sustainability

Article

The Integration of HBIM-SIG in the Development of a Virtual Itinerary in a Historical Centre

Concepción López-González * and Jorge García-Valldecabres

Research Center for Architecture, Heritage and Management for Sustainable Development (PEGASO), Universitat Politècnica de València, 46022 Valencia, Spain; jgvallde@ega.upv.es

* Correspondence: mlopezg@ega.upv.es

Abstract: The continuous increase in cultural tourism, together with the deficient planning of public use, increases the risk of heritage resource degradation. Currently, there are collaborative methodologies enabling all the agents involved in the conservation of a heritage site to work in a coordinated way (HBIM), such as in the management of public use. However, in this study, through a review of the scientific literature, the lack of a method and tool that allows sustainable conservation management and the planning of cultural tourism of heritage assets in a specific geographical environment is demonstrated. The objective of this research is thus to explore and identify the possibilities of interoperability between HBIM and GIS for the development of a protocol aimed at synchronizing the information concerning heritage architecture across the management and cultural tourism planning and preventive conservation. This protocol was implemented for three monumental buildings in the historic centre of the city of Valencia (Spain). This novel protocol provides a new technological system that fosters the cultural development and preservation and conservation of heritage assets through a single tool integrating HBIM and GIS.

Keywords: HBIM-GIS-Tourism; heritage conservation; heritage management; management of cultural visits; digital twin

check for updates

Citation: López-González, C.; García-Valldecabres, J. The Integration of HBIM-SIG in the Development of a Virtual Itinerary in a Historical Centre. *Sustainability* **2023**, *15*, 13931. https://doi.org/10.3390/su151813931

Academic Editors: Laura Medeghini, Michela Botticelli and Alessandro Ciccola

Received: 17 August 2023
Revised: 8 September 2023
Accepted: 13 September 2023
Published: 19 September 2023

1. Introduction

Public bodies, scientific communities and society in general are becoming increasingly aware of the importance of the conservation of cultural heritage. The preservation of heritage assets implies strengthening the collective memory of a society and entails economic development linked to an ongoing increase in cultural tourism. However, in many cases, there is a lack of coordination in the management and planning of these assets, consistently demonstrated after the pandemic. This increase in public interest in cultural heritage, together with uncoordinated planning among the different sectors involved, such as heritage, urban planning and tourism, can result in an increase in the risk of heritage resource degradation [1].

It is therefore necessary to propose a management protocol that through technological means collaborates in resolving the above problem and advances the achievement of sustainable management. The research presented below is motivated by the need to find solutions that address the challenges posed above. As a test laboratory, the historic centre of the city of Valencia, one of the largest cities in Europe and among the most visited in Spain, was used.

The BIM methodology, applied to architectural heritage (HBIM), is a promising tool for the management and documentation of heritage assets. In 2009, Murphy et al. [2] assessed the advantages that BIM methodology provides to the study of architectural heritage, developing a parametric library of architectural elements based on classical architecture manuals. The scientific literature has since revealed the potential of HBIM for documenting existing buildings [3] and managing various aspects related to the maintenance and preventive conservation of property [4]. Recently, it has been found that HBIM offers a great capacity for the management of public use and, specifically, of cultural tourism [5].

However, HBIM exclusively documents and manages a single asset without considering the cultural, semantic and technical links and connections that it may have with other monuments or heritage sites that could be integrated into the same geographical area (municipal, regional, provincial, autonomous or national). In this sense, the GIS tool allows the management and analysis of information from different sources, linking this information with real locations, thereby achieving results related to statistical data, thematic maps, etc. [6]. Therefore, this tool, which has been developed and primarily used for several decades in the management of public land assets due to its versatility and effectiveness [7,8], constitutes the perfect complement for interoperating with BIM to carry out efficient cultural tourism planning. These digital twins, capable of containing semantic information about cities and historic centres, serve as a technology with great potentialities for the management and visualisation of cultural public visits and the risks that they entail. However, this tool's operability can be affected by an excessive accumulation of data, especially in regard to the management of geographical areas in the field of historic centres. Three-dimensional digital models of urban areas lack, in many cases, the ability to make changes automatically and efficiently. Visualisation, topology, geometry and level of detail (LoD) can be affected by these gaps.

This study therefore focuses on a specific part of this research project, an HBIM-GIS integration protocol that allows the interoperability of the geometric and semantic information related to the morphology of buildings to ensure comfortable cultural visits. The information implemented in HBIM and GIS includes data related to the flow of visitors and sensors, ensuring the sustainable conservation and effective management of heritage assets.

The integration of HBIM in GIS is being approached by some authors in certain architectural aspects, as its adaptation to the sphere of tourism management is pioneering. In the following analysis of the scientific literature, the method of Zupic and Čater [9] was followed to ensure objectivity and rigor.

Pavel Tobiáš [10] conducted a review of the scientific literature on the capabilities of HBIM and GIS, which was later completed by Xiucheng Yang et al. [11]. There is little information on the integration of both tools. In Italy, due to its large amount of heritage assets and its tradition of safeguarding its monuments, various studies have been performed. At the Politécnico di Milano (POLIMI), the research group led by Raffaella Brumana [12] has extensive experience with HBIM and its integration in GIS for the conservation of parks and gardens. At the Università di Pisa, the research group led by Marco Bevilacqua [13] studied the integration of 3D models in geomatic systems regarding the conservation of cultural heritage. At Università degli Studi Firenze (UNIFI), geomatics professor Grazia Tucci [14] investigated the integration of point clouds in geographic networks in case studies, and Politecnico di Torino Colucci et al. [15] studied the integration of HBIM in GIS, using the church of San Lorenzo Norcia (Italy) as a case study to obtain a unique model and vocabulary for the 3D GIS project aimed at the conservation thereof. At the Univertà di Cagliari, Vacca et al. [16] used HBIM and GIS for the study and conservation of the Gran Torre di Oristano. Matrone et al. [17] performed a reconstruction and visualisation of complex architecture by integrating an HBIM model in a structured spatial database (DB) and performing its 3D visualisation in a GIS environment. All these studies focused on a specific case study. However, studies have also been carried out on the integration of HBIM in GIS in an urban geographic area. Specifically, Martín, et al. [18] evaluated the potential risks to the heritage assets in a given location. Mascort Albea et al. [19] investigated the generation of interactive maps of heritage sets for public consultation through spatial data infrastructures. Bruno et al. [20] also studied the development of an online information system capable of integrating BIM and GIS data, focusing on a historic city and its main buildings over time while taking into consideration three aspects: the conceptual organisation of data to integrate GIS and BIM in a single environment, the integration of data belonging to different historical periods for analysis over time (4D) and the integration of preexisting datasets into the system. Similarly, concerning the integration of historic buildings in the urban environment, Chenaux et al. [21] addressed the integration of BIM with GIS in the creation of Virtual Historic Dublin.

In Spain, Francisco Pinto Puerto et al. [22] made important advances in the application of digital models based on BIM and GIS for the integral and sustainable management of patrimonial protection. Luis Agustín Hernández et al. [23] constructed a database using GIS technology, integrating historical cartography across platforms. Abellán Alemán [24] developed the interconnection of the API AUTODESK© REVIT™ platform of BIM models with other platforms and government data to automate tasks related to georeferencing, obtaining cadastral data, inserting maps and aerial images and automatically producing topographies, starting with the extant digital terrain models in Spain. Regarding historical urban heritage, the BIM team of C95 Creative [25] developed a georeference strategy for BIM to enhance and restore the historic centre of the city of Ayacucho.

However, the great management capacity that can be achieved with the interoperability of BIM and GIS in the management of architectural heritage is not yet being fully exploited. For example, it has not yet been tested in the management of public use and cultural tourism. No studies have explored the capabilities of HBIM-GIS for visitor planning and management.

