167	0.253	0.081
6h. Relative innovation	**0.734**	0.062	0.355	0.280
6i. Relative motivation	**0.769**	0.159	0.345	0.077
6j. Relative versatility of use	**0.778**	0.257	0.291	−0.004
6k. Relative adaptability	**0.758**	0.105	0.374	0.058
6l. Relative personalization	**0.777**	0.257	0.225	0.144
6m. Relative completeness	**0.789**	0.111	0.290	0.121

6n. Relative overall satisfaction	**0.799**	0.207	0.290	0.014

The results in this table came from the principal component analysis extraction method and the varimax rotation method with Kaiser normalization, converging the rotation in six iterations.

The factorial solution offered indicates the existence of four factors grouping all the variables included in the analysis and, in all cases, with factorial loads greater than 0.6. The first was made up of the 14 items of the COMPARISON dimension (from P6a to P6n). The second appeared to be formed by six of the eight specific items of INTEREST, called INTEREST A (P5a, P5d, P5e, P5f, P5g and P5h), appearing as a new fourth factor of said dimension, called INTEREST B, which contained the remaining two items (P5b and P5c). This nomenclature differentiation between both factors was due to the fact that the INTEREST B eigenvalues were scored higher than those in the INTEREST A factor. The third factor that configured the evaluations of the Biblio-Smart system was composed of the five specific items of the QUALITY dimension (from P4a to P4d).

It seems reasonable to think that the differences in valuations between the factors of INTEREST were because the items corresponding to "INTEREST B" (P5b (color attributed to the state of occupation of the seat) and P5c (summary table of data of interest of each seat)) presented two characteristics different from the rest. On the one hand, there is the quick display of one's information in the app without the need to use links, as occurs in the others (P5a, P5d, P5e, P5f, P5g and P5h). On the other hand, there is the general usefulness of its content for the majority of users, while the remaining options could be considered as complementary information for a more restricted audience, rendering them less in a hurry when booking and wanting to consult specific aspects related to their personal needs.

These results therefore allowed us to identify four ways or expressions of evaluation of the Biblio-Smart system corresponding to COMPARISON (factor 1), INTEREST A at the level of general information (factor 2), INTEREST B at the level of specific information (factor 4) and a QUALITY level (factor 3). Moreover, if the sign of the factorial scores is observed, then the four factors can be interpreted positively.

4. Discussion and Conclusions

To begin, certain limitations of the project will be presented before continuing with a discussion of the results and final conclusions.

The first limitation is related to the system chosen for hosting and showing the BIM model to the users: Autodesk A360. Although the reasons for choosing Autodesk A360 were explained in the Materials and Methods section, it should be mentioned that budgetary factors were also decisive for the project, which led to the use of free services. Therefore, for the implementation of the system in the rest of the UMA libraries, the use of Autodesk Forge is planned. This is because this cloud platform, made up of a set of web service application programming interfaces (APIs), enables the creation of custom applications, automating processes and accessing data and the models hosted in the Autodesk cloud more efficiently. This will improve the update of the BIM model in response to each scheduled task in the C# language to optimize the workflow and real-time data visualization in the reservation system app.

As for limitations, it is also worth mentioning other functions proposed during the research process that ultimately were not included in the prototype due to budgetary limitations but are expected to be implemented in the future. The first one was the integration into the device of a decibel measurement system and another LED (flashing blue light) that would serve as a visual warning indicator to the occupants of a table of having exceeded the noise level allowed in the library and to keep silence or reduce noise. This module would also help librarians to follow established protocols if, on their control screens, an excessive noise alert appeared several times at the same table. Another option considered was the possibility of incorporating a lighting controller to automatically turn off the lights of unoccupied tables. It was also suggested to include an algorithm for

suggesting seats based on the interests specified by the user. These could be of a physical nature (level, area, close proximity to the subject of the books to be consulted, etc.) or even the type of user (undergraduate, master's or doctorate students, researchers, professors, etc.). This would facilitate detection by the managers of the characteristics preferred by the users, which would allow making informed decisions when prioritizing between types of improvements to be made in the enclosure and would also allow the detection of priority areas by groups, which would make it possible to restrict or enable a minimum number of seats in certain rooms or areas for use by certain occupant profiles.

On the other hand, the option of associating a study planning system with the job reservation system was proposed. In other words, given that it is possible to count the hours of library use with this system as well as the dates on which they take place, another innovation could consist of linking the reservation app with another programming app, which would allow students to plan their study schedules based on the dates of their exams. Likewise, as the designed system was linked to the BIM model of the space where the device was located, there are other information options that can enrich the virtual model and be linked to the reservation system application. For example, it would be feasible to insert families with a low level of detail into the model which are associated with each book in the library. Thus, as in a BIM project, each element has a unique identifier (id) associated with it, and each id could be associated with its corresponding reference in the library database. This would allow options such as a virtual 2D or 3D visualization of the location of each volume to speed up the location of the copies to be consulted by users or to be replaced and inventoried by library staff.

This prototype was developed to test its effectiveness with a view toward future implementation of the system in the rest of the UMA libraries. Thus, it has been designed so that the management of the system in each library can be carried out individually and independently. Consequently, this means that it could even be used to send communications to the users of each particular center and establish differentiated reservation times based on the degree of occupation of each library or the exam dates of each faculty or school, for example.

As discussed in the background section, currently existing systems do not usually detect the abandonment of a seat until its occupant leaves the library. The solutions devised to evaluate this task are too expensive to be borne by universities. Therefore, it is also important to note that the Biblio-Smart system is not only capable of managing reservations both remotely and in person but also controlling seat occupancy in real time, allowing web service managers to define a period of time during which users can take breaks without losing their reservations. This is an important added value for the optimization of the management of spaces during peak times which could be widely implemented in other systems.

