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Complex Spaces in HBIM Models: Volumetric Visualization for a Data Insertion

Renan Rolim

Centro de Investigación en Arquitectura, Patrimonio y Gestión para el Desarrollo Sostenible (PEGASO), Universitat Politècnica de València, , recorvi@upv.es

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Abstract

In recent years, digital technologies are increasingly being used to document and monitor heritage buildings, acting as decision support tools for technicians and managers working in these buildings. Among the most widely used tools, HBIM (Heritage Building Information Modeling) as a methodology for virtual documentation of information on heritage buildings and their life cycle, and sensors as tools for recording environmental data of extreme relevance for preventive conservation, maintenance and visitor management in heritage buildings stand out. This paper presents a 3D modelling process using BIM software, where the model allows a more accurate measurement of the volume of interior spaces in rooms bounded by complex ceilings. This process also makes it possible to visualise the spatial volume in 3D as well as to attribute informative parameters to it. For this purpose, the vaults of the church of the Real Colegio-Seminario del Patriarca in Valencia, Spain, have been used as a case study.

Keywords: *HBIM, 3D Model, Revit, Spatial Volume, Environmental Sensors, Dynamo, Preventive Conservation, Maintenance, Cultural Heritage Management.*

1. Introduction

The development of different methodologies for the integration between the monitoring data of heritage buildings collected by sensors and HBIM models is growing, as can be seen in Rolim et al. (2024). As important as this integration is the definition of how they will be visualised, i.e. how the collected information will be visualised within the HBIM software itself where the 3D modelling of the building was done, or how these data will be visualised in another external platform when exported. Studies by Banfi et al. (2017); O'Shea & Murphy (2020); Nagy & Ashraf (2021); Ni et al. (2021); Hou et al. (2022); Meoni et al. (2022); Mitro et al. (2022); Machete et al. (2023); Moyano et al. (2023) show some of the different possibilities of visualisation of sensor data integrated into HBIM models.

The definition of the level of semantic and geometric information that the 3D model will have is highly relevant, as is the consideration of its final objective and its preparation for possible exportation to other platforms that can facilitate its visualisation and analysis of the integrated data, such as scenario simulation, GIS (Geographic Information System) software and DesignBuilder® simulation software. These integrated tools can assist technicians and managers in the decision-making process related to preventive conservation, maintenance, and management of public use. They can also be applied to an isolated building or a group of them.

Regarding the levels of semantic and geometric information that the 3D model must have, Escudero (2021) discusses the different strategies that can be taken when developing the geometric model and the election of its Level of Development - LOD, which is formed by a set of different sub-levels. Some relevant concepts on this subject are: the Level of Detail – LoD (Biljecki et al., 2016; Historic England, 2017; Freitas et al., 2023); the Level of Information – LoI (Garcia-Gago et al., 2022); the Grade of Generation – GoG (Banfi, 2017); the Indoor/Outdoor Level of Detail – ILoD/OLoD (Tang et al., 2018); the Level of Geometry – LOG (Brumana et al., 2018, 2022); the Level of Knowledge – LOK (Castellano-Román & Pinto-Puerto, 2019); and the Level of Development – LOD (Talaverano et al., 2021).

In this context, this work has been devoted to developing a 3D modelling process where it is possible to visualise and generate more accurate data about the internal volumes of the environments of heritage buildings with complex roof shapes. From this process, it is possible to add informative parameters to this volume that can be extrapolated to GIS software.

2. Aims and Objective

The integration between environmental sensor data and the HBIM methodology to monitor the state of conservation of heritage buildings, in addition to considering the building's constructive structure and internal elements, whether or not they are integrated into its structure, such as frescoes and paintings, must also consider its public use and spatial elements such as rooms. With that, it is necessary to identify the environmental conditions of these rooms and analyse data on temperature, humidity, air quality and load-bearing capacity. The analysis of these data is essential for monitoring the preventive conservation conditions of the building and the safety and comfort of its users. In order for the analysis and management of environmental data to be more efficient and accurate, it is necessary that the environmental data be directly associated with its corresponding inner space and not with its built elements.