This framework of this research is the Special Plan for the Protection of the "Ciutat Vella" of Valencia (Spain) (PEP Ciutat Vella, 2020). The aim is to create a first 3D-GIS prototype for future visitor management and preventive maintenance of heritage buildings management using the ArcGIS Pro platform. The aim is to verify the exportability of the data collected in HBIM concerning visitor flow and building conservation to an HBIM-GIS platform, so that, when implemented, visitor management of several buildings at the same time will be possible. This objective is based on the potential of HBIM-GIS integration for the management of architectural heritage in a geographical area (documentation, conservation and visiting the public). This purpose involves not only the application of HBIM and GIS methodologies but also other related technologies, such as reality capture (RC), 3D scanning (TLS), data processing and recording, and 3D modelling and monitoring for preventive maintenance.

This objective concerns three monuments selected for their cultural interest and their architectural complexity: the Metropolitan Cathedral, whose architectural styles reflect long years of extension and intervention; San Juan del Hospital, built in the Gothic style and possessing the only walled medieval cemetery with perimeter arches and a burial chapel atop a burial mound; and the Real Colegio Seminario de Corpus Christi, the greatest exemplar of the Renaissance in Valencia and the depository of a large number of artworks, exhibited in its museum. These three monuments are in the "Ciutat Vella" of the city of Valencia, designated BIC in the category of "historic center". In this geographical area, the oldest part of the city, the various cultures that have inhabited this urban nucleus since its foundation in 138 BC converge [26] (Figure 1).

The first proposed 3D-GIS model is intended to estimate the volume of visitors who access each of the selected monuments, as well as those who pass through the urban environment. Likewise, through the model presented here, it is possible in the future to detect the patterns of citizen mobility by checking the conflictive points and relating them to the focal timetable and seasonal periods. The problems that an excessive number of visitors can cause for the conservation of a monument are controlled through sensors placed within the three buildings, providing data related to their concentrations of CO_2, humidity and temperature and establishing connections between their number of visitors and the data provided. The results obtained thus contribute to the more efficient management of cultural visits at a destination, as well as to the conservation and preventive maintenance of heritage assets.

This article presents first partial results related to the integration of HBIM in the three selected buildings and to the point clouds of the delimited area in a GIS system with the associated geometric and semantic information destined for the management of visitors and conservation of cultural heritage.

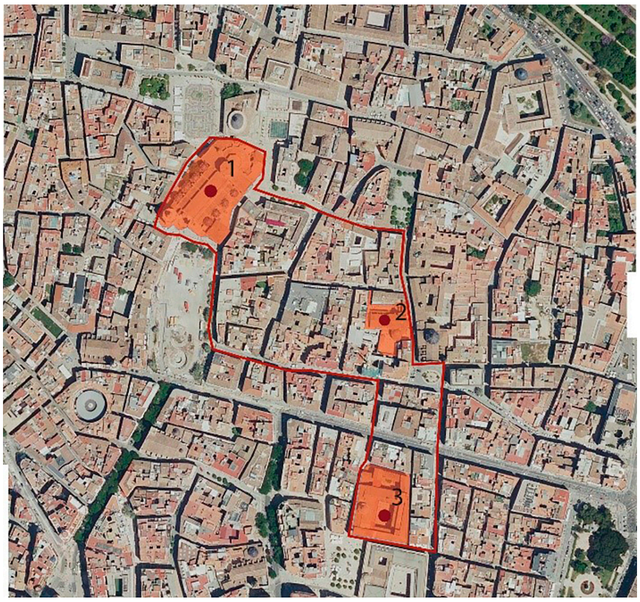

Figure 1. Study area and the three buildings: 1: Cathedral; 2: San Juan del Hospital; 3: Real Colegio Seminario de Corpus Christi.

2. Materials and Methods

The methodology adopted to achieve the proposed objectives is the design science research (DSR) method, as the main objective is to design an action protocol that solves a problem. The five DSR stages suggested by Vaishnavi et al. [27], Holmström et al. [28], and Chaves et al. [29] were followed (Figure 2):

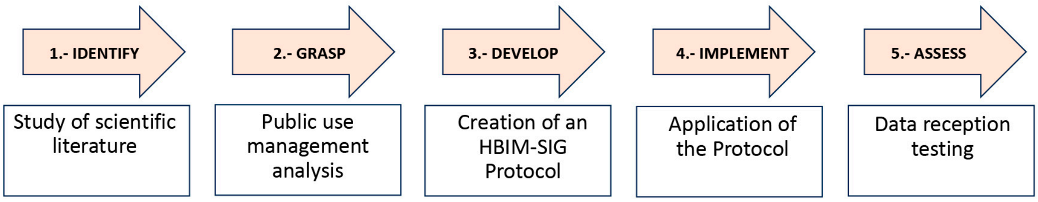

Figure 2. Methodological process.

1. Identification of the problem: an in-depth review of the scientific literature analysing the current state of the art, verifying that there are no studies related to the management of cultural tourism of architectural heritage through the integration of HBIM-SIG.

2. Understanding the problem: analysis of the management of public visits at the three proposed monuments and its impact on the conservation thereof via monitoring certain parameters (CO_2, temperature and humidity) that indicate the air quality of interiors as well as the appearance of condensation that affects paintings and stone.

3. Development of a solution: a protocol for the integration of the HBIM-GIS functions, whose results will enable in the future the efficient management of cultural tourism, as well as the conservation of heritage assets.

4. Implementation of the solution: the application of the Protocol established in the previous stage to one of the three selected monuments: the church of San Juan del Hospital.

5. Evaluation of the solution: Assessment of the effectiveness of the Protocol and its potential exportability to other case studies. The correct reception of the data and its integration in HBIM-GIS was tested. However, it was not possible to define patterns because of the need to capture information over a long period of time.

No research has thus far explored the integration of both methodologies for the efficient planning of cultural visits (stage 1). The scope of the problem (stage 2) was addressed through analysis of the volume, distribution and mobility of visitor flows within the heritage spaces. Various tools related to these aspects were used: load capacity (number of people who can fill a space without losing the feeling of comfort); visit pattern design (reasoned and argued routes concerning the motivating backbone of a visit, maintaining a common thread without interference across different groups of visitors); visitor frequency, which is absolutely necessary to optimize the management of the organizations responsible for cultural visits [30]; and the impact of public use on the conservation of a heritage asset through sensors that collaborate in proactive conservation.

For the counting of people, authors such as Le Corre et al. [31] and, more recently, Spenceley et al. [32] have proposed direct methods (in situ, from photographs, through satellite images) and automated counts using mechanisms (infrared, video cameras, etc.). The incorporation of artificial intelligence based on images has led to an optimisation of such quantification [33]. Both methods were used in this research. An on-site count was carried out by a team of 10 people located at strategic points in each of the three case studies: in the cathedral, at the entrance to the temple, to the museum, to the chapel of the Holy Grail and to the bell tower (Miguelete); in the church of San Juan del Hospital, at the entrance to the San Juan complex, to the temple and to the museum; and in the Real Colegio Seminario de Corpus Christi, at the entrance to the building, the museum and the cloister. These counts were made on the days of arrival of tourist cruise ships to the city and, therefore, amid a considerable increase in visitors to the selected buildings. At the same time, video cameras were placed on the busiest streets that lead to the cathedral, as these are typically located in the itineraries of groups of visitors with a tour guide. The CPF-SENSOR model, manufactured by WitekLab, was used. Its characteristics are: 2K QHD: image recording with sharp definition of 2560 × 1440; night vision capability; motion detection; local storage of up to 256 GB of video; a central system with a detection and calculation process algorithm with HD graphics card. Through the use of algorithms, the video camera detects the flow of people. The data collected by the video camera are sent to a server where they can be consulted from any device (Figure 3).

