

From Surveying Techniques to a 3D GIS Geodatabase

Barbara Marana¹, Giorgio Ubbiali²

¹ *DISA, Department of Engineering and Applied Sciences, University of Bergamo, Viale G. Marconi, 5 - 24044 Dalmine (Bergamo), barbara.marana@unibg.it*

² *Diemme Strumenti, Via Grandi 24/c - 22063 Cantù (Como), ubbiali@diemmestrumenti.com*

Abstract – Topographic surveys of buildings are usually performed with a variety of instruments and techniques. Then, dedicated software packages provide 3D metric models that can be enriched with a series of descriptive information. The user can choose between three different options: Building Information Modelling (BIM), Historical Building Information Modelling (HBIM) and 3D GIS Geodatabases.

Particularly regarding cultural heritage buildings, information is extremely heterogeneous.

Geographic Information System (GIS) software packages facilitate the creation of georeferenced 3D environments and geodatabases. This allows linking all the information to the referenced metric building; it is useful for its maintenance, restoration and management. The surrounding environment, to which it is closely connected, plays an important role.

This paper describes how we built a GIS geodatabase of two 3D-modelled apses of a small church in the province of Bergamo. All the available information was gathered and linked in a 3D GIS scene.

I. INTRODUCTION

Surveying buildings, with laser scanners and photogrammetric techniques, provides the input required to construct 3D building models and derive a variety of 2D information, such as vertical and horizontal sections and raster images detailing the building's description at different resolutions. These products are managed with the help of dedicated SFW packages.

Then, the digital description of a building can be achieved in different ways, through BIM (Building Information Modelling) [1], HBIM (Historic Building Information Modelling) [2] and 3D GIS geodatabases.

BIM applications are typically adopted for new buildings, describing their structural elements with a defined library of parametric objects, representing construction components that contain not only geometric attributes, but also information about the physical properties of the applied materials. They are useful across a building's entire lifecycle, starting from its project and construction [3].

HBIM stems from BIM, as a standardised library of parametric objects is insufficient for the complex and diverse architecture of cultural heritage buildings [4]. It is

useful for renovation, maintenance and conservation projects.

3D GIS geodatabases are collectors of heterogeneous information linked to 3D metric features inside GIS georeferenced scenes. In the case of heritage buildings and their ancient origin, they have undergone restoration, maintenance and interventions in time and also have a lot of related documentation which requires long and demanding research work. This material can be made by photos, projects, analyses and text documents of different origins and times. 3D GIS geodatabases become the most effective solution for storing all this heterogeneous material in a single environment and placing the referenced one in the proper spatial position. The advantage is also the possibility to make queries, define topological rules, enrich and update the collected information and add the products of new analyses and acquisitions. The spatial reference also becomes highly useful when considering the environment in which the building is located, and that deeply influences it with its changes and all kinds of phenomena occurring around it. This allows a better understanding of the building and to find the most suitable decisions for interventions, maintenance and restoration. This way, HBIM models and 3D GIS geodatabases represent the two faces of the same coin and their integration can be useful in many cases [5, 6].

It is also important to underline that the subject of BIM and GIS integration has been widely analyzed [7, 8, 9]. However, recently, a major step towards resolving this debate has been made thanks to a new partnership that allows users to integrate BIM products into GIS environments directly. Esri has partnered with Autodesk [10] to put GIS and BIM integration at the centre of construction projects. By accurately georeferencing BIM models, they are correctly placed in the real world. This alignment is essential for integrating BIM data with other geospatial data layers, such as maps, satellite imagery and environmental data [11].

The solution is provided by a relevant package called ArcGIS GeoBIM [12].

This is the first step, primarily focused on the project and management of buildings. However, in time, we hope to have new developments, also concerning a more complete and effective management of cultural heritage buildings and their heterogeneous information.

Going back to the digital description of a building, the first step, common to all three ways previously mentioned, is a topographic survey: surveying buildings, with laser scanners, GNSS receivers and photogrammetric techniques, provides the input required to construct georeferenced 3D building models and derive a variety of 2D information, such as vertical and horizontal sections and raster images detailing the building description at different resolutions. These products are managed with the help of dedicated SFW packages.

