INTEGRATION OF DYNAMIC INFORMATION ON ENERGY PARAMETERS IN HBIM MODELS

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ABSTRACT:

The conservation of cultural heritage can be affected by different changes in temperature and humidity within architectural spaces, so energy performance and interior microclimate of historic buildings require adaptation to new maintenance and prevention studies. The search for these new investigations brings cultural heritage closer to new digital technologies such as Historic Building Information Modelling (HBIM). In this work, a new interdisciplinary methodology is developed between energy operators and BIM operators, so that a new framework is created to monitor energy parameters through intelligent sensors that measure temperature and humidity in the fully interoperable and semantically enriched 3D model itself. The study's commitment involves solving the interoperability workflow between sensors and the BIM platform, taking advantage of this new interconnectivity. For the study, a methodology applied to the Church of the Sacred Heart of Jesus in Seville was carried out, where from a survey through a georeferenced terrestrial laser scanner with topographic equipment, it is modelled from the point cloud, incorporating the sensors in the HBIM Project. In the workflow, it has been shown that the integration of microclimate data inside churches can be managed directly in the environment of an HBIM-based model and transfer a reverse flow in the process.

1. INTRODUCTION

The architectural heritage is subject to factors that alter the morphological and structural characteristics of the elements. These environmental factors such as humidity, dew point, energy flows allow us to know the alterations that can occur in the monuments.
The parameters that condition the colonisation of organisms that can alter materials can be light, temperature, CO2 level, among others. Therefore, knowing the temperature changes that occur in spaces and the climatic conditions that affect them is essential to be able to assess the state of prevention, conservation, and maintenance of architectural heritage. These analyses, both of energy performance, and the general study of the interior microclimate of heritage buildings, need procedures that are adapted to new technologies that involve interdisciplinary methodologies (de Rubeis et al. 2020).
In this context of new disruptive technologies, Building Information Modelling (BIM) is presented as the great commitment of the study and the applicability of information management models. This can make the BIM environment an ideal platform to collect microclimate datasets and energy data based on machine learning.
It should be noted that research projects are currently developing an integrated digital-based methodology to efficiently document heritage buildings and involve owners in the conservation process (HeritageCare) (Masciotta et al. 2019). And in this line, it appears as one of the premises of BIM which is to provide a repository for all data related to construction (Chen et al. 2014).
However, information is often treated as a static source of knowledge, adding reports to the model (Fernández-Alconchel et al. 2022) as if it were a horizontal addition in the enrichment of the semantics of the building information model. The BIM methodology, established based on a 3D modelling of the construction process, moves in a collaborative data management environment and in this sense can monitor and control the processes of design, planning, cost control, construction, and maintenance of buildings.
Another important fact that can be a challenge for this research work is the insertion of sensors that monitor microclimatic aspects in a network that can be observed in real time.
One of the objectives that the scientific community currently has is the implementation of BIM methodologies in the Cultural Heritage (CH) sector, especially in the advancement of the interoperability of data sets.
Thus, the digital twin is among the ten main strategic technological trends for the year 2019.
A digital twin is a virtual prototype of a real object, in which you can perform experiments and test hypotheses, as well as predict behaviour and solve problems throughout the life cycle (Massel et al. 2020).
Therefore, bringing the Historic-BIM model closer to the Digital Twin means implementing the monitoring of the historic building in a process of data recording, analysis and interpretation of environmental parameters, which means integrating dynamic parameters into the information model of the historic building.
But this collaborative data management can be done through the exchange of information by Industry Foundation Classes (IFC) files that are made up of entities, that is, by geometric, constructive and basic elements (Colucci et al. 2020) that the modelling software manages in layers. or classifying groups and can later be transformed into parametric objects.
But there are other connections that can be implemented in conservation projects, and that have the possibility of operating in the same environment of the BIM methodology. An example is that of Rogage et al. (Rogage et al. 2020), where IFC geometric data was used to provide a visual representation of the building.