Figure 3. Detection of the flow of people with the CPF-SENSOR video camera in Miguelete street.

The sensors for the detection of the levels of CO_2, temperature and humidity were placed in the most conflictive points of the cathedral: in the Chapel of the Holy Grail, a confined place with a large influx of visitors and travertine stone that can be affected by the condensation produced by an excess thereof; and on the altarpiece of the main altar to verify the potential impact of condensation on the valuable Renaissance paintings in the vault of the apse. In the church of San Juan del Hospital, sensors were placed in the chapel of San Miguel Arcángel due to the danger that excess humidity represents for the magnificent Romanesque paintings that cover the vault.

These sensors measure ambient CO_2, using a nondispersive infrared (NDIR) principle for the measurement of its concentration. This detector has an optical filter that eliminates light except the wavelength selected for CO_2. The measurement range is between 400 and 10,000 ppm, with an accuracy of ±30 ppm (+3%) and a repeatability of ±10 ppm. The temperature sensor measures a linearity of ±0.5 °C across all measuring ranges. Relative humidity is measured with an accuracy of ±5% for humidities between 0% and 59% and ±8% for ranges between 60% and 100%.

For convenience in obtaining, consulting and analysing data, the information from these sensors was sent in real time through a WiFi connection to a mySQL database hosted on a secure server with storage redundancy. These data were processed and saved for presentation on the web or in an app. The system was connected to the UPV's IoT network to continuously verify this remote data acquisition. The collected data were transferred to Excel pages and integrated into HBIM via a SQL Server database and a Revit plug-in. This system allows bidirectional, real-time synchronisation of the data entered regarding visitor flow and the data emitted by the sensors.

Based on these data, a first protocol was proposed to improve public use planning, which directly affects heritage conservation and sustainable management. This made the information available in an information repository that will facilitate future public use planning that directly affects heritage conservation and sustainable management (stage 3). For this, the three selected monuments were scanned, and the point clouds were integrated in HBIM. Specific information for future visitor management and heritage interpretation was added to the HBIM models: (1) number of visitors per day and hour of the building; (2) data emitted by the sensors (CO_2, temperature and humidity); (3) identification of tourist landmarks: the tourist landmarks were identified with a "location pin" and the zoning of spaces was indicated by colours. Likewise, the geographic area comprising the three assets was scanned. Both the results of HBIM with associated information and the point clouds of the urban environment were implemented in GIS. ArcGIS software was used for integration. This online platform provides a combination of 2D and 3D scans, made using different software within an intuitive interface. Likewise, it facilitates the visualisation, as well as the analysis and processing, of images. In addition, it allows data management, integrating all the information generated, both via HBIM methodology and that incorporated in GIS related to the urban environment, including the counting of people. For the integration of the models obtained in HBIM of the three selected monuments, ArcGIS software was used. This online platform provides the combination of 2D and 3D scans produced using different software within an intuitive interface. Likewise, it facilitates the visualisation as well as the analysis and processing of images. In addition, it allows data management, integrating all the information generated, both in the use of the HBIM methodology and in that which was incorporated into the GIS related to the urban environment, including people counting. These tasks enabled the creation of a 3D-GIS model prototype for a historic centre including data related to the flow of visitors and the results of the installed sensors (stage 4) (Figure 4).

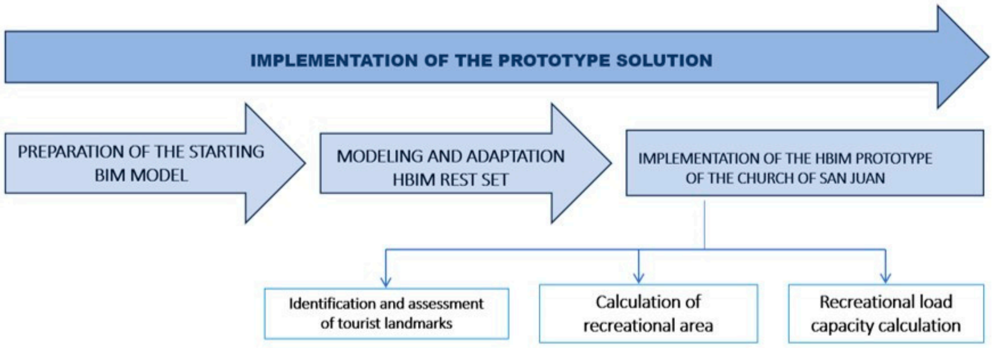

Figure 4. Process for the creation of the prototype.

3. Results

3.1. Big Data Acquisition and 3D Modelling

The acquisition of massive data for digital modelling and their integration into GIS were performed using 3D laser scanning and photogrammetry. These two geomatic technologies have challenged each other in terms of the preferences of operators for obtaining digital twins. However, both techniques are complementary: the terrestrial laser scanner (TLS) has the ability to capture the geometry of the scanned element with excellent dimensional precision [34], and photogrammetric procedures improve the visualisation of textures and finishes. In the field of BIM, there is a clear preference for terrestrial laser scanning, demonstrated by the use of the scan-to-BIM concept to describe the geometric documentation of a building and of TLS for the subsequent parametric modelling.

To collect data from the urban environment, a Leica RTC360 laser scanner and Cyclone Register 360 2022.0.0 software associated with Leica were used to record and process the point clouds. The result was the creation of a virtual tour based on the point clouds obtained. The scan of the route lasted two days, and 94 stations were made, with an average error of 4.7 mm. The necessary georeferencing was performed using five predefined ground control points and by aligning the clouds (Figure 5).

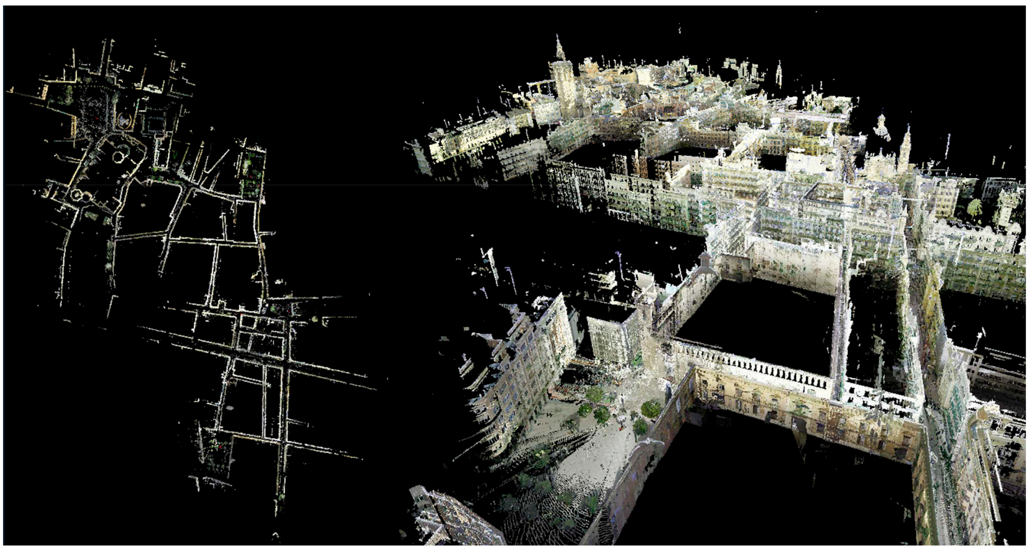

Figure 5. Geographic area point cloud.

The type of scanner used to collect data from the buildings varied according to the architectural and environmental characteristics thereof: initially, the FARO Focus-130-3D model was used to scan San Juan del Hospital because it is an architectural complex with little complexity. In the Cathedral and in the real Colegio Seminario de Corpus Christi, the Focus Premium model was used for its efficiency in data capture and time needed, since these two buildings are extremely complex; the FARO Freestyle 2 portable scanner was used in spiral staircases and hard-to-reach areas. Finally, the Focus 360 model was used to create virtual itineraries.