The Autodesk® Revit 2024 software presents data on the areas and volumes of rooms linked to a family of spatial elements. These data are calculated semi-automatically, requiring the insertion of the height limit to report the volume data. The vertical limits can be realised by the roof, floor or ceiling tools. Already, the horizontal room boundaries are detected automatically, being delimited by walls and, when necessary, by the room separation tool.

Dealing specifically with vertical delineation, Autodesk® Revit 2024 software performs well when dealing with relatively simple geometric shapes, such as pitched roofs, domes and simple vaults. But when it is bounded by more complex geometric shapes, such as groined vaults, there is where the problems start.

The ‘room’ tool does not obey the vertical delimitation of some complex shapes, generating errors in the measurement of volume data and in its 2D visualisation. Furthermore, these errors prevent the volumes of the environments from being recognised in Autodesk® Dynamo, making it impossible to visualise and assign parameters to the volume generated by the plugin.

Considering this, the aim of this work is to identify a 3D modelling process where the room tool of the Autodesk® Revit software recognises the vertical delimitations in environments with complex ceilings and thus can generate more accurate data on the spatial volume of the room and allows its linkage to the Autodesk® Dynamo plugin to attribute the necessary parameters for the analysis and management of its environmental data. For this purpose, the vaults of the Church of the Royal College-Seminary of Corpus Christi in the city of Valencia, Spain, have been used as a case study.

The Real Colegio-Seminario de Corpus Christi de Valencia, commonly known as the Colegio del Patriarca, occupies an entire block in the heart of the district of Ciutat Vella, the old quarter of the city of Valencia, Spain (Figure 1). It was built between 1586 and 1615, during the Counter-Reformation period, with the aim of training priests according to the guidelines emanating from the Council of Trent. The building stands out in the Spanish panorama for being one of the few religious buildings that have preserved in its entirety both its fabric and its belongings. The church, which stands out for its bell tower (Figure 2a), occupies the southwest corner of the college complex, which has its rooms distributed around a central cloister. The internal spaces of the church are vertically limited by groin vaults reinforced by ribs in each section, which in turn are supported by the walls that separate these spaces (Figures 2b and 2c).

This work is part of the HBIM-SIG-Tourism research project of the Universitat Politècnica de València, where the whole of the Colegio del Patriarca is being modelled, and sensors for environmental monitoring have been installed in some of its rooms in order to carry out the environmental analysis and integrate them into the HBIM model and subsequently extrapolate it to a GIS platform.

Figure 1. Location of the Real Colegio-Seminario de Corpus Christi in the historic centre of Valencia. Source: Own elaboration from images generated in Google Earth (2024).