Drawing on previous studies [13 and mainly 14], this paper describes how it is possible to import a georeferenced 3D building model – in this case, of a cultural heritage building – into a GIS software package and establish connections between all the available information. This doesn't provide an HBIM model, but a 3D georeferenced geodatabase, into which all the building's information can be stored and linked to the structure under examination. This can be achieved by creating a geodatabase inside a 3D scene. Here, all the geometric information is referenced and therefore correctly placed, and the non-georeferenced information (such as images, texts, etc.) is linked via attribute tables to the corresponding geometric elements.

In the past, it was difficult to import and manage 3D models in GIS SFW packages, but this is now possible thanks to improved hardware and software.

Geographic Information Systems do not provide the advanced tools of BIM for modelling complex surface shapes of 3D objects. They allow, by now, only 3D basic elements to be edited, such as lines, points and simple 3D objects. On the other hand, GIS applications offer a major advantage: topological rules can be established among objects to evaluate their geometrical and spatial relationships. It is also possible to make queries. This way, the georeferenced 3D model of the building becomes a shell that, with the aid of a geodatabase, allows connecting, storing and updating all the available and new heterogeneous information.

Starting from these assumptions, this paper describes the steps followed to provide a 3D geodatabase of a test case: a small church in the province of Bergamo, which is called the Sanctuary of The Madonna dell'Olmo. The work was completed by taking the following steps: topographic surveys were performed, with varying instruments, and the survey data were processed. Three-dimensional georeferenced models were constructed and some 2D information (horizontal and vertical sections) was derived. Finally, a 3D GIS geodatabase was created in a suitable 3D GIS environment. The geodatabase collects all the referenced information and data without spatial reference, such as texts, images, etc.

Figure 1 outlines the steps required to complete the tasks mentioned above.

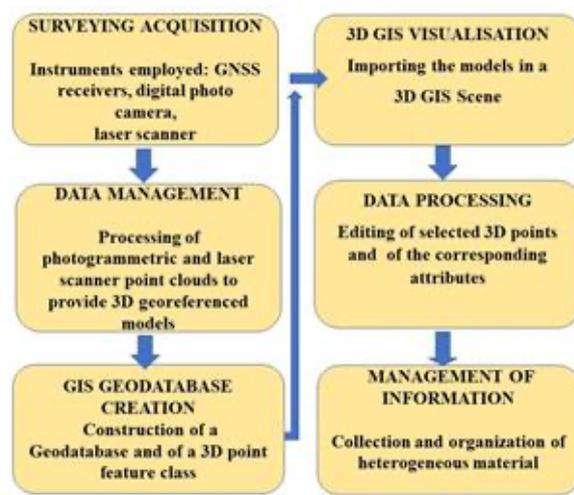


Fig. 1. Flowchart describing the steps taken in this work.

II. THE SANCTUARY OF THE MADONNA DELL'OLMO

The Sanctuary of the Madonna dell'Olmo, which dates to the fourteenth century, is in the southern part of the municipality of Verdellino, a village in the province of Bergamo [15, 16, 17]. The name of the church derives from an ancient legend about a miracle being performed by the Holy Mary through an elm tree once located in what later became the front yard of the church.



Fig. 2. The Sanctuary of the Madonna dell'Olmo.

The church, in Figure 2, was initially built in a rural area and then gradually absorbed by the industrial and residential settlement of Zingonia (around 1960), in the municipality of Verdellino. In 1400, the sanctuary already existed in its present form. It has not undergone major changes over the centuries.

In its outer part, there is a low wall that contains a grassy churchyard, a well, the rustic sacristy and a small bell tower. In the middle of the churchyard stands what remains of the secular elm (part of the trunk with a hollow inside), surrounded by a gate. Behind the elm tree is the entrance, preceded by a small porch that completely covers the façade. Inside, as shown in Figure 3, the sanctuary has a single nave divided into two bays by a pointed arch protruding from the wall.