For the subsequent cloud registration and data processing, the SCENE software associated with FARO was used, obtaining highly accurate and reliable results. The scan of the Cathedral lasted 22 days, and 573 scans were made with 130 groups. The mean error was 4.1 mm, a perfectly acceptable value for the purposes of this research (Figures 6 and 7). The scan of the Real Colegio Seminario de Corpus Christi lasted 42 h, generating a total of 341 scans in 11 groups, with an average error of 2.7 mm. (Figures 8 and 9). The San Juan scan lasted 16 h with a total of 152 scans and an average error of 3.1 mm (Figure 10).

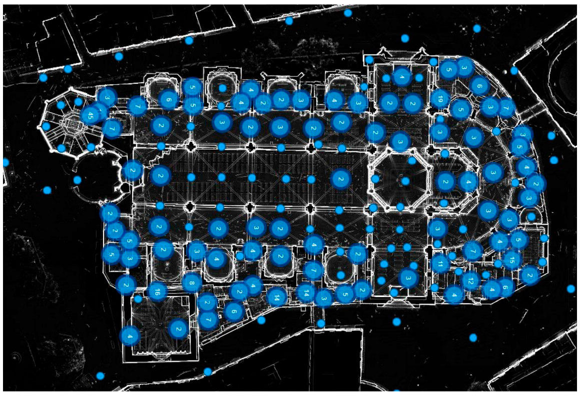

Figure 6. Cathedral. Scanning stations.

Figure 7. Cathedral. Orthophoto of the point cloud. Longitudinal section.

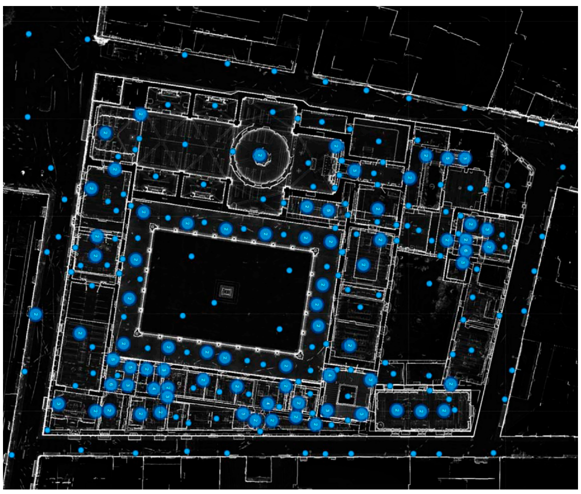

Figure 8. Real Colegio Seminario de Corpus Chirsti. Scanning stations. Authors: Junshan Liu and Danielle Willkens.

Figure 9. Real Colegio Seminario de Corpus Christi point cloud. Author: Junshan Liu and Danielle Willkens.

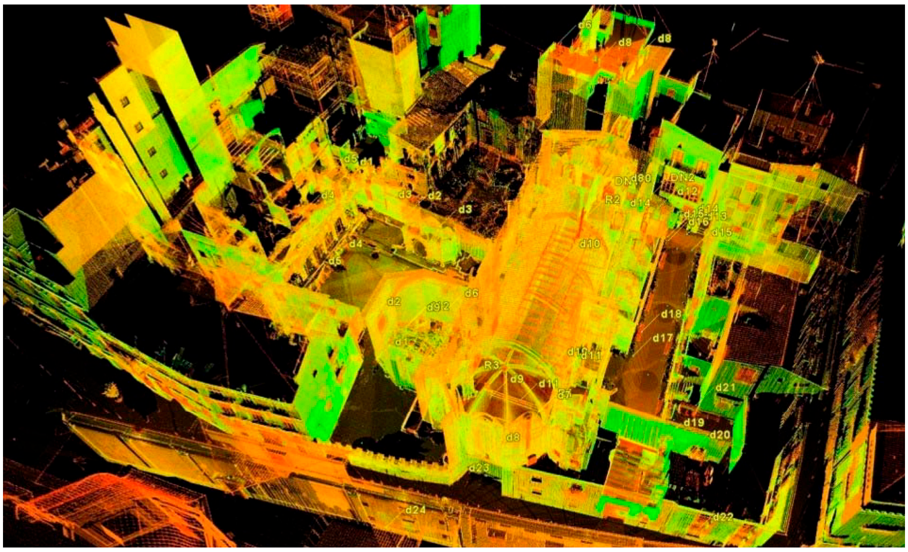

Figure 10. San Juan point cloud.

Subsequently, the point clouds obtained in Revit were implemented for digital modelling. The Scan to BIM plug-in was used, although this automatic conversion simplifies the parametric elements that present a complex geometry [35]. These simplifications are admissible, given the final objective of the investigation, as they do not affect the creation of the HBIM-GIS integration protocol. The implementation of the point clouds of the geographic area in HBIM for its implementation in GIS is in the process of being executed. This will allow studying the movement patterns of people and the interest they show in patrimonial buildings.

3.2. Data Relating to Cultural Visits

The information gathering related to the counting of people was carried out using the direct method, counting people in situ at the entrances of and inside the three selected buildings. Data were available for each day of the year and on an hourly basis. These data were transferred to an Excel page and incorporated into HBIM. In this research, only the most conflictive data were used, i.e., those corresponding to the days with the highest number of visitors: the arrival of tourist cruise ships with a number of passengers between 8000 and 9000. A greater number of nonspecialized rapid visits were detected with durations of less than an hour and a quarter in the Cathedral, between thirty-five and forty minutes in San Juan del Hospital and between fifty minutes and one hour and five minutes in the Patriarca. These results were calculated on the days where visit comfort may have been affected by the large influx of visitors via tourist cruise ships with passengers totalling between 8000 and 9000.

HBIM can be used to determine the conflictive moments in a visit because it calculates the recreational useful surface of the subspaces into which each building has been divided; it can be used to know the number of visitors of each space in real time, as well as the data emitted by the sensors (CO_2, temperature and humidity) through the SQL Server database and a Revit plug-in; through an algorithm, it can be used to calculate the recreational load capacity in an Excel document by sending it to HBIM through a plug-in, such as Dynamo. In this way, it can be used to detect in real time situations where physical and psychological comfort conditions are not met. The proxemics standards used for a group activity in enclosed spaces are 1.2 m^2 and for open spaces 1.5 m^2.

In the case of San Juan del Hospital, the interpretative landmarks were implemented in HBIM (Figure 11). Another layer of information was added with the distribution of the spaces where they are located. The useful recreational surfaces were calculated (Figure 12). Finally, the proxemic index was introduced to ensure the comfort of the visit. With these data, the load capacity of each of the spaces was established. This procedure, performed through HBIM, resulted in a distribution of visiting groups (Figure 13). The size of the group can range between 12 and 15 people without losing the feeling of comfort. As seen in Figure 13, the groups can access the site through the "Tránsito" and advance through the North Patio to the temple. Then, they go to the South Patio and go out to the street again. The total number of groups that San Juan del Hospital can admit is 10.