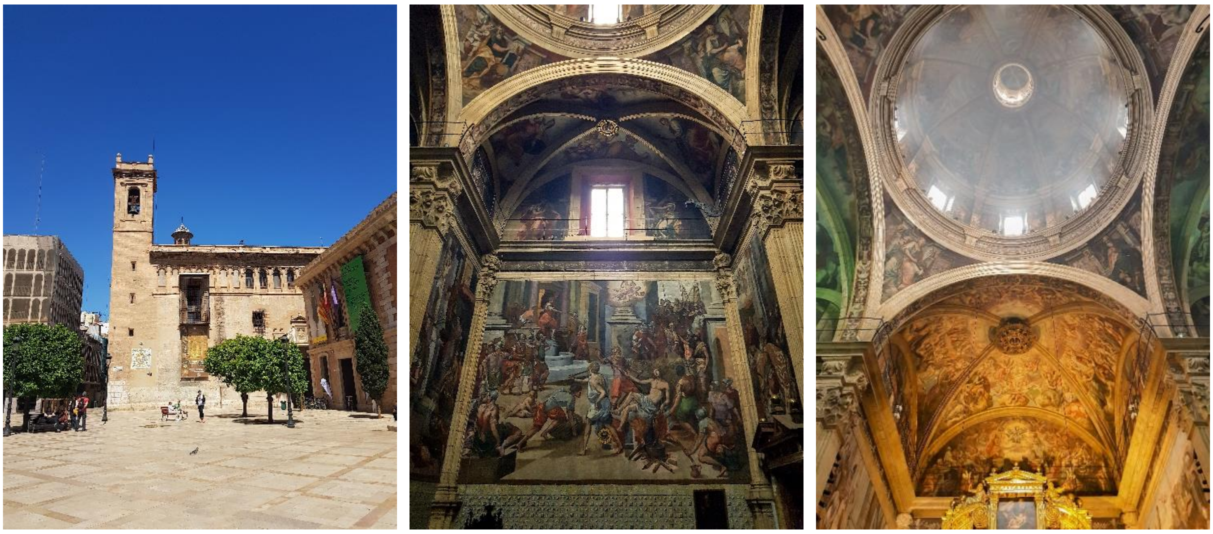

Figure 2. a. View of *Colegio del Patriarca* from the Plaza del Colegio del Patriarca (2024); b. Vault of the transept nave-gospel side (2023); Vault of the Altar-Mor (2024). Source: Author.

3. Methods and procedure

The point cloud of the *Colegio del Patriarca* taken by PhD. Junshan Liu, which was made available by the researchers involved in the HBIM-SIG-Tourism project, was used for this study. From the point cloud, the development of a 3D model of the *Colegio del Patriarca* was started using Autodesk® Revit 2024 (Figure 3).

Figure 3. Point cloud of Colegio del Patriarca; Point cloud superimposed on the 3D model; 3D model of Colegio del Patriarca under development. Source: Own elaboration from the point cloud taken in 2023 by PhD Junshan Liu.

Considering that one of the objectives of the 3D model developed in the project is to enable the visual representation of the environmental data collected by the sensors installed in the building, an efficient way was sought to insert and visualise the information collected by the sensors directly in the software in which it was being modelled. To make the incorporation of parameters and the materialisation of the 3D volume in Autodesk® Revit 2024 feasible, the Autodesk® Dynamo plugin was used as an auxiliary tool.

3.1. Tests carried out

3.1.1. First Modelling Test

In order to model the ribbed vaulting infilling masonry, the mass tool was used due to its ease of modelling and its plasticity, which allows it to get very close to the original representation of the point cloud. At the moment of generating a thickness for the masonry using the mass layer, errors occurred in the extrusion of its curvature, deforming the final volume of the masonry (Figure 4).

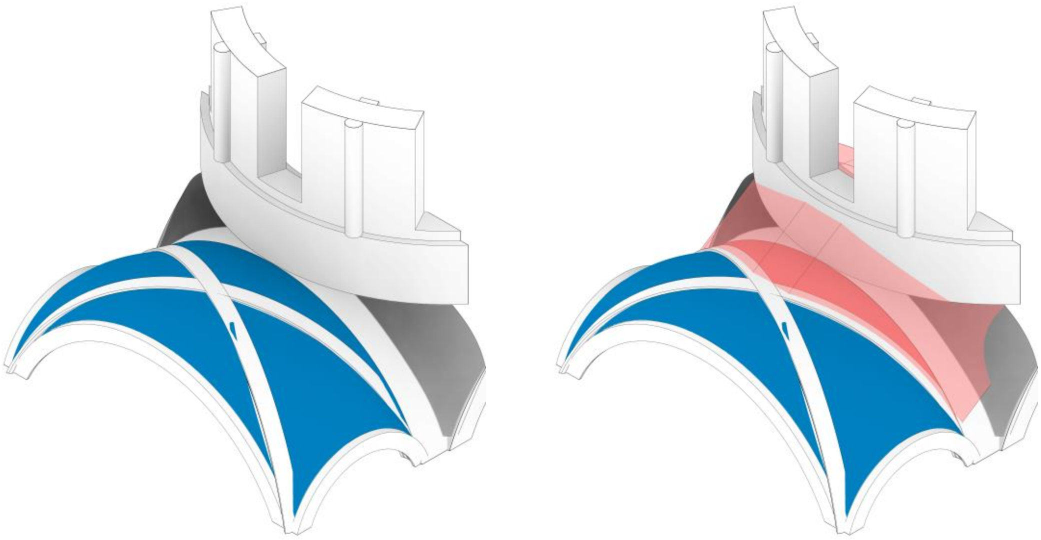

Figure 4. In blue - Modelling of the plementeries with the dough tool; In red - Error in the extrusion of the modelled plementeries. Source: Own elaboration (2024).