Sensor data was linked to these spaces within the BIM. In other cases, a storage model based on data from IFC files is proposed, where these files work as a data centre and connectivity is done through an API procedure of Open Database Connectivity (ODBC) API procedure to use SQL (Li et al. 2016).
Other similar examples are developed with Unity software (Edirisinghe et al. 2021), and in other study cases (Zhang et al. 2022), the generation of geometry through meshes is used for the simulation of computational fluid dynamics (CDF) and although it names the term digital twin, there is no connection of the sensors with the BIM environment itself.
Conservation procedures such as examination, analysis, diagnosis, preventive conservation require documentation to be coherent and known, in order to reach conclusions (Moraitou et al. 2019) and make important conservation decisions, both moving and immovable. of heritage.
Continuing in the same context of the processes of management and conservation of the architectural heritage, adequate integration of the movable goods arranged in the container of the historic building is essential.
These works of art have singular characteristics that should be examined and studied by academics and scientists in the field of conservation (Moraitou et al. 2019).
In preventive conservation, researchers use sensors to control physical parameters related to the degradation of works of art. And the combination of documented reports and data recorders improves the evaluation conditions in the conservation of cultural heritage. But in addition to these analyses, there are important data sets that come from sensors and data managers that determine energy parameters.
Among the most outstanding studies on the analysis of microclimate parameters for the conservation of cultural heritage, there is risk-based analysis (Aste et al. 2019) where the conservation limits that can affect works of art are established.
Another study that may be interesting to mention is the external platforms of the web-based BIM environment as an alternative to managing Historic Building Information Modelling (HBIM) (Nagy et al. 2021).
The term HBIM was introduced by Murphy et al. (Murphy et al. 2009) to refer to the information model of the historic building, and from this work it has been consolidated as a new area of knowledge where 3D modelling studies are integrated with the combination of libraries of parametric objects, interoperability, and semantic units.
Referring to research related to HBIM, there is a recent work in which it is proposed to create a workflow that integrates HBIM tools with Building Performance Simulation (BPS) with the aim of improving the energy aspects of listed buildings in Italy (Massafra et al. 2022).
In the field of studying thermal comfort in new buildings, Penna et al. (Penna et al. 2019) established a workflow to link sensors through an SQL database and through other external software, Dynamo communicates with Revit.
Dynamo's node architecture base is used for data insertion from MS Excel. Works related to radargram, orthophotos and images Infrared Thermographic Imaging (IRT) (Solla et al. 2020) inserts content through different "dummy" walls in Revit, so the metadata association is superficial. Consequently, most of the studies of inserting metadata to the HBIM model are done through either an external platform, or through minor insertion sequences.
This paper proposes a design methodology for the incorporation of energy parameters into building information models applied to architectural heritage, a monitoring process built and managed from an HBIM project. These parameters are non-quasi-static representations, and therefore the readings of the parameters could be in real time. Therefore, it would be a semantic enrichment of the HBIM environment, leading to an approach to the configuration of a digital twin with dynamic information content.
The proposed methodology can be used in all monuments and artefacts that are modelled in the BIM platform environment.
In addition, a validation of the development of the digital environment is proposed in a real case with environmental variables of the indoor microclimate. For this purpose, the proposed research aims to establish a reversible model, where the data from the data loggers are inserted in the model and the operators can be managed with reverse processes.

2. CASE STUDY

The churches are religious buildings that are an important part of the Cultural Heritage as are the historical buildings. In Spain, visits to cathedrals and other buildings account for 2.17% of the country's GDP, and their conservation is directly related to the funds they receive, generally 80% of which belong to the Church. Therefore, an analysis of these historic buildings is presented as an opportunity to characterise the main advantages of studies of microclimate that can affect both the container and the works of art.

For this study, the Church of the Sacred Heart of Jesus of Bellavista, located in a town south of Seville (Spain), has been taken. The church designed by the architect José Gómez Millán has a quadrangular plan, and in its configuration it is designed with a Baroque structure through walls and load-bearing arches. Inside, it presents Mudejar reminiscences due to the presence of wooden coffered ceiling vaults in the main nave and the side vaults. Its construction date is dated to the first half of the nineteenth century, as is known through a historical photograph that it was under construction in 1947.

2.1. Monitoring

In order to monitor the energy performance of heritage buildings, from an HBIM Project, the geometric record of the exterior and interior surface of the church is carried out Figure 1.
The latest generation RIEGL VZ-400i 3D laser scanner has Internet connectivity with the latest LiDAR waveform processing technology. The real-time data flow is carried out through two processing platforms: i) a processing system dedicated to the simultaneous acquisition of scan data and image data, waveform processing, and system operations, and ii) processing platform that allows automatic registration on board (Moyano et al. 2022).