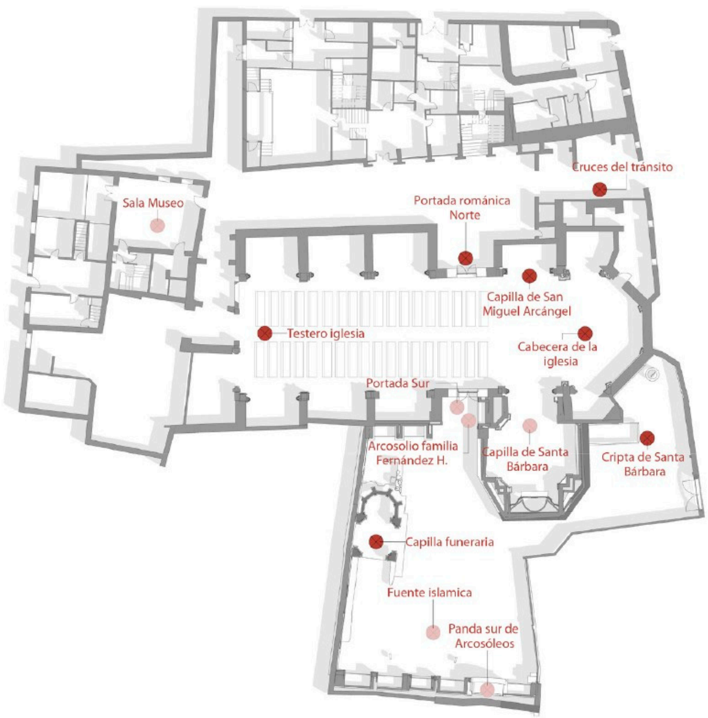

Figure 11. Interpretive landmarks of San Juan del Hospital.

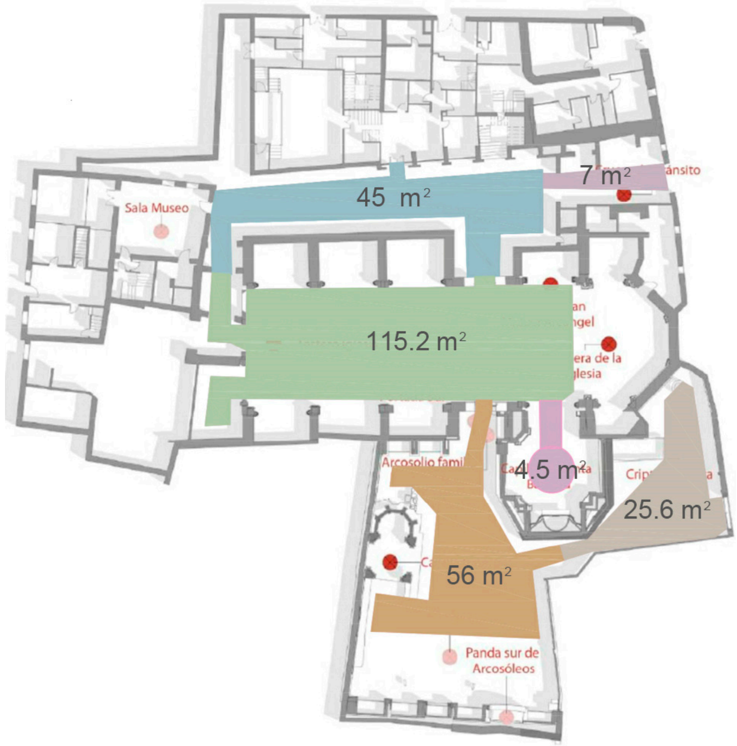

Figure 12. Division of spaces and useful recreational surfaces.

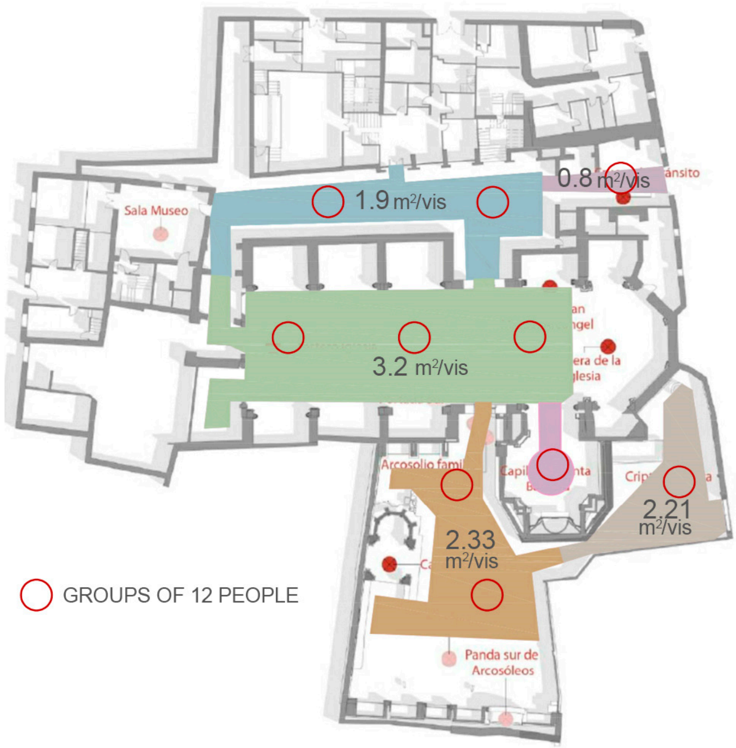

Figure 13. Load capacity and proximity index.

The data were extracted from the day with the highest number of visitors due to a massive religious ceremony (Table 1).

Table 1. Visitor data on the most conflictive day.

BUILDING	PLACE	DATE	VISITORS	USEFUL RECCRE-ATIONAL SURFAE (m^2)	PROXEMIC INDEX (m^2/visitors)	COMFORT
SAN JUAN	Temple	29/07/2022	173	115.2	0.67	NO
	South Coulthard	29/07/2022	173	81.6	0.47	NO
	North Coulthard	20/07/2022	128	52.0	0.40	NO

In the urban environment, the count was carried out automatically to detect the flow of people on the busiest roads in the geographical area of study. Two types of devices were used: video cameras (Calle del Miguelete) and video images captured by two mobile phones (Calle de Trinquete de Caballeros) (Figure 10). Both types were placed in a direction on the street covering all of the entrances to the Sanjuanista complex. Simple mobile devices (Galaxy A20e) were used with 32 GB of internal storage and a 5000 mAh battery with fast charging.

In both cases, postprocessing was necessary using a Python script, via the open-source library CVLIB (Ponnusamy, nf), with the capacity to detect people in photographs using artificial intelligence algorithms. The open source YOLOv3 was pretrained with RGB images from the COCO Dataset [36] because it offers good performance and balanced speed and precision and has been tested in similar cases, e.g., traffic congestion [37]. Once people were detected, all the pedestrians were counted.

The two methods used for automatic counting provided high-quality data because both are capable of providing a complete record without interruption. Postprocessing using the Python language and the CVLIB library is simple and can be performed at any time by verifying the analyses as many times as necessary. Likewise, it is possible to use both systems in real time, which favours a cartographic visualisation that is added to the established data.

After verifying the effectiveness of both methods in the counting of people, although both devices fulfilled the proposed purpose, the cameras were much more efficient and optimal than the mobile devices. The latter require constant monitoring due to battery discharge or other interferences via the operation of a phone itself. At this time, this has not yet been implemented in the prototype. Only the church of San Juan del Hospital was implemented, as indicated above.

3.3. Data Related to the Monitoring of Hotspots

The manufacture and placement of the sensors was carried out by the SMART monitoring research group of the Polytechnic University of Valencia including professors Juan Soto, Manuel Valcuende and José Manuel Gandía and Professor Antonio Galiano of the University of Alicante. An acceptable CO_2 value of 900 ppm was taken. When this value is exceeded due to an excess of visitors, the corresponding sensors launch an alert via HBIM. Similarly, when the dew humidity and relative humidity coincide (risk of condensation), the humidity sensors launch another alert. These data, as explained in the methodology, are linked to the number of visitors on the HBIM platform. In this way, all the information is unified in a single database. This database can then be used by the managers of the tourist visit. The data recorded on the platform show that large increases in CO_2, temperature and humidity occur amid an excessive influx of visitors, making it necessary to incorporate forced ventilation in the chapel of the Holy Grail and the church of San Juan del Hospital. However, no significant increases were detected by the sensors in the apse of San Juan del Hospital (Table 2, Figure 14).