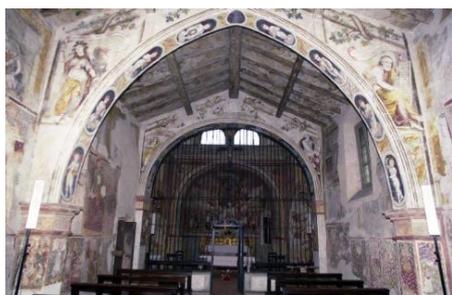


Fig. 3. The interior of the sanctuary [18].

A round arch leads into the presbytery, which has a rectangular plan with three small apses, a high altar and a minor altar on the right. The church is richly decorated with frescoes throughout its interior, on the ceilings, arches and walls. They have been painted in different periods by authors who are, unfortunately, unknown. These frescoes, which hold great historical value, earned the church a special grant in 1914, when the Superintendence of the Monuments of Lombardy declared that the Sanctuary of the Madonna dell'Olmo would be included among the national monuments of art [17].

Up to now, this sanctuary has been studied only from a historical and cultural point of view, and the existing documentation is limited to textbooks and images. Now, thanks to modern surveying techniques, it is possible to create thoroughly georeferenced geometric documentation of the building. This metric and referenced information will help facilitate the management of the building.

III. SURVEY AND DATA MANAGEMENT

All the instruments and software packages employed in this work and the resultant outputs achieved are summarized in Table 1.

Table 1. Instruments, SFW packages and outputs.

	Surveying	GIS
Acquisition Instruments	eSurvey E300 Pro GNSS receiver; Nikon D3300 reflex camera; Faro Focus Premium laser scanner	
Software Packages	Mercurio and Meridiana by Geopro; Scene by Faro; Riscan Pro by Regl; 3DF Zephyr by 3DFlow	ArcGISPro 3.1.3 by Esri
Resultant Outputs	3D Georeferenced Models	3D GIS Geodatabase

The outside of the church was surveyed using a Global Navigation Satellite System (GNSS) receiver, for

georeferencing, and other instruments. A laser scanner, with a camera mounted on board, was used to acquire information on the interior and exterior of the building, while a photogrammetric survey targeted the major and right lateral apses inside the church. The laser scanner was used to survey the complete interior area, but not some side areas of the exterior or the roof. Further surveys could then be performed to complete the missing information.

A GNSS eSurvey receiver, the E300 Pro, was employed [19] to identify a set of points that could serve as the basis for georeferencing the products of the laser scanner and camera. For the interior analyses, we focused on the right side and the major apses of the presbytery. The photogrammetric survey was carried out with a Nikon D3300 reflex camera [20] with a 24.2-megapixel sensor, and the images were taken at a resolution of $6,000 \times 4,000$ pixels. In addition, a Faro Focus Premium laser scanner with a 13-megapixel camera mounted onboard was employed in the survey project [21].

The data were processed using multiple software packages: Mercurio and Meridiana [22] by Geopro, Scene [23] by Faro, Riscan Pro [24] by Regl and 3DF Zephyr [25] by 3DFlow. They allowed us to build a georeferenced (WGS84 UTM32N) laser scanner 3D point cloud for the interior part of the building and two dense photogrammetric 3D point clouds for the two apses. These clouds were then aligned, and finally, with the use of meshes and textures, two 3D georeferenced models were produced. In Figures 4 and 5, we can see (in Zephyr) the final 3D georeferenced models of the right side and major apses of the presbytery section of the sanctuary.



Fig. 4. The right lateral apse.



Fig. 5. The major apse.

It is worth noting that the resolution of the final models was set to the highest possible level. It follows, for example, that, for the 3D model of the major apse, the mesh is of 3,838,878 triangles.

In addition to the georeferenced geometric information, i.e. the two 3D models and horizontal and vertical sections, we collected textual information and images. The whole complex of material was then uploaded into a GIS software. Hence, both the georeferenced and non-georeferenced material facilitated the construction of a 3D geodatabase of the building within a GIS 3D environment, called scene.

IV. A 3D GIS BUILDING GEODATABASE

At this point, we were working inside the SFW package ArcGISPro, version 3.1.3, made by Esri [26]. The aim was to store all the available heterogeneous information, connected with the building, in a geodatabase. This way, it would be possible to easily learn what data are already available, to plan to enrich them with new acquisitions, and evaluate possible maintenance interventions.