Another problem encountered was that the modelled infillings did not vertically limit the volume generated by the 'room' tool of the Autodesk® Revit 2024 software. The volume was only visible so far through the 2D sections of the model (Figure 5).

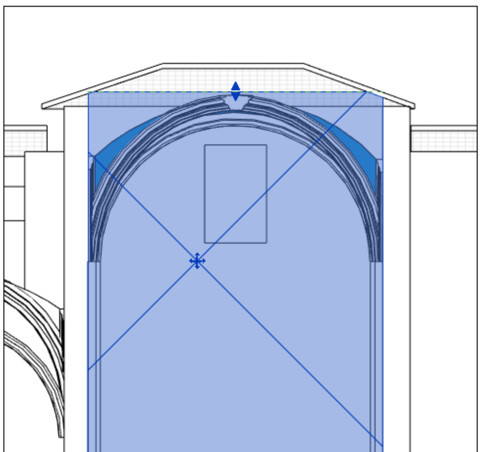

Figure 5. Volume of a room without vertical limitation visualised in a 2D section of Autodesk® Revit 2024. Source: Own elaboration (2024).

Subsequently, it has been identified that the vertical limitation for volumes would only be possible if the massing was modelled as curtain wall, roof, ceiling, roofing, or floor families. An attempt has been made to convert the modelled mass layer into one of these elements, where a third problem was identified: the impossibility of converting the mass layer into one of the above volume-limiting elements, with the exception of the curtain wall. By converting the modelled mass layer into a curtain wall, it was possible to limit the vertical volumes, but there were still errors in the connections between the infillings and the walls (Figure 6).

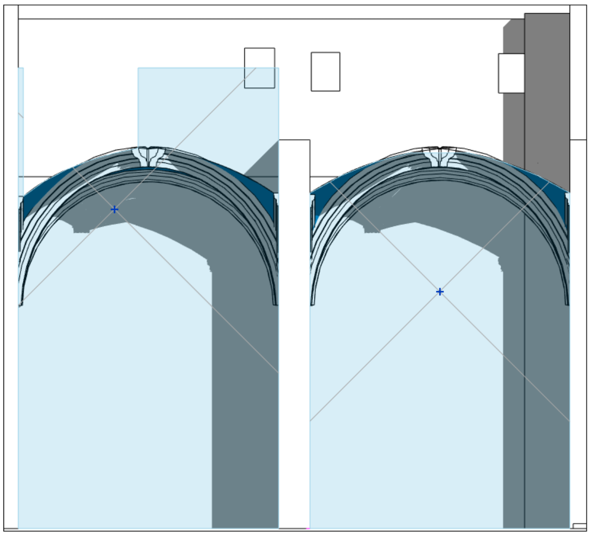

Figure 6. Volumes of two rooms constrained with the ‘curtain wall’ tool visualised in a 2D section of Autodesk® Revit 2024, (left) error in the vertical constraint, (right) vertical constraint corrected manually. Source: Own elaboration (2024).

In addition, the adoption of curtain walls as a solution was not satisfactory, as it required detailed manual adjustments to make it possible to avoid boundary errors, not meeting our expectations of a more automated solution.

3.1.2. 3D volume visualisation

The volume generated by the ‘room’ tool in the previous process was only visible in 2D sections of the model (Figures 5 and 6). Therefore, in parallel to the modelling of the vault infillings, tests were carried out to generate the 3D volume using a routine implemented in the Autodesk® Dynamo plugin. From the generated 3D volumes, it was possible to identify the modelling errors and correct them, but the volumes produced errors that did not allow the attribution of their materialisation for parameter attribution, only their visualisation (Figure 7).