The RisCAN PRO software (v 2.2) (Riegl Laser Measurement Systems 2020) is responsible for processing and organising all data obtained by the RIEGL VZ-400i scanner. This software with the corresponding algorithms is orientated to work in such a way that the data acquired during the measurement campaign is organised and stored in a project structure. Among all the data, there are surveys by scans, captured details, photographs taken by the Nikon D810 camera, GNSS data, and the coordinates marked by the control points and refractors.

Figure 1 shows a view of the point cloud of the central nave of the Church within the RISCAN PRO software environment.

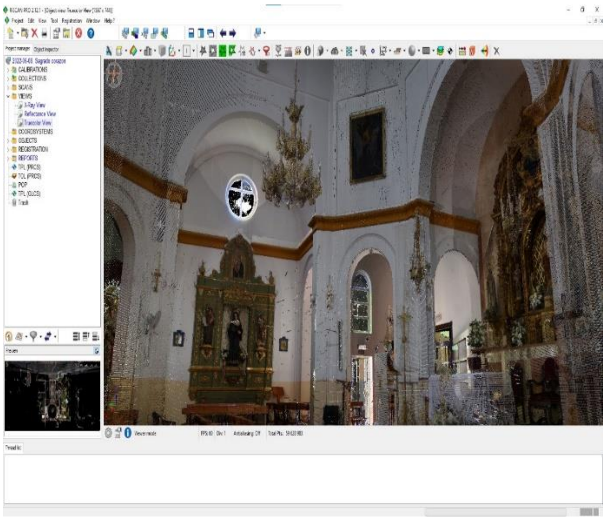

Figure 1. Point cloud inside the Church of the Sacred Heart of Jesus in Bellavista

In order to make the process of building the 3D model in a BIM environment as efficient as possible, the whole point cloud has been structured into sectors to find an efficient way to proceed, maximising processor and card resources. PC graphics.

Many scientific studies reveal the importance of transferring point cloud data to 3D parametric modelling on BIM platforms (Tang et al. 2010; Thomson et al. 2015; Moyano et al. 2021), and that automatic scan-to-BIM procedures generate value engineering in systems. For this, the TLS iG global point set is preprocessed in the CloudCompare (Girardeau-Montaut 2015) software in its corresponding segmentation part.

Current software provides the point cloud with not only precise geometric characteristics (x,y,z) that can infer with certain precision the location in 3D space, they also provide certain attributes that have to do with chromatic aspects (Xue et al. 2020), RGB colours, and their intensity can be a classifying element through artificial intelligence technologies (Santos Ortiz Correa et al. 2018).

In the new concept of smart cities, as well as buildings with smart procedures, BIM provides a platform to integrate spatial relationships of assets, regional conditions, and simulation of active movements (Lin et al. 2020). In this line with respect to energy monitoring in the environmental and microclimatic study, it is possible to introduce numerous measurement instruments that have to do with aspects that determine energy audits.

In this rectangular church, three HOBO UX100-011 sensors were permanently placed, with reading intervals every half hour. As these sensors do not need an electrical source, the data are monitored for a period of forty-five days during which the data are plotted according to Figure 2.

External data are collected through the Spanish Meteorological Agency (AEMET). There is also the possibility of installing a low consumption data logger and a wide temperature range, Datalogger Cambell CR1000KD, with flexible programming and telecommunication options (Yonghua 2012).