The imported files contain the following information:

- two 3D georeferenced models of the right side and major apses of the sanctuary;
- available photos, text and pictures and new georeferenced data, such as vertical and horizontal sections.

We decided to create a geodatabase and a 3D point feature class, to consolidate all the information within the GIS environment. The 3D files were then imported into a 3D scene to provide a geometric referenced vision of the two apses. Figure 6 shows the two models and the volumetry of the surrounding buildings (visualised at their real Orthometric height), in the municipality of Verdellino. This shapefile was downloaded from the Lombardy Geoportal [27]. A topographic basemap, provided by Esri, was chosen as the background.

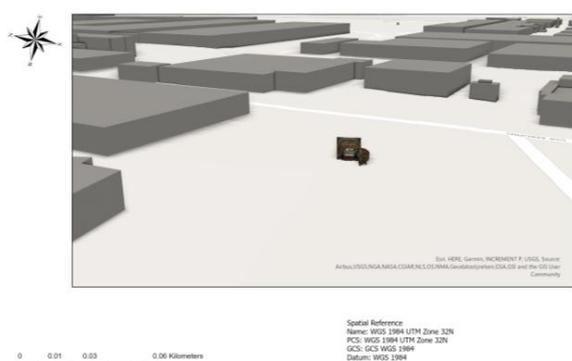


Fig. 6. The 3D referenced models in an ArcGISPro scene with the DBGT (Geo-Topographical Database) buildings.

Focusing, at first, on the major apse, an editing step allowed the selection of some points of interest and to link the corresponding information, such as images, texts and descriptions, inside the attribute table. Consequently,

these points could be easily identified and selected in the 3D scene by clicking on special symbols.

Figure 7 shows, for a selected point (in cyan) of the major apse, in the 3D scene, the corresponding pop-up window, with the relevant information stored in the attribute table. If there is a preview image, one can click on it and view an enlarged version inside an image editing program.

Then, for each selectable point, we also added, in the attribute table, three fields (columns) which store, in different folders, the corresponding available and new information. They are named Literature (for books, articles, papers, letters, etc.), Pictures (for paintings, images, pictures, photos, etc.) and Analyses (for plans, projects, interventions, restorations, etc.). Each folder can then be organised in subfolders, according to the variety and amount of the available and new information. It is important to collect, keep and update this information in case of future analyses and works.

Two-dimensional georeferenced information derived from the models, such as horizontal and vertical sections, can also be correctly placed in a 3D GIS scene.

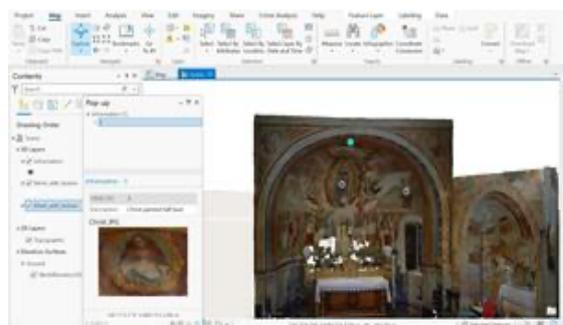


Fig. 7. The available information stored in an attribute table and linked to a selectable point on the 3D georeferenced model of the major apse, in an ArcGISPro scene.

V. DISCUSSION AND CONCLUSION

Thanks to the advantages offered by recent developments in survey instruments and software packages, it is nearly unthinkable to perform a building survey using only one type of instrument. The work described in this paper shows how the use of joint survey instruments and techniques can provide fast and thorough metric georeferenced information on a building.

Our goal was to create a 3D georeferenced geodatabase of a religious cultural heritage building. A GIS environment offers the advantage of providing a complete georeferenced description of a building's geometrical features, which can be enriched with associated heterogeneous information (texts, images, etc.). This is now possible, thanks to advancements in software and hardware. We have described how we were able to create a 3D geodatabase for two apses of the sanctuary.