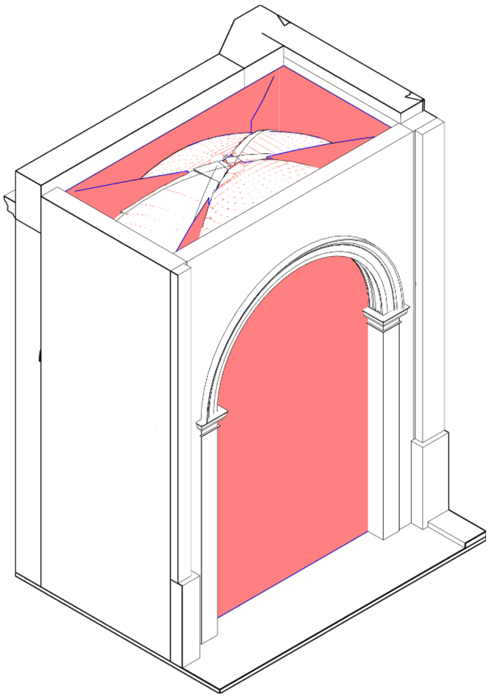

Figure 7. Visualisation of the volume generated by the ‘room’ tool using the Autodesk® Dynamo plugin. Source: Own elaboration (2024).

3.1.3. Second modelling test

Considering that the first solution was not satisfactory, the modelling of the infillings was started using the 'cover' family of the software. This tool, despite limiting the volumes vertically, reduced the accuracy of the model, as it made it difficult to model the original deformations of the plementeries, visible in the point cloud.

The modelling of the infillings was started separately, using the tools for creating volumes by extrusion, sweeping, revolution and subtraction of voids. The resulting infillings continued to generate errors in the connections between the plements and with the walls, limiting the vertical volumes in parts, as was the case with the masses converted into curtain walls. An attempt was, therefore, made to model the whole of the plementeria as a single element. This attempt has led to a large error of divergence between the original infillings of the building, identified in the point cloud, and the ones generated in the model. In addition, it still did not limit the vertical volumes, giving worse results than the previous solution.

With the worsening of the result, it was possible to work again with the infillings separately, where it was identified that, by means of the union of only two infillings facing each other, it was possible to limit the volume. This way of modelling presented only small errors in the connections with the walls, which were not completely orthogonal, and in the central connection between the infillings, where the keystone of the vault is located. To solve the first problem, the infillings were extended to the central axis of the walls, and to solve the second, a small central circumference was placed so that the points that conceived the infillings did not touch each other, thus achieving a satisfactory result (Figure 8).