Table 2. Sensor measurements in san Juan del Hospital.

VISITORS	CO_2 (ppm)	DEW RH	RH	TEMPERATURE (°C)	CONDENSATION
173	1272	72.2%	69.9%	28.88	SI

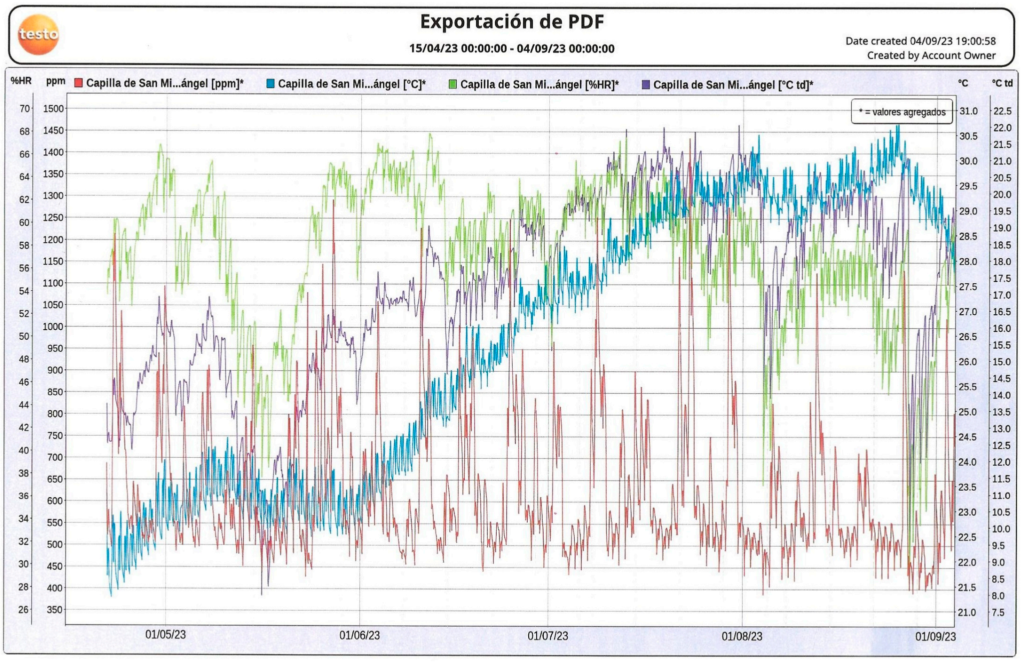

Figure 14. Sensor measurements in San Juan del Hospital.

3.4. Integration of HBIM Models in GIS

A 3D-GIS model prototype was developed in which the LoD-200 HBIM digital twins of the three selected buildings were incorporated. The level of detail of the models is not significant at this stage of the research, whose aim is to establish a prototype of HBIM-GIS integration beyond the level of detail of the models (Figures 15–18).

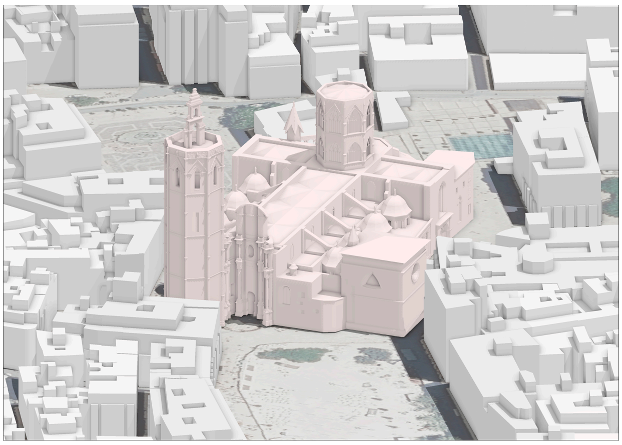

Figure 15. Cathedral. Visualisation of HBIM implemented in GIS.

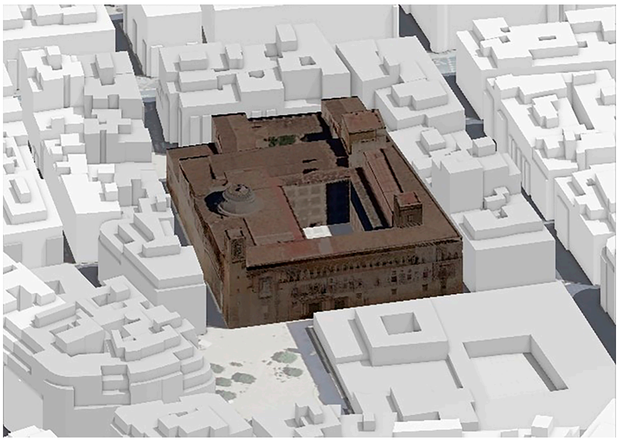

Figure 16. Real Colegio Seminario de Corpus Christi. Visualisation of HBIM implemented in GIS.

Figure 17. San Juan del Hospital. Visualisation of HBIM implemented in GIS.

Figure 18. Visualisation of HBIM implemented in GIS.

The created prototype incorporates the databases that are associated with the HBIM models of the selected buildings, which were described above, as well as those linked to the urban environment. Likewise, this first the prototype incorporates the documentary information associated with the GIS model of the historic centre that is linked to the virtual itineraries (Figures 19–21).

<Hito - Estado visitable / no>

A	B	C	D	E
Hito -Nombre	Estado del Hito	Descripción del estado del hito	Hito - accesible	Disponible
Arcosolio familia Fernández H.	Disponible		☑	Sí
Cabecera de la iglesia	Disponible		☑	Sí
Capilla de San Miguel Arcángel	Disponible		☑	Sí
Capilla de Santa Bárbara	En restauración	Restaurando sillería	☐	No
Capilla funeraria	Disponible		☐	Sí
Cripta de Santa Bárbara	Disponible		☐	Sí
Cruces del tránsito	Disponible		☑	Sí
Fuente islamica	Otros		☐	No
Panda sur de Arcosóleos	Disponible		☑	Sí
Portada románica Norte	Disponible		☑	Sí
Portada Sur	Disponible		☑	Sí
Sala Museo	Disponible		☐	Sí
Testero iglesia	Disponible		☑	Sí

Figure 19. Parameters for each element in the Revit model. Parameters of the Church of San Juan del Hospital.

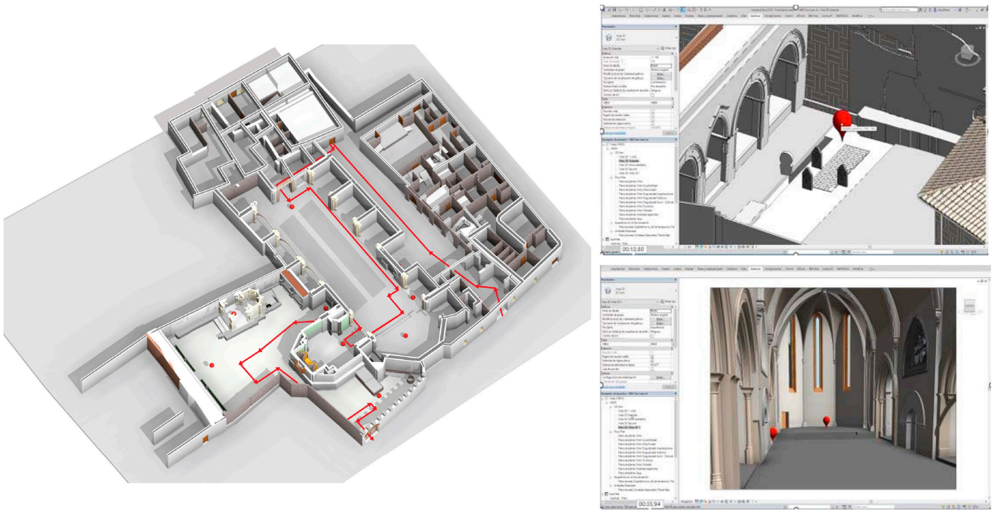

Figure 20. Management of the tourist visit through HBIM in San Juan del Hospital. Location of points of interest and routes. Author: Elena Salvador García.