The next step will be to enrich the database, following two different but parallel paths. The first will focus on the research, collection and reordering of all existing heterogeneous material that can be found. The second

will provide new georeferenced and non-georeferenced information, starting, for instance, with a survey of the exquisite ceiling frescoes of the two spans and the presbytery dome. This procedure will also be performed for the other frescoes on the walls, to build as many georeferenced 3D models as possible. These will then be connected to the geodatabase, with the corresponding information. As a further step, we plan to use a drone to acquire a comprehensive 3D georeferenced model of the building exteriors. Another task will be to perform a georadar survey of the floors inside the sanctuary and the outside areas at the front. It has been claimed, but not yet verified, that some hidden rooms and built areas could exist just below the sanctuary's interior and close to the premises.

As noted above, this will help to produce a 3D geodatabase, always updatable with both old and new data, that is useful for managing the building, for instance, by maintenance and possible restoration. Geographical referencing also facilitates the analysis of the influence and possible problems related to the surrounding environment, such as atmospheric phenomena, air quality, soil texture and geology, seismic events, etc. It is important to consider the close relationship between a building and its surroundings and only georeferenced information can help achieve this purpose. In fact, at the sanctuary we studied, an issue with water infiltration had recently damaged the dome. Work is underway to repair the church and prevent future damage.

Besides, GIS environments are extremely flexible, allowing work at different scales, according to requirements. This way, it is possible to focus on large-scale particulars, with a high Level of Detail (LOD), or to consider a wider environment, at small-scale, with a reduced Level of Detail.

The OGC standard CityGML defines five LODs, ranging from 0 to 4, which state the amount of geometric and semantic information provided to describe a building. At LOD0, a 3D edifice is represented by its simple 2D footprint and, finally, LOD4 defines the interior features of an architecturally detailed 3D model [28].

GIS applications typically address territorial issues at a small scale; however, when they focus on specific analyses of a building at a large scale, the level of detail plays an important role. For this reason, it is crucial to decide the priorities of a project. If the purpose, for instance, is the study of a building within its environment, the building LOD can be low; otherwise, if the work is focused on the analysis of the walls of a crypt, the LOD must be higher. As said, GIS environments offer the advantage of being extremely flexible and allow working at different scales.

According to these assumptions, a building survey is performed with different instruments, from drones to laser scanners, which provide 3D models at different resolutions.

It has to be remembered, anyway, that only the integration of BIM and GIS is the best approach for a

thorough description of a building, whose project and management are highly influenced by the surrounding environment. As seen above, this integration is now possible and, in time, it will hopefully evolve, also concerning the management of cultural heritage buildings and their legacy and new heterogeneous information.

ACKNOWLEDGEMENTS

The authors would like to thank Nicolò Perquis, a former student at the University of Bergamo, who constructed the georeferenced 3D models of the two apses on the occasion of his junior thesis in building engineering.

REFERENCES

- [1] C.Eastman, C.M.Eastman, P.Teicholz, et al., "BIM Handbook: A Guide to Building Information Modeling for Owner, Manager, Designer, Engineers and Contractors", Hoboken, NJ: John Wiley & Sons, 2011, p. 243.
- [2] M.Murphy, E.McGovern, S.Pavia, "Historic building information modelling (HBIM)", *Structural Survey*, Vol. 27 No. 4, 2009, pp. 311-327.
- [3] A.Sampaio, N.Gomes, A.Gomes, A.Sanchez-Lite, "Multi-Project in an Integrated BIM Model: Clash Detection and Construction Planning", *Journal of Software Engineering and Applications*, 15, 2022, pp. 345-358.
- [4] D.P.Pocobelli, J.Boehm, P.Bryan, J.Still, J.Grau-Bové, "BIM for heritage science: a review", *Herit. Sci.* 6, 2018, pp 23-26.
- [5] G.Saygi, G.Agugiario, M.Hamamcioğlu-Turan, F.Remondino, "Evaluation of GIS and BIM roles for the information management of historical buildings", *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, II-5/W1, 2013, pp. 283-288.
- [6] G.Vacca, E.Quaquero, D.Pili, M.Brandolini, "GIS BIM integration for the management of historical building", *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2, 2018, pp. 1129-1135.
- [7] B.Pedó, A.Teziel, D.Goethals, L.Koskela, M.Leaver, A.Victory, E.Vrabie, E.Bocian, "BIM and GIS integration: lessons learned from multiple case studies", *proceedings of the 2023 European Conference on Computing in Construction and the 40th International CIB W78 Conference*, 2023,10.35490/EC3.2023.248.
- [8] M.Sani, A.Rahman, "GIS and BIM integration at data level: a review", *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* (2018). XLII-4/W9, pp. 299-306. 10.5194/isprs-archives-XLII-4-W9-299-2018.
- [9] Z.Ma, Y.Ren, "Integrated Application of BIM and GIS: An Overview", *Procedia Engineering*, 2017, Volume 196, pp. 1072-1079, ISSN 1877-7058.
- [10] Esri & Autodesk by Esri Webpage, <https://www.esri.com/en-us/about/partners/our-partners/strategic-alliances/autodesk/overview>, last accessed 2025/09/05.

