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A Scan-to-BIM Approach for the Preservation of the Architectural and Archaeological Heritage: the Digitisation of the Complex of San Nicolò Regale in Mazara del Vallo (Italy)

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Abstract

In recent years, Built Heritage (BH) management has greatly benefited from advances in digital survey technologies and the application of Building Information Modelling (BIM) processes for digitisation and preservation purposes. The integration of range-based (static and mobile) and image-based (aerial and terrestrial) survey techniques enables the creation of comprehensive 3D geospatial datasets for BIM modelling. This study presents the Heritage BIM (HBIM) digitisation of an architectural and archaeological complex in Mazara del Vallo (Italy). The site includes two assets: the 12th-century Arab-Norman church of San Nicolò Regale and the remains of a late Roman domus (3rd-4th century C.E.) beneath it, featuring polychrome mosaic floors. This digitisation aimed to provide exhaustive and detailed geometric documentation and create an accurate digital model for conservation and management purposes. Data acquisition combined mobile and static laser scanning with close-range photogrammetry. The final model was obtained through a Scan-to-BIM approach for the church and an integrated Scan-to-Mesh-to-BIM approach for the domus, ensuring accurate representation of both architectural and archaeological elements. This methodology serves as a reference for digitising and preserving similar heritage sites.

1. Introduction

In the last decades, Historic Building Information Modelling (HBIM) has proven a smart and effective methodology for managing Built Heritage (BH) assets and fostering maintenance and preservation plans [RMF24]. HBIM usually relies on a Scan-to-BIM approach to document existing buildings by acquiring their as-is geometry through digital surveys, with range-based and image-based survey techniques, processing the data into a detailed and reliable dataset, and modelling parametric as-built replicas [ALM23]. These digital models are an essential tool as they contain complete and structured semantic and geometric information useful to BH management for any scope of work related to the maintenance of the real assets.

Nowadays, the modelling phase, carried out within BIM environments, is based on the use of standardized parametric architectural elements (generally called “families”) for building reconstruction. However, this approach is not always easy to be applied due to the lack of families related to historical architectural elements in BIM software, and flexible modelling tools to embody the complexities of the historical construction methods [ADL*20]. Digitizing BH becomes even more challenging in archaeological contexts, where parametric modelling is often unfeasible due to the fragmentary and irregular nature of remains [Ban20]. The irregularity of the archaeological remains, due to the intense degradation occurred over the centuries, represents a significant obstacle for parametric modelling, which requires very well-defined geometric shapes [SGL20]. Consequently, non-parametric approaches — such as converting mesh models into BIM objects — are frequently adopted [LR24]. While these methods offer higher geometric accuracy, they typically lack the ability to encode semantic information [MON*20].

This work aims to test an ad-hoc integrated HBIM digitization with a Scan-to-BIM and a so-called Scan-to-Mesh-to-BIM [NAL25] approach of an architectural and archaeological complex and to develop a possible strategy to address the issues of parametric modelling for both architectural and archaeological features whenever coexisting in the same assets. The study was carried out for the complex of San Nicolò Regale in Mazara del Vallo (Italy), comprising two overlapping assets on the same footprint: the medieval church of San Nicolò Regale and the underlying remains of a late Roman domus, notable for its mosaic floors. . The digitisation was provided by a 3D survey integrating static TLS, Handheld Mobile Laser Scanning (HMLS) and terrestrial photogrammetry applied to different parts of the complex for granting an integral acquisition of the whole complex, intended for documentation purposes. Parametric modelling was carried out for the upper church, whilst a mesh model of the archaeological remains was added to the HBIM model in order to adequately represent all parts of the site within a unified project. Furthermore, the integration of the textures of the mosaics into the HBIM model delivered from the photogrammetric survey allowed for a more realistic representation of the archeological findings. The digital model thus obtained has been developed in view of future requalification plans on the site aimed at an enhanced fruition of the archaeological area by visitors.