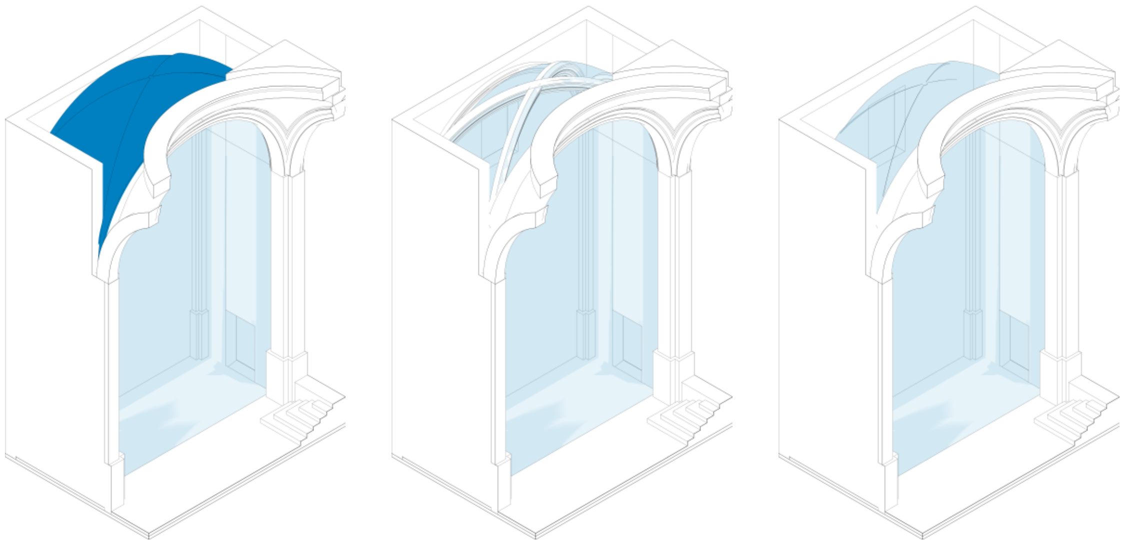

Figure 8. 3D volume vertically bounded by the de Autodesk® Revit 2024 "roof" tool visible by the Autodesk® plugin Dynamo. Source: Own elaboration (2024).

3.1.4. Attribution of parameters

Through tests with the different geometric shapes, it was identified that when complex volumes were generated, they were not visible on the Autodesk® Dynamo plugin screen, only on the Autodesk® Revit software screen, and therefore it was not possible to attribute parameters to them. Therefore, we tried to change the 'mass' category in which the volumes were being generated, looking for another category of family where we could materialise it in 3D and attribute informative parameters to it. The successful category was that of 'piece'.

4. Results

From the process presented, it was possible to generate spatial volumes in environments with complex ceilings that allow their visualisation and the attribution of informative parameters within the software in which the building has been modelled (Figure 9).

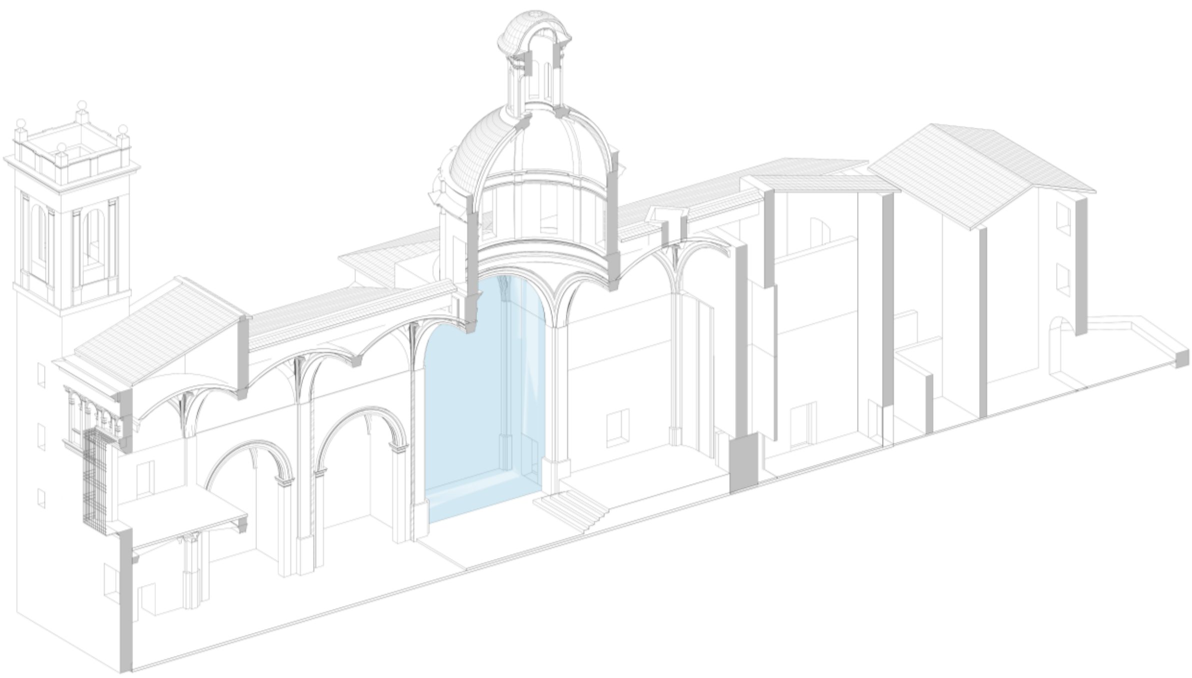

Figure 9. 3D volume visualised inside a 3D section of the Colegio del Patriarca church. Source: Own elaboration (2024).