- [11] Locations and extents in ArcGIS GeoBIM BIM by Esri Webpage, <https://doc.arcgis.com/en/geobim/latest/get-started/locations-and-extents-in-arcgis-geobim.htm>, last accessed 2025/09/05.
- [12] ArcGIS GeoBIM product overview, <https://www.esri.com/it-it/arcgis/products/arcgis-geobim/overview>, last accessed 2025/09/05.
- [13] N.Dell'Unto, et al., "Experiencing ancient buildings from a 3D GIS perspective: A case drawn from the Swedish Pompeii Project", *Journal of Archaeological Method and Theory* 23(1), 2016, pp. 73–94.
- [14] M.Polig, "3D GIS for building archaeology – Combining old and new data in a three-dimensional information system in the case study of Lund Cathedral", *Studies in Digital Heritage* 1(2), 2017, pp. 225–238.
- [15] P.Damiani, "La Madonna dell'Olmo a Verdellino", Printed in Mazara del Vallo-Trapani, 1948.
- [16] C.Amadeo, "Il Santuario della Madonna dell'Olmo in Verdellino", Printed by Benti and Ghilardi in Gorlago (Bergamo), 1974.
- [17] G.Stefanoni, "La Madonna dell'Olmo", Printed by La Grafica in Ciserano, Verdellino (Bergamo), 2006.
- [18] Lombardy Cultural Heritage Geoportal (scroll the photos), <https://www.lombardiabeniculturali.it/architetture/sc-hede/4m010-00353/>, last accessed 2025/09/05.
- [19] E300 Pro GNSS receiver by eSurvey Webpage, <https://esurvey-gnss.com/product/landsurvey/e300pro>, last accessed 2025/09/05.
- [20] D3300 camera by Nikon Webpage, <https://downloadcenter.nikonimglib.com/it/products/21/D3300.html>, last accessed 2025/09/05.
- [21] Focus laser scanner by Faro Webpage, <https://www.faro.com/it-IT/Products/Hardware/Focus-Laser-Scanners>, last accessed 2025/09/05.
- [22] Geopro Homepage, <https://www.geopro.it/programmi>, last accessed 2025/09/05.
- [23] Scene software by Faro Webpage, <https://www.faro.com/it-IT/Products/Software/SCENE-Software>, last accessed 2025/09/05.
- [24] Riscan Pro by Riegl Webpage, <http://www.riegl.com/products/software-packages/riscan-pro/>, last accessed 2025/09/05.
- [25] 3DF Zephyr by 3DFlow Webpage, <https://www.3dflow.net/it/software-di-fotogrammetria-3df-zephyr/>, last accessed 2025/09/05.
- [26] Esri Homepage, <https://www.esri.com/en-us/home>, last accessed 2025/09/05.
- [27] Lombardy Region Geoportal Homepage, <https://www.geoportale.regione.lombardia.it/>, last accessed 2025/09/05.
- [28] F.Biljecki, H.Ledoux, J.Stoter, "An improved LOD specification for 3D building models", 2016, *Computers Environment and Urban Systems*, vol. 59, pp. 25-37.