2. The church of San Niccolò Regale

The church of San Nicolò Regale is in the historic center of Mazara del Vallo (western Sicily, Italy) and was built in 1124 by order of King Roger II, in an Arab-Norman style. The building was heavily altered between 1606 and 1626 in a Baroque style, but several restoration interventions which have taken place in 1947, 1968 and 1980, removed the Baroque additions to recover its original appearance [Riz58]. The building is an almost perfect cube (about 10.5 meters per side), topped by a central hemispherical dome on a tambour. Its sandstone walls display multiple decorative blind arches and pointed windows, with three apses on the east side whose the central one is the largest. A continuous rounded battlement runs along the top. The tambour-mounted dome, rebuilt during the restoration works of the 1980s, is externally clad in

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corrugated copper sheets and supports an internal plastered false ceiling. Inside, four Corinthian columns support arches dividing the space into nine parts. Barrel vaults cover the arms of the Greek cross layout, whilst cross vaults cover the corners. The central bay is topped by the dome, supported by angular squinched recesses (Figure 1).

Figure 1: *External and internal view of the upper church of San Nicolò Regale.*

In 1933, renovation works on the frontal churchyard accidentally uncovered the remains of a Roman house (domus) from the 3rd or 4th century C.E., located 2.5 meters below the church's floor. Excavations revealed five rooms, some with well-preserved mosaic floors (Figure 2). A well and some water channels suggest the domus may have had a thermal bath system. Since 1960, the site has been protected through a surrounding terrace.

Figure 2: *Detail of a mosaic paving one of the rooms in the domus.*

3. Data acquisition

Data acquisition was planned with three different methodologies to provide the most complete documentation of the complex: a HMLS survey which provided scans on all the accessible areas, both internal and external, a static TLS survey carried out to detect the roofing system of the church and acquire more detailed data about the archaeological area and a terrestrial photogrammetric survey focused on the Roman mosaics only.

3.1. HMLS survey

The laser scanner used for the HMLS survey was the BLK2GO by Leica Geosystem; this device is based on Simultaneous Localization And Mapping (SLAM) technology enabling mobile acquisition and providing very detailed point clouds in real-time. The BLK2GO combines LiDAR SLAM, Visual SLAM, and an IMU for its localization and mapping of the surrounding environment. The device is characterized by a measurement speed up to 420.000 p/s, a range from 0.2 to 25 m, and a vertical and horizontal field of view of 270° and 360°. Its 12 MPx RGB camera can acquire high-resolution images together with three 4.8 MPx panoramic cameras for spherical images. Point cloud resolution varies according on walking speed and the sensor-to-object distance. Furthermore, the paths should start and end at the same reference points to ensure trajectory control.

The HMLS survey of the whole complex forecasts three different paths, to be walked in both directions (Figure 3):

- the first one regards the church, for the acquisition of its interior parts and its external fronts;
- the second one regards the archaeological area;
- the third one, starting from the ancient ruins, connects the Roman domus to the external fronts of the church, the terrace and the churchyard.

The paths were planned and executed with generous portions of overlapping areas to ensure the correct alignment of the point clouds. Despite its indisputable advantages, such as versatility and portability, the HMLS doesn't allow the acquisition of the external part of the church roof due to limited acquisition range.

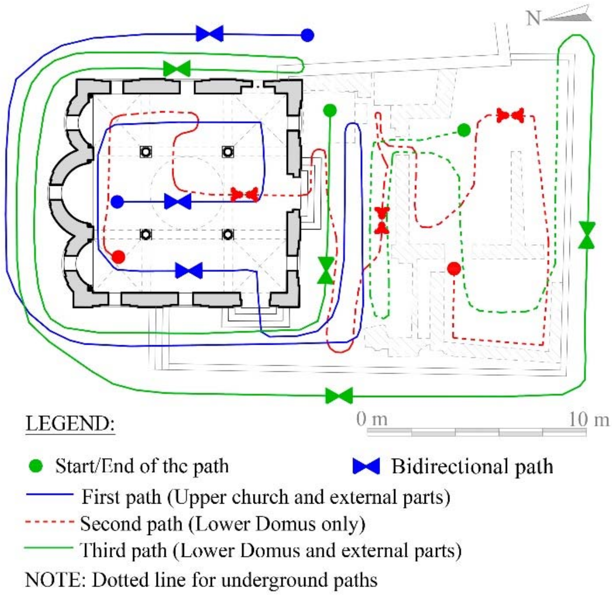

Figure 3: *The three paths for the HMLS survey.*

3.2. Static TLS survey

Given the inaccessibility of the roofing system of the church and the need to acquire more detailed and complete data of the archaeological area, some static TLS surveys were carried out using a FARO Focus 3D S120, characterized by a distance accuracy up to ±2 mm, a range from 0.6 m up to 120 m, a measurement speed of 976.000 points/second, and a vertical and horizontal field of view of 305° and 360°.