The information incorporated in the volumes can be extrapolated to GIS platforms by means of the IFC format and is also recognised by other plugins compatible with Autodesk® Revit software, such as DiRoots®, allowing the use of filters and comparative analysis between parameters using colour ranges.

5. Conclusions

From the Autodesk® Revit 2024 software, using the 'room' tool, it is possible to accurately calculate its area, as well as to calculate its volume. But, unlike the area that is generated automatically, the volume needs manual adjustments. The demilitation of the height of room volumes works very well for simple shapes such as pitched roofs, domes or simple vaults, but when it comes to more complex shapes such as ribbed vaults, measurement errors occur.

The solution adopted allows more precise volumetric data to be generated, enabling a more accurate environmental analysis that is closer to the real one. The process also facilitates compatibility with plugins and export to GIS platforms of the integrated parameters and 3D volumes, allowing them to be visualised by colour range, generating different visualisation maps according to the parameter used, facilitating the visual analysis of all the building's environments, and also allowing analysis in conjunction with other buildings.

Taking as a reference the ILoD presented by Tang et al. (2018) and the current level of detail of the 3D model, an ILoD2 level would fit. But considering the final objective of this model, which is the environmental analysis closer to the real one and dedicated to the improvement of the preventive conservation and maintenance of heritage buildings and the comfort and safety of its users, it is possible that the level of detail increases up to ILoD4 level.

The result of the process implemented in this work may help future stakeholders in the integration of environmental sensor data with HBIM models, allowing a more accurate and closer analysis of the real environment, as well as facilitating the compatibility of the model with plugins and other external tools such as GIS or simulation software.

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8. References

Banfi, F. (2017). BIM orientation: Grades of generation and information for different type of analysis and management process. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(2W5), 57–64. https://doi.org/10.5194/isprs-archives-XLII-2-W5-57-2017

Banfi, F., Barazzetti, L., Previtali, M., & Roncoroni, F. (2017). Historic BIM: A New Repository for Structural Health Monitoring. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-5/W1*(W1), 269–274. https://doi.org/10.5194/isprs-archives-XLII-5-W1-269-2017

Biljecki, F., Ledoux, H., & Stoter, J. (2016). An improved LOD specification for 3D building models. *Computers, Environment and Urban Systems*, *59*, 25–37. https://doi.org/10.1016/j.compenvurbsys.2016.04.005

Brumana, R., Della Torre, S., Previtali, M., Barazzetti, L., Cantini, L., Oreni, D., & Banfi, F. (2018). Generative HBIM modelling to embody complexity (LOD, LOG, LOA, LOI): surveying, preservation, site intervention—the Basilica di Collemaggio (L'Aquila). *Applied Geomatics*, *10*(4), 545–567. https://doi.org/10.1007/s12518-018-0233-3

Brumana, R., Stanga, C., & Banfi, F. (2022). Models and scales for quality control: toward the definition of specifications (GOA-LOG) for the generation and re-use of HBIM object libraries in a Common Data Environment. *Applied Geomatics*, *14*, 151–179. https://doi.org/10.1007/s12518-020-00351-2

Castellano-Román, M., & Pinto-Puerto, F. (2019). Dimensions and Levels of Knowledge in Heritage Building Information Modelling, HBIM: The model of the Charterhouse of Jerez (Cádiz, Spain). *Digital Applications in Archaeology and Cultural Heritage*, *14*(August). https://doi.org/10.1016/j.daach.2019.e00110

Escudero, P. A. (2021). *La gestión eficiente de los Bienes Patrimoniales mediante la aplicación de la metodología HBIM. El caso de la Iglesia de San Lorenzo en Valencia.* 2020–2021. https://riunet.upv.es:443/handle/10251/174849