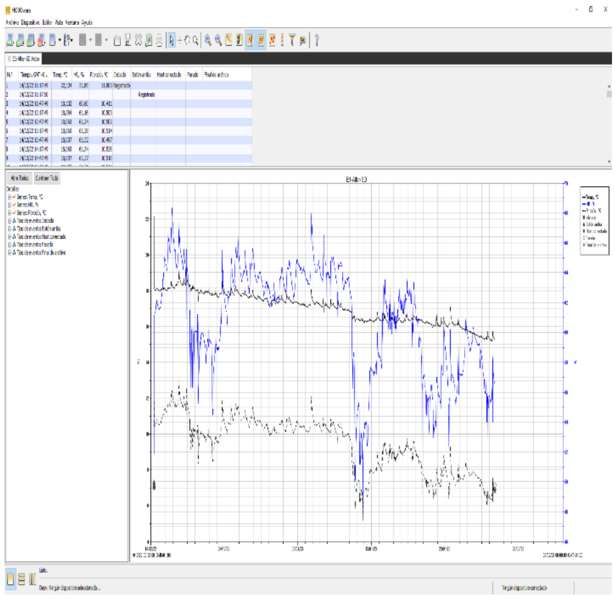

Figure 2. Sensor data

For the measurement of the thermoflowmetric analysis (HFM) regulated by the ISO 9869-1 (International Organization for Standardization 2014) standard, an Ahlborn brand Almemo 2590-4AS datalogger with type thermocouple sensors (T 190-2) for air temperature and a film sensor for surface temperature of a 15x15 cm plate (FQA018C), already used in other works, such as measurements in traditional housing enclosures (Bienvenido-Huertas et al. 2019) or in the case of shipbuilding studies (Bienvenido-Huertas et al. 2020).

Figure 3 shows the church plan and the position of the different equipment installed with its corresponding geographic coordinates.

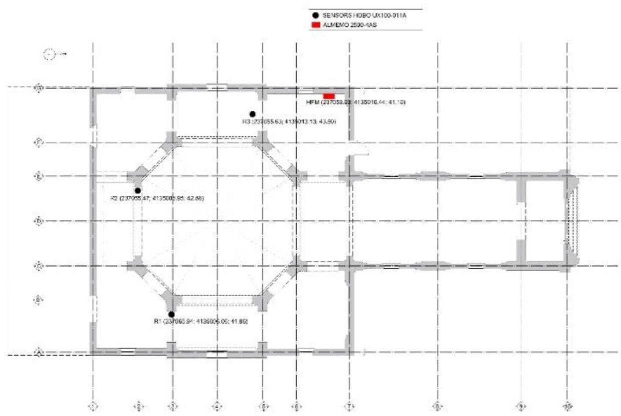

Figure 3. Position of the temperature and humidity sensors and datalogger (HFM)

2.2. Database entities

In the energy data collection stage, some entities have been selected that have to do with the most important experimental parameters that contribute to the effects of cultural assets. Among them, the parameters responsible for correct conservation stand out, such as interior temperature, surface temperature, lighting, relative humidity, and air speed.

- Indoor air temperature (ºC) (T)
- Indoor relative humidity (%) (RH)
- Air velocity (m/s) (V)
- Illumination (Lx) (I)
- Occupant Predicted Mean Vote (PMV)
- Maximum daily temperature fluctuation
- Thermal transmittance

On the other hand, the parameters that can cause damage to the surface of works of art are poor air quality (Ilieş et al. 2021) and high concentrations of contaminant, such as corrosion or oxidation (Pigliautile et al. 2019). The energy performance of historic buildings, as well as the interior comfort conditions, also depend on the type of thermal envelope, which will determine the loss or gain of energy that the wall is capable of transmitting.

Recent studies by Lucchi (Lucchi 2017) characterised different components of envelopes in the historical context, analysing and estimating the U value with measurements through the heat flow metre (HFM). In a similar line of work is the study by Llorente-Álvarez et al. (Llorente-Alvarez et al. 2022) whose work makes it possible to estimate the thermal conductivity of four types or samples that simulate masonry thicknesses with different bricks from different scenarios depending on the degree of humidity, through a laboratory hot box. Therefore, there are exogenous factors that can determine variations in the thermal transmittance of the wall.

3. MONITORING SYSTEM

3.1. Measurement instrument

Instruments used for monitoring.
The characteristics of the equipment are shown in Table 1.