A first static TLS data acquisition was carried out by placing the laser scanner in five different locations on balconies and roofs on the surrounding buildings to acquire the external parts of the church's roof (Figure 4) granting the best visibility of the church's roof. To obtain resolutions at long distance compatible with those of the close-range mobile laser scanner, the acquisitions were performed at the highest possible resolutions (1.5 mm at 10 meters and 3 mm at 10 meters). A second static TLS survey was carried out to acquire the relevant parts of the Roman domus with a high level of detail. To acquire this area, ten scans were required with a wide overlap, a resolution of 7.6 mm at 10 m, and a horizontal and vertical field of view of 360° and 90°, respectively. This configuration ensured the maximum coverage of the horizontal surfaces, excluding the ceiling above for preventing redundant information.

Figure 4: *TLS acquisition of the external part of the roof.*

3.3. Terrestrial photogrammetric survey

The photogrammetric survey was carried out to obtain the textured 3D model and the orthophotos of each mosaic inside the domus. A very closed-range acquisition was performed, with camera-to-object distances ranging about 1.5÷2.0 meters in relation to the size of the mosaics. Several images all around the mosaics with convergent or stereoscopic schemes were taken. Given the characteristics of the used cameras (Nikon D5200 and Nikon D5100 both with a focal length of 28 mm), millimetric or sub-millimetric Ground Sample Distance (GSD) was obtained. The photogrammetric survey was conducted both on the largest and most complete mosaics and on the various fragments, even of limited dimensions, scattered in various positions of the domus.

4. Data processing

Data processing began from the HMLS survey using the Leica Cyclone Register 360. The point cloud obtained from the third path was used as reference for the alignment process to the other two point clouds. These were first manually aligned to the reference point cloud and then registered with a cloud-to-cloud procedure based on the Iterative Closest Point (ICP) algorithm. This automatic refinement allowed to estimate a RMSE of ±0.003 m for the first path point cloud alignment and of ±0.012 m for the second path point cloud alignment. The registered scans were imported into CloudCompare for editing and manually segmenting to remove redundant information. Finally, they have been merged to form the final point cloud.

The static TLS survey data for the church's roof was processed in Autodesk ReCap; the scans were divided into two projects (one for the north side and the other for the south side of the church) and registered using the ICP algorithms. Afterwards, they were imported into CloudCompare and aligned to the previous HMLS cluster through a point-based and ICP based registration. After verification to prevent misalignment, the datasets of the church's roof were merged with the HMLS cluster (Figure 5).

Figure 5: *A section view of the point cloud of the Complex of San Nicolò Regale.*

Similarly, the archaeological trench scans were processed in Autodesk ReCap, for a first alignment and registration, then aligned to the main HMLS dataset using the point based and ICP based registration in CloudCompare. This point cloud was not integrated and merged with HMLS dataset but imported into Agisoft Metashape to generate a detailed mesh model of the domus (Figure 6).

Mosaic images were processed in Agisoft Metashape for obtaining textured meshes and orthophotos for each mosaic in the domus. Images were oriented via Structure from Motion (SfM) algorithms and bundle adjustment, using the coordinates of some points measured from the static laser scanner dataset as Ground Control Points.

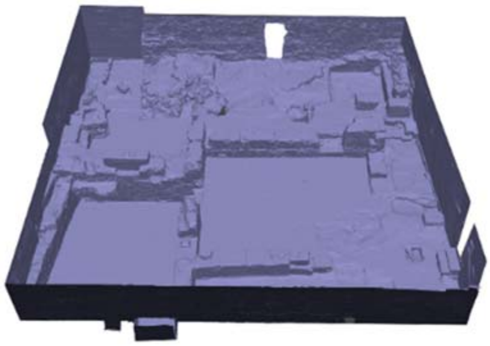

Figure 6: *The mesh model of the archaeological trench.*

5. HBIM modelling

The HBIM modelling phase was aimed at turning the geometric information from the point cloud into recognizable parametric items and at digitizing the church with a high level of detail. The parametric model was developed through Autodesk Revit software with a top-down approach, from the simplest to the most challenging elements. The in-built system families provided by the BIM software enabled the immediate shaping of walls, floor, vaults and the different parts of the flat roof, according to their outlines and geometric features as detected by the point cloud.