Freitas, C.A. da C., Xavier Junior, E.D., & da Silva, A.B.A. (2023). A door to access HBIM : didactic aspects to advance in the level of detail (LoD), geometry (LOG) and information (LOI). In *XXVII SIGraDi Conference 2023*. 203–214. https://papers.cumincad.org/data/works/att/sigradi2023_358.pdf

Garcia-Gago, J., Sánchez-Aparicio, L.J., Soilán, M., & González-Aguilera, D. (2022). HBIM for supporting the diagnosis of historical buildings: case study of the Master Gate of San Francisco in Portugal. *Automation in Construction*, *141*(2007), 104453. https://doi.org/10.1016/j.autcon.2022.104453

Historic England. (2017). *BIM for Heritage: Developing a Historic Building Information Model. Swindon. Historic England.* Historic England. https://historicengland.org.uk/advice/technical-advice/recording-heritage/

Hou, G., Li, L., Xu, Z., Chen, Q., Liu, Y., & Mu, X. (2022). A Visual Management System for Structural Health Monitoring Based on Web-BIM and Dynamic Multi-source Monitoring Data-driven. *Arabian Journal for Science and Engineering*, *47*(4), 4731–4748. https://doi.org/10.1007/s13369-021-06268-1

Machete, R., Neves, M., Ponte, M., Falcão, A.P., & Bento, R. (2023). A BIM-Based Model for Structural Health Monitoring of the Central Body of the Monserrate Palace: A First Approach. *Buildings*, *13*(6), 1532. https://doi.org/10.3390/buildings13061532

Meoni, A., Vittori, F., Piselli, C., D'Alessandro, A., Pisello, A.L., & Ubertini, F. (2022). Integration of structural performance and human-centric comfort monitoring in historical building information modeling. *Automation in Construction*, *138*(December 2021), 104220. https://doi.org/10.1016/j.autcon.2022.104220

Mitro, N., Krommyda, M., & Amditis, A. (2022). Smart Tags: IoT Sensors for Monitoring the Micro-Climate of Cultural Heritage Monuments. *Applied Sciences*, *12*(5), 2315. https://doi.org/10.3390/app12052315

Moyano, J., Fernández-Alconchel, M., Nieto-Julián, J. E., Marín-García, D., & Bruno, S. (2023). Integration of dynamic information on energy parameters in hbim models. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *48*(M-2–2023), 1089–1096. https://doi.org/10.5194/isprs-Archives-XLVIII-M-2-2023-1089-2023

Nagy, G., & Ashraf, F. (2021). HBIM platform & smart sensing as a tool for monitoring and visualizing energy performance of heritage buildings. *Developments in the Built Environment*, *8*, 100056. https://doi.org/10.1016/j.dibe.2021.100056

Ni, Z., Liu, Y., Karlsson, M., & Gong, S. (2021). A Sensing System Based on Public Cloud to Monitor Indoor Environment of Historic Buildings. *Sensors*, *21*(16), 5266. https://doi.org/10.3390/s21165266

O'Shea, M., & Murphy, J. (2020). Design of a BIM Integrated Structural Health Monitoring System for a Historic Offshore Lighthouse. *Buildings*, *10*(7), 131. https://doi.org/10.3390/buildings10070131

Rolim, R., López-González, C., & Viñals, M. J. (2024). Analysis of the Current Status of Sensors and HBIM Integration: A Review Based on Bibliometric Analysis. *Heritage*, *7*(4), 2071–2087. https://doi.org/10.3390/heritage7040098

Talaverano, R.M., Fragero, J.I.M., & De los Ángeles Utrero Agudo, M. (2021). Reflections and criteria related to the creation of BIM models of historical buildings. *Arqueologia de La Arquitectura*, *18*, 1–10. https://doi.org/10.3989/ARQ.ARQT.2021.005

Tang, L., Li, L., Ying, S., & Lei, Y. (2018). A Full Level-of-Detail Specification for 3D Building Models Combining Indoor and Outdoor Scenes. *ISPRS International Journal of Geo-Information*, *7*(11), 419. https://doi.org/10.3390/ijgi7110419