Figure 21. Information of the points of interest of the three buildings implemented in GIS.

4. Discussion

The HBIM-GIS integration prototype can host data that allow calculations related to the recreational carrying capacity (RCC) linking semantic data. The visualisation capacity facilitates the holistic understanding of the information related to the heritage buildings and their urban environment. All this confirms that the combination of both technologies provides a highly efficient result.

Salvador-García's [5] research has already pointed to the feasibility of managing the public use of a monument through HBIM. Following this research, it was possible to verify that the Autodesk Revit software fully allows the incorporation of information, both geometric and semantic, generated by the individuals involved in the planning and management of a cultural visit in the HBIM model. The data of the HBIM-SIG platform was proven to allow the interconnection of the data related to the number of visitors with the data provided by the sensors in each space or room of each building. This allows the manager of the cultural visit to plan routes that avoid exceeding the proxemic index, CO_2, temperature and humidity in such a way that would compromise the comfort of the visit or the conservation of the heritage property. At the same time, it is an effective means of making decisions regarding the planning of tourist routes while accounting the flow of visitors. In this way, efficient management of public use is made possible by reducing the time invested in, as well as the costs generated by, planning, increasing the comfort of visitors and achieving, therefore, more sustainable management.

By integrating GIS and HBIM methodologies, it is possible to develop a comprehensive solution that addresses the challenges faced by the cultural tourism sector. In relation to the methodology used, DSR, the first four stages were notably addressed and overcome by studying the problem, focusing on it through the digitisation of heritage buildings and measurements related to visitor flows and monitoring of the environmental parameters. Finally, an HBIM-GIS integration prototype was created, fulfilling the stated objective. However, this prototype must be evaluated by expert panels and implementations in other buildings to demonstrate its exportability (stage 5). Previous works such as Korro Bañuelos, J. et al. [38] and Bilgin Altınöz, A. G., et al. [39] (2023) studied a new concept of information to enhance cultural; tourism uses the former. The latter defined a unified platform model, the METU_GIS, as a repository of data related to conservation and sustainability management policies and strategies. The results of our contribution incorporate and integrate all the information in a single GIS repository focused on the future management and exploitation of the buildings and the environment for cultural tourism visits.

5. Conclusions

This study demonstrates the potential of the integration of the HBIM and GIS tools for the evaluation of public use in heritage buildings, as well as in urban environments with the highest influx of visitors. This prototype's interoperability allows the efficient management of tourist visits, contributing to the conservation of heritage assets and increasing levels of sustainability. The combination of the models generated in HBIM and incorporated into a GIS system offers a comprehensive platform for the manipulation of geometric, spatial and semantic information, facilitating decision making for the design of tourist itineraries and the flow of visitors in both building interiors as well as the urban environment.

Although this study concerned three specific monumental buildings and a delimited geographical area, the Historic Centre of Valencia, the prototype can be extrapolated to a municipal or even intermunicipal management network, encompassing buildings and urban spaces of cultural and heritage interest. The integration of HBIM-GIS also allows the combination of data at different scales, given the magnitude of the study areas and the number of buildings included in them. Likewise, it provides an appropriate tool for the management of data across different strata, from the construction level to the territorial level.

In conclusion, this research highlights the HBIM-GIS integration tool in the evaluation and management of tourist visits, both within heritage architectures and urban environments, contributing to a more comprehensive understanding and management of heritage sites. This work opens a line of research aimed at improving the planning and management of public use in heritage buildings and environments through a single digital tool, encouraging a more efficient and sustainable practice.

The use of digital tools for the management of cultural tourism is becoming a necessity. Its integration into the Smart City concept will facilitate the unification of information in a repository and, therefore, will facilitate the work of those responsible for cultural visits. In this way, this research aligns with Development Goals 9 and 11 of the 2030 Agenda (SDG).

Author Contributions: Both authors have participated in all aspects related to the research and writing of this article. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Science and Innovation of the Government of Spain grant number PID2020-119088RB-I00 and The APC (10%) was funded by CRUE-Universitat Politècnica de València.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data can be found at the links: https://hbimsigtur.webs.upv.es/ (accessed on 22 May 2023).

Acknowledgments: We thank the Cathedral Chapter and the Rectorate and managers of the Royal Seminary College of Corpus Christi and the rectory church of San Juan del Hospital for their availability so that this research could be carried out. We thank Junshan Liu and Danielle Wilkens for their collaboration in collecting data from the Real Colegio Seminario.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. García-Hernández, M. *Turismo y Conjuntos Monumentales: Capacidad de Acogida Turística y Gestión de Flujos de Visitantes*; Tirant lo Blanch: Valencia, Spain, 2003.
2. Murphy, M.; McGovern, E.; Pavia, S. Historic Building Information Modelling—Adding intelligence to laser and imagebased surveys of European classical architecture. *J. Photogramm. Remote Sens.* **2013**, *76*, 89–102. [CrossRef]
3. Jordán-Palomar, I.; Tzortzopoulos, P.; García-Valldecabres, J.; Pellicer, E. Protocol to manage heritage-building interventions using Heritage Building Information Modelling (HBIM). *Sustainability* **2018**, *4*, 908. [CrossRef]
4. Fassi, F.; Mandelli, A.; Teruggi, S.; Rechichi, F.; Fiorillo, F.; Achille, C. VR for Cultural Heritage A VR-WEB-BIM for the Future Maintenance of Milan's Cathedral. In Proceedings of the International Conference on Augmented Reality, Virtual Reality and Computer Graphics, Lecce, Italy, 15–18 June 2016; De Paolis, L.T., Mongelli, A., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 139–157.
5. Salvador-García, E.; Viñals Blasco, M.J.; García-Valldecabres, J. Potential of HBIM to improve the efficiency of visitor flow management in heritage sites. Towards smart heritage management. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2020**, *XLIV-M-1-2020*, 451–456. [CrossRef]
6. Seguí, A.; Portalés, C.; Cabrelles, M.; Lerma, J.L. Los sistemas de información geográfica: Concepto, ventajas y posibilidades en el campo de la restauración. *Loggia* **2012**, *24–25*, 122–131. [CrossRef]
7. Nogués Linares, S.; Salas Olmedo, H.; Canga Villegas, M. Aplicación de los SIG a la gestión del patrimonio público de suelo. *GeoFocus* **2008**, *8*, 43–65.
8. Guonian, L.; Batty, M.; Strobl, J.; Lin, H.; Zhu, A.-X.; Chen, M. Reflections and speculations on the progress in Geographic Information Systems (GIS): A geographic perspective. *IJGIS Int. J. Geogr. Inf. Sci.* **2019**, *33*, 346–367.
9. Zupic, I.; Čater, T. Métodos bibliométricos en gestión y organización. *Métodos De Investig. Organ.* **2015**, *18*, 429–472.
10. Pavel, T. BIM, GIS and semantic models of cultural heritage buildings. *Geoinform. FCE CTU* **2016**, *15*, 27–42. [CrossRef]
11. Yang, X.; Grussenmeyer, P.; Koehl, M.; Macher, H.; Murtiyoso, A.; Landes, T. Review of built heritage modelling: Integration of HBIM and other information techniques. *J. Cult. Herit.* **2020**, *4*, 350–360. [CrossRef]
12. Brumana, R.; Condoleo, P.; Grimoldi, A.; Previtali, M. Towards a semantic based hub platform of vaulted systems: HBIM meets a geodb. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* **2019**, *XLII-2/W11*, 301–308. [CrossRef]