Equipment/Probe	Variable	Measuring Range	Accuracy
HOBO UX100-011A	Temperature	-20º a +70ºC	± 0,21ºC
	Relative Humidity	1% a 95%	± 2,5%
CR1000KD	Temperature	-20ºC a +50ºC	± 0,12ºC
	Field of View (FOV)	25º x 19º	
FLIR E60bx Infrared Camera (systems FLIR, Portland, OR, EE.UU.)	Spectral Range	7,5 to 13 microns	
	Thermal Sensitivity	< 0,05ºC a 30ºC	

Table 1. Characteristics of the equipment used

4. METHODOLOGY AND IMPLEMENTATION ANALYSIS

The methodology of analysis and verification of the systems used goes through the control of the thermal comfort of the churches that can be followed through a procedure through the information added to an information model of the historic building. Certain standards contain guidelines for the energy improvement of current buildings that are based on studies and analyses that address the cultural value of the historic building. These monitoring methodologies can be based on different standards from the point of view of ergonomics and thermal comfort; therefore, ISO 11079 contains the procedures necessary to measure these parameters (Adán et al. 2021). Also, in EN 15759-1 (Comité Europeo de Normalización 2012), the use of these heating systems is considered both for the conservation of materials and for thermal comfort.

4.1. Monitoring System

To define a monitoring system, it is necessary to identify the items or parameters involved in the measurement of historic buildings. Thus, the BIM building information model, with its semantic properties, is the ideal environment to serve as a cataloguing and registration system. A 3D model with geometric precision, based on a scanned survey, has a precision of the geometry to centimeters levels. The aggregation of experimental measurements and energy parameters in situ is an ambitious challenge that is currently not fully experienced. For this reason, it is intended to enrich the HBIM with dynamic data to become a digital twin of the heritage asset.

Figure 4 presents the diagram of the different phases and processes that are carried out in the investigation. From the recording of the capture of the geometry of the building to the introduction of the metadata in the BIM environment and to explain this, we proceed to analyse the monitoring design in detail.

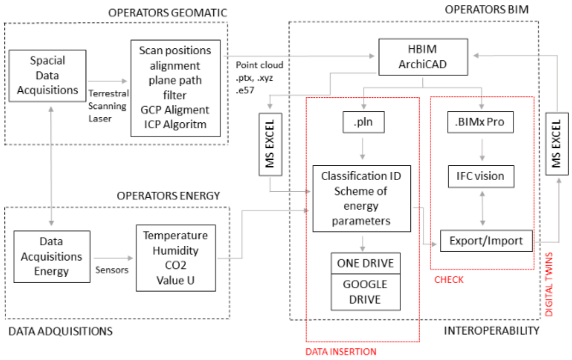

Figure 4. Workflow of the proposed methodology

4.2. Monitoring design in the BIM environment

The database is classified by identifying a unique ID for each of the sensors or for each datalogger device or representative sample. This object sensor with its geometric properties and with a predetermined location (x,y,z) within the digital model of the church, Figure 5, is assigned in the ArchiCAD BIM environment some specific properties, prepared and available in the administrator. of properties "property manager".

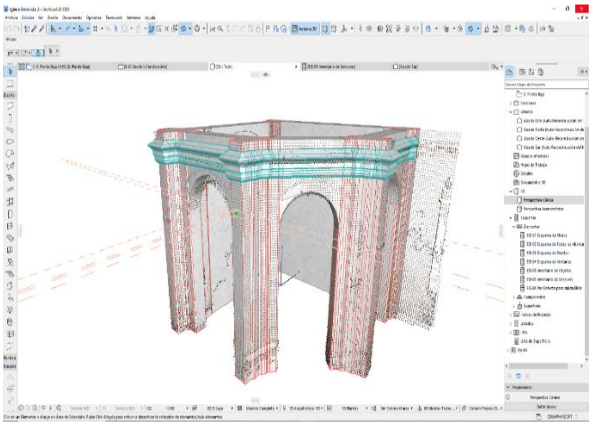

Figure 5. Model of the side chapel of the Church of the Sacred Heart of Jesus.

In addition to the various specific parameters, each of the devices was classified with an ID. The classification is made by adapting it to the MEP elements. For example, the "distribution control elements' has been made to classify it as a "sensor" element. With this methodology, interactive data models are being carried out that incorporate some items pre-established by the energy operator. This sensor is associated with both geometric characteristics and properties of the microclimate parameters obtained in the experimental campaigns.