Requiring users to identify themselves in order to use the institutional application, both for online and in-person seat reservations, by scanning the QR code of the study station with the QR code reader of the UMA app prevents fraudulent use of the facilities by people who are not members of the UMA, as occurs with the use of cards. Moreover, as it is integrated into the official application used by all students enrolled in the UMA, all of them have easy access to the reservation module, avoiding the need for new installations.

Unlike other systems, programming in DUAL allows its use through two different wireless connection technologies, such as Wi-fi and BLE. First of all, the possibility of using Bluetooth technology allows multiple devices to be paired simultaneously with a single device, which reduces costs. However, in addition, programming in DUAL gives the system a comparative advantage over others using Bluetooth technology for two reasons. The first is the battery savings that this entails, and the second is that since it is not necessary to use the smartphone's Bluetooth to maintain pairing, it can be used to pair the phone with other devices such as watches, handsfree devices or headsets.

Apart from this, the increased comfort for the user that the incorporation of USB connections in the physical device means cable recharging of portable devices, which also prevents the smartphone's occupant from running out of battery and unpairing from the device. Moreover, as a result of its design and the use of a single, inexpensive small computer included in the hardware, which serves six workstations, manufacturing costs and energy consumption are reduced, optimizing management costs.

Regarding the survey conducted to evaluate the Biblio-Smart prototype, several aspects should be noted. The difficulty of locating vacant seats, especially during exam periods, a time when library use soars, underscores the need for an efficient reservation system. The results support the usefulness, suitability for use, attractiveness, excellence and user satisfaction, qualities that support the Biblio-Smart prototype´s quality and efficiency. When compared with other similar booking applications, the survey shows its general comparative superiority with respect to other reservation systems previously used by the respondents, with the most valuable aspect recognized by students being its degree of innovation.

Likewise, the results of the univariate and bivariate analysis suggest that the quality of the information offered to users to consult information of interest regarding reservations, using BIM methodology, provides an optimal representation of the data necessary for personalized seat selection. Among the information query options most valued by the respondents, the following stand out: the summary table of data of interest for reservations linked to the BIM parameters of each seat (4.54 out of 5), the 360-degree interactive panoramas of the BIM model from each seat (4.19 out of 5) and the consultation of the properties of the BIM model elements in A360 (4.03 out of 5). It was also verified that the virtual tour embedded in the explanatory video of the system (Supplementary Materials S5) was quite useful, possibly because most of the respondents were students enrolled in their first two years of study who, therefore, had limited knowledge of the physical facilities of the library.

The exploratory factorial analysis has made it possible to detect the Biblio-Smart system's strengths based on the assessments. Thus, the existence of four configuration factors of the evaluation made by the users of said system with respect to its quality, interest and comparison with other reservation systems has been shown. The first is COMPARISON, the second INTEREST A at the level of general information, the third is QUALITY, and the fourth INTEREST B at the level of specific information. It has also been verified that the evaluations related to INTEREST at the level of general information are better valued than the level of specific information, because they contain information related to the reservation of direct visualization without the need to use links and general utility for most of the users.

In short, all the reasons stated above demonstrate that the Biblio-Smart system is a utility model for real-time management of occupancy and reservations in university libraries and, by extension, in other free-entry spaces of institutional buildings, which guarantees maximum efficiency at the minimum cost.

Extending the use of BIM models from the construction process to the management of the building (6D) also contributes to the optimization of the human dimension of comfort, as it expands efficiency to a greater extent from more traditional energetic approaches. It not only introduces advances in the state of the art of occupancy management, but it also opens innovative lines of research. It can be concluded that the adaptability of the BIM model as a relational database in multiple fields makes possible the development of many new uses in which it can be exploited, as shown in the example of seat occupancy, to comply with the different social distancing restrictions imposed during the course of the COVID-19 pandemic. Moreover, extending the centralized control of buildings will undoubtedly lead to more efficient management of buildings. For example, as described earlier, the system could easily be configured to optimize lighting, heating, ventilation and air conditioning (HVAC) infrastructures by initially making seats available in just one room until the room reaches full capacity and only then al-

lowing reservations in the adjoining room which, in the meantime, would be without lighting or air conditioning. This method of progressive occupancy, combined with the sectorization of lighting and HVAC systems, would result in considerable savings in energy costs and finally in the optimization of the efficiency of these systems.

Additionally, if this model is designed for use in a public library, then its general structure and coding could be easily exported to many other free or paid environments or events. In fact, it would only require the implementation of a payment gateway as the last step in the process of reservation.

As a final remark, with the introduction of machine learning, the use of this system could allow the university institution to better understand the behavior and tastes of its members, to predict vacancies based on occupancy patterns and preferences and to offer personalized seats. BIM visualization could also be used to predict and offer vacancies based on occupancy preferences. Most importantly, it also opens the use of BIM models to ubiquitous real-time viewing by the public of the information stored in them, as the Biblio-Smart occupancy management system has shown.

This is an important added value for the optimization of the management of public spaces during peak times, which should be a general implementation in other systems. In fact, at the moment, only more expensive solutions are sometimes implemented for assessing this task, and reservations are often managed for a full period of time (morning and afternoon slots) and not for the real time each student is really occupying the seat. Another topic of interest is the possibility offered by the mobile application of reserving a seat through a login system, both remotely and in person, by scanning the QR code corresponding to the selected seat.

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