Currently, there is not typological library of Arab-Norman architectural elements. The most typical features of the church had thus to be modelled from scratch through loadable families; for this purpose, brand new families were created using the template editor of the software and then implemented into the project. In this way, the openings, arches, windows, the recessed squinches on the corners of the tambour, the apse basins, the dome and its pendentives were shaped (Figure 7). At the end of the process, the parametric model was completed in all its parts (Figure 8).

Once obtained the HBIM model of the upper church, the Scan-to-Mesh-to-BIM process enabled the digitization of the Roman domus. This experimental process was necessary due to the complex and irregular shape of the archeological remains that did not allow the adoption of a traditional Scan-to-BIM process.

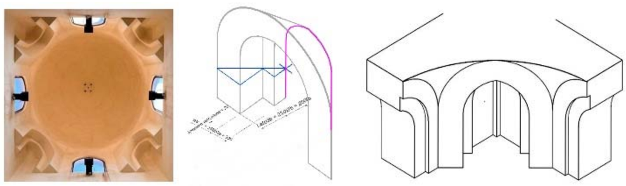

Figure 7: *Generation of the parametric loadable family of recessed squinches.*

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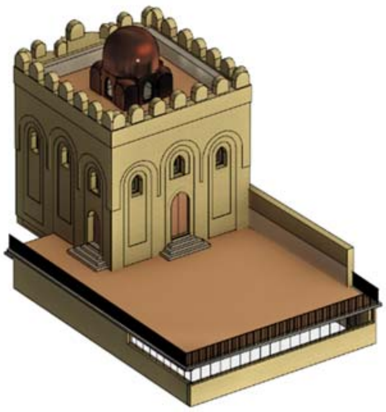

Figure 8: *View of the parametric model the complex of San Nicolò Regale.*

The polygonal mesh of the domus, generated from the static TLS point cloud, enabled the digitization of the slopes and the shapes of the surfaces. The mesh was segmented into the main architectural elements (walls and floors), imported into the BIM environment and connected to the parametric model. Then, the orthophotos of the mosaics have been mapped onto the uneven surfaces of the floors in the 3D mesh model. In this way it was possible to integrate parametric and surface 3D models and obtain a realistic rendering of the mosaics into a unique platform (Figure 9).

Figure 9: *View of the archaeological area in BIM environment.*

6. Conclusions

The work enabled the documentation and the HBIM digitisation of the architectural/archaeological complex of S. Nicolò Regale in Mazara, integrating a Scan-to-BIM approach for the architectural context with an experimental Scan-to-Mesh-to-BIM for the archaeological area. The results demonstrate how these approaches could provide effective support for the 3D digitization of BH complexes. From a methodological standpoint, the work has proven how the integration of different survey techniques is very useful in delivering a complete and accurate digitisation of a monumental complex. This integration provided a highly accurate point cloud, which served as a basis for the HBIM modelling. In addition, the photogrammetric survey was fundamental for the generation of orthophotos of the mosaic pavements within the archaeological trench, thereby completing the digital representation of the site.

One of the most significant aspects of the work was also the proper modelling phase, which highlighted the challenges of representing some geometries typical of Arab-Norman architecture and the irregular surfaces of the archaeological excavation. These complexities led to a diversified approach: for the architectural items, loadable families were created from scratch (a process proved time-consuming), whilst for the archaeological site, a Scan-to-Mesh-to-BIM process was applied. The approach represents a valid solution for the 3D digitization of monumental complexes containing architectural and archaeological features, but some challenges remain. In particular, the Scan-to-Mesh-to-BIM doesn't yet allow the management of semantic information of the architectural elements, despite some recent property software solutions are trying to fill this gap to import segmented mesh object as new families into BIM environment (i.e., the newest version of Autodesk ReCap 2026) . In this way, the segmented mesh, once imported into the BIM environment, could host semantic information, which would be beneficial to the relational database management system. This field constitutes a focus for future improvements of research.

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