Figure 6 shows the sensor placement system with respect to the geometric structure of the model. In addition to the ability of the sensor to measure temperature and humidity parameters, it includes the possibility of making thermal maps knowing the UTM coordinates of the system. Although the HOBO UX100-011 sensors allow recording over a long period, a future study will introduce dynamic type sensors, that is, those sensors that provide real-time information on weather properties.

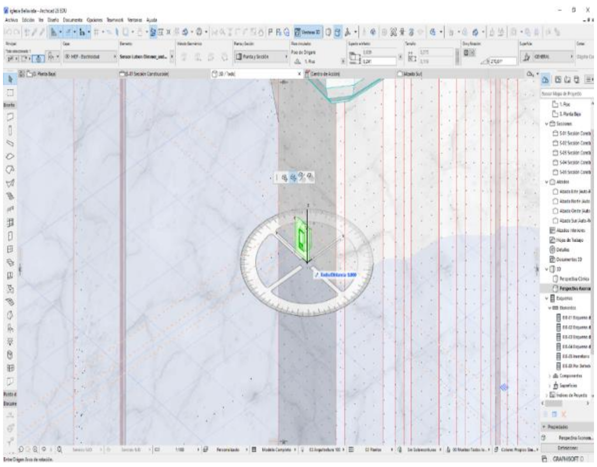

Figure 6. Model of the sensor location in the architectural structure of the ship

4.3. Database management and interoperability between operators

The database includes the energy parameters that affect the microclimate of heritage buildings. The data transfer between the energy operator and the BIM operator is carried out using the.xlsx format to which any type of data set can be inserted; be it numerical, formulas, or even a URL link with additional technical information.
The use of a data web as a content management system allows for the dynamic and global integration of data sets and for the energy operator to link the link between them.

For the development of a database in a cloud such as Google Drive (CDE) an open link is used that is generated by uploading the file to the folder a common data environment, with the option of sharing in open.

CDE currently provides a single platform for construction operators to collaborate on an Electronic Document Management (EDM) system (Kiu et al. 2022).

In addition, BIM environment software such as ArchiCAD (Grafisoft 2019) has applicability such as the Teamwork-HBIM-CDE project (Nieto-Julián et al. 2021). To be able to share this link, firstly, the structured folder is created in ID-Sensor_01 and then the files of the work that you want to share with the users are uploaded.

Once these files have been uploaded, "click" on the folder and with the right button, select the "share" option, and later in "general access" the tab is displayed and select "anyone with the link". Once this link is obtained, the URL will be validated to establish links to the metadata of the obtained energy datasets.

The BIM platform can associate objects in the dialogue boxes with the usual properties related to both construction material and manufacturing (Nieto-Julián et al. 2021). In this sense, ArchiCAD's property management is used to create and manage the set of properties that have to do with environmental and microclimatic parameters.

To link the monitoring data based on BIM, ArchiCAD has the possibility of reversing the process from the creation of the ES_05 "sensor inventory" scheme until the metadata is incorporated by the energy operator. Once the data set has been modified and entered, (i.e. Air velocity in m/s of each one of the buildings in the heritage building), there is the possibility that the file in.xls "scheme" format will be reverted to the system, either by incorporating all the information or each of the data separately. This way of proceeding allows us to read the last reading values of each of the parameters designed in the HBIM-microclimate Project.

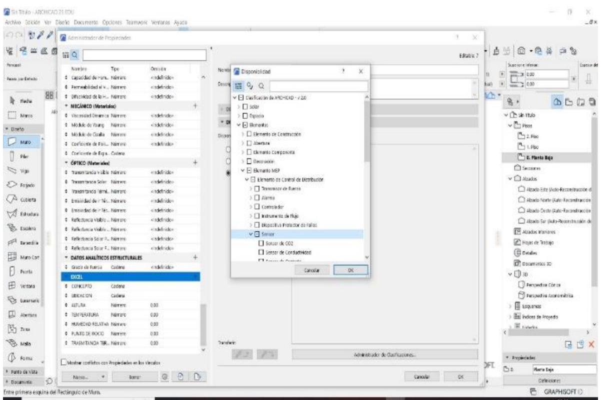

Figure 7. Editing scheme

The advantage of the proposed system allows to include the metadata linked to each one of the sensors, so the items are associated and linked to the monitoring of each one of the equipment, be it datalogger, pyranometer sensor, any temperature sensor or any other sensor. nature. It must be said that the connection between the scheme in the BIM environment and the CDE occurs through an electronic link.