13. Croce, V.; Caroti, G.; Piemonte, A.; Bevilacqua, M. Geomatics for Cultural Heritage conservation: Integrated survey and 3D modeling. In Proceedings of the IMEKO TC4 International Conference on Metrology for Archaeology and Cultural Heritage, MetroArchaeo, Florence, Italy, 4–6 December 2019; pp. 271–276.
14. Tucci, G.; Bonora, V.; Conti, A.; Fiorini, L. High-quality 3D models and their use in a cultural heritage conservation project. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *XLII-2/W5*, 687–693. [CrossRef]
15. Colucci, E.; De Ruvo, V.; Lingua, A.; Matrone, F.; Rizzo, G. HBIM-GIS Integration: From IFC to CityGML Standard for Damaged Cultural Heritage in a Multiscale 3D GIS. *Appl. Sci.* **2020**, *10*, 1356. [CrossRef]
16. Vacca, G.; Quaquero, E.; Pili, D.; Brandolini, M. GIS-HBIM integration for the management of historical buildings. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2018**, *XLII-2*, 1129–1135. [CrossRef]
17. Matrone, F.; Colucci, E.; De Ruvo, V.; Lingua, A.; Spanò, A. HBIM in a semantic 3D GIS database. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *XLII-2/W11*, 857–865. [CrossRef]
18. Martín Talaverano, R.; Murillo Fragero, J.I. La consideración histórica y arqueológica en la creación de modelos HBIM. Los estudios previos. In Proceedings of the VII Seminario de Estrategias para el Conocimiento del Patrimonio Arquitectónico, Online, 26–27 November 2020.
19. Mascort-Albea, E.J.; Ruiz-Jaramillo, J.; López Larrínaga, F.; de la Peña Bernal, A. Sevilla, Patrimonio Mundial: Guía cultural interactiva para dispositivos móviles. *PH—Boletín Inst. Andal. Patrim. Histórico* **2016**, *90*, 152–168. [CrossRef]
20. Bruno, S.; de Fino, M.; Fatiguso, F. Historic Building Information Modelling: Performance assessment for diagnosis-aided information modelling and management. *Autom. Constr.* **2018**, *86*, 256–276. [CrossRef]
21. Chenaux, A.; Murphy, M.; Pavia, S.; Fai, S.; Molnar, T.; Cahill, J.; Lenihan, S.; Corns, A. A review of 3D GIS for use in creating virtual historic Dublin. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *XLII-2/W9*, 249–254. [CrossRef]
22. Pinto Puerto, F.S. La tutela sostenible del patrimonio cultural a través de modelos digitales BIM y SIG como contribución al conocimiento e innovación social. *PH Boletín Inst. Andal. Patrim. Histórico* **2018**, *26*, 27–29. [CrossRef]
23. Fernández Morales, A.; Agustín Hernández, L. Reconstrucción virtual de Saraqustä. *EGA Rev. Expresión Gráfica Arquit.* **2019**, *24*, 96–107. [CrossRef]
24. Abellán Alemán, J.M. Geolocalización y generación automática de emplazamientos a través de servicios y datos de plataformas gubernamentales mediante la API AUTODESK© REVIT™–BIM. In Proceedings of the International Conference/7º Encuentro de Usuarios BIM, València, Spain, 17–19 May 2018.
25. Pascual, M. Ayacucho—La Ciudad Digital con BIM. Editeca. 24 September 2019. Available online: https://editeca.com/la-ciudad-digital-de-ayacucho-bim/ (accessed on 5 August 2023).
26. López González, M.C.; Máñez Testor, S. Revisión y nuevas contribuciones al límite meridional y oriental de la segunda judería de Valencia y fijación de los límites de la tercera y última judería: 1390-1392-1492. *Sefarad Rev. Estud. Hebraicos Sefardíes* **2020**, *80*, 25–54. [CrossRef]
27. Vaishnavi, V.; Kuechler, W.S. Design Science Research. In *Information Systems*; Petter, J., Ed.; Association for Information Systems: Atlanta, GA, USA, 2004; pp. 1–66.
28. Holmström, J.; Ketokivi, M.; Hameri, A. Bridging practice and theory: A design science approach. *Decis. Sci.* **2009**, *40*, 65–87. [CrossRef]
29. Chaves, F.J.; Tzortzopoulos, P.; Formoso, C.T.; Biotto, C.N. Building information modelling to cut disruption in housing retrofit. *Proc. Inst. Civ. Eng. Eng. Sustain.* **2016**, *170*, 322–333. [CrossRef]
30. Baggio, R.; Scaglione, M. Strategic Visitor Flows and destination management. *Inf. Technol. Tour.* **2018**, *18*, 29–42. [CrossRef]
31. Le Corre, N.; Le Berre, S.; Brigand, L.; Peuziat, I. Comment étudier et suivre la fréquentation dans les espaces littoraux, marins et insulaires? De l'état de l'art à une vision prospective de la recherche. *EchoGéo* **2012**, *19*, 12749. [CrossRef]
32. Spenceley, A.; Schägner, J.P.; Engels, B.; Cullinane, T.C.; Engelbauer, M.; Erkkonen, J.; Job, H.; Kajala, L.; Majewski, L.; Metzler, D.; et al. *Visitors Count! Guidance for Protected Areas on the Economic Analysis of Visitation*; UNESCO: Paris, France; German Federal Agency for Nature Conservation: Bonn, Germany, 2021.
33. Wang, W.; Kumar, N.; Chen, J.; Gong, Z.; Kong, X.; Wei, W.; Gao, H. Realizing the potential of the internet of things for smart tourism with 5G and AI. *IEEE Netw.* **2020**, *34*, 295–301. [CrossRef]
34. Molina Sánchez, S.; Juan Vidal, F.; Cipriani, L.; Denia Ríos, J.L. Limitations in the digital survey of heritage assets with tower typology. *EGA Rev. Expresión Gráfica Arquit.* **2021**, *26*, 76–89. [CrossRef]
35. Dore, C.; Murphy, M. Current state of the art historic building information modelling. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *2*, 185–192. [CrossRef]
36. Collado, A.; Marqués-Mateu, A.; Viñals, J.M.; Salvador-García, E.; Sanasaryan, A. Detección y cuantificación automática de visitantes para la gestión inteligente de atractivos turísticos. In Proceedings of the 3rd UNWTO Conference on Smart Destinations, Valencia, Spain, 21–23 November 2022.
37. Galán-Cuenca, A.; Vázquez-Martín, R.; Mandow, A.; Morales, J.; García-Cerezo, A. Análisis de técnicas de aumento de datos y entrenamiento en YOLOv3 para detección de objetos en imágenes RGB y TIR del UMA-SAR Dataset. *J. Automática* **2021**, *XLII*, 686–694. [CrossRef]

38. Korro Bañuelos, J.; Rodríguez Miranda, Á.J.; Valle Melón, J.M.J.; Zornoza Indart, A.; Castellano Román, M.; Angulo Fornos, R.; Ferreira Lopes, P. The role of information management for the sustainable conservation of cultural heritage. *Sustainability* **2021**, *13*, 4325. [CrossRef]
39. Bilgin Altınöz, A.G. Utilising GIS for documentation, conservation, and sustainable management of middle east technical university campus in Ankara as a modern period living heritage place. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2023**, *XLVIII-M-2-2023*, 211–218. [CrossRef]