The Mechanical, Electrical and Plumbing (MEP) design is a process of creating the design or modelling of an installation that contains all the related information of the system, made up of intelligent objects; both physical, mechanical, and electronic related to intelligent objects that in principle are fixed. In the case of exposed monitoring, they must include information taken from time and, therefore, of a dynamic type. A dynamic information base is similar to a type of database that can store data regularly, with the quality that all information can be edited through each moment of time.

In the BIM environment, the system manages a three-dimensional model of the building in its life cycle, where the semantically enriched objects contain geometric properties, and all the properties of the technical data sheets of the suppliers, the maintenance programme for the facilities, or the control of other systems, such as structural, thermal comfort, which are necessary to review or monitor temporarily. This simile with the work developed in this methodology means opening a communication channel between real life and the digital model, in the sense that the data can be obtained directly.

5. DISCUSSION

The integration of data in an HBIM Project can contribute to the improvement of decision-making regarding the design of the programming of a restoration project or configure the management in the life cycle of the historic building.

Building performance can represent different aspects and concepts related to energy, for example, energy performance, thermal performance, air quality performance, and functional performance (Khalil et al. 2019). It is not just about analysing the energy cost of the building, but through monitoring the microclimate of historic buildings, the possibility of seeing how they affect climate conditions in the future is known. For this purpose, a monitoring system methodology based on a BIM environment has been proposed that integrates the different sensors and dataloggers in the same platform, without having to resort to complementary software that allows for this connection.

The linking of the data sets is done through MS Excel files, which also serve as an interface between energy operators and BIM operators.

The process is reversible as long as the operator external to the HBIM project completes the specific information, data that will be entered into the fields created and associated with the model objects. The data obtained and reviewed will be uploaded to the CDE platform through URL links that are inserted into the object classification scheme with its displayed data items. The CDE will be accessible by all the agents involved in the HBIM project, even by those collaborators who have access and/or editing permission.

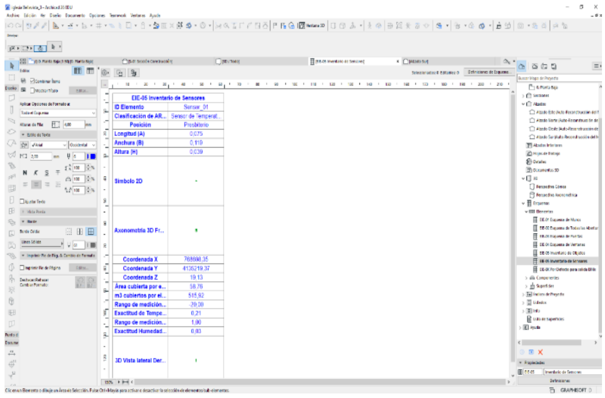

Figure 8. Schematic Data in the BIM Environment

6. CONCLUSION

The results of this research work show that the design methodology for inserting energy parameters into building information models applied to architectural heritage is one of the most interesting monitoring processes when managed from an HBIM project.

The semantic enrichment of BIM platforms opens a new path in the exploration of the insertion of energy data, giving rise to an approach to the configuration of a digital twin with dynamic information content.

This proposed methodology can be used in all types of heritage construction such as monuments, churches, cultural spaces, and applicable to small artefacts that are modelled under the BIM platform environment, and specifically movable cultural heritage assets.

The use of a data web as a content management system allows for the dynamic and global integration of data sets and for the energy operator to link the link between them. This possibility opens the way to further interop work with IFC file interop.

The integration has been done with the classification of a parametric object in SENSOR. To resolve the direct transmission of information from the equipment to the CDE from the HBIM model, other methodological proposals will have to be made with sensors directly transmitted to the cloud. Another of the processes that is intended to be implemented in the future is the identification of the ontology with the characteristics of the sensor. Including the attributes and properties of an external software system would implement and facilitate the data inclusion process between the energy operator and the BIM operator. To carry out this phase of work, you would have to have a viewer that manages the data of the schemes through IFC files. The operability of the system will be more efficient at the cost of the integration of new software in a flow structure that can contain multivarious parameters.

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