

Applicability of a parametric and semantic model for the HBIM project of the Church of the Company of Jesus in Quito

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Abstract. This research addresses the parametric and semantic heritage modelling of the Church of the Company of Jesus in Quito, Ecuador, within the Historic Building Information Modelling (HBIM) context to manage information and support its preventive conservation and maintenance. The construction, architectural and artistic particularities of this emblematic example of the Latin American Baroque of the Jesuit order, built from 1605 to 1765, require an exhaustive 3D digital replica. An accurate model enables programmed actions in a comprehensive management project and further monitoring of the asset.

Massive data acquisition technologies, e.g., Terrestrial Laser Scanning (TLS) and Structure-from-Motion photogrammetry, greatly help capture the real state of historic constructions. These protocols provide accurate details that enrich the building's intrinsic database—structure, materiality, evolution and metamorphosis—and are constantly updated to support future interventions. A large library of heritage objects that supports the 3D model of the historic building is pursued. To face this challenge, progress must still be made to effectively implement unstructured data organisation processes and semantic classification by architectural and artistic typologies.

This work addresses the analysis and implementation of semi-automatic modelling techniques for accurate heritage representation. Based on TLS data, this Scan-to-mesh-to-BIM workflow culminates in the creation of 3D parametric objects. The methodological process developed explores several complementary paths to automate modelling processes, whether parts or complete historical systems, to reinforce the HBIM project.

Keywords: Terrestrial laser scanning, Photogrammetry, Heritage-BIM, Algorithmic modelling, Religious architecture of Quito, Church of the Company of Jesus.

1 Introduction

Advanced data acquisition technologies, e.g., Terrestrial Laser Scanning (TLS) and Structure-from-Motion photogrammetry, greatly aid in capturing the current condition of historic structures, essential for their preservation and maintenance. These protocols provide accurate details that enrich the building's intrinsic database—covering structure, materiality, evolution, and transformations—continuously updated to support future interventions on movable and immovable assets. A comprehensive library of heritage objects is crucial to support the 3D model of the historic building. To address this challenge, work is to be done to effectively organise unstructured TLS data and semantically classify architectural and artistic typologies.

2 The Heritage-BIM project

Building Information Modelling (BIM) methodology integrates building design through 3D digital representations of physical, functional, and semantic characteristics (Bruno et al. 2018; Pezeshki and Ivani 2018). BIM platforms provide tools to model architectural and construction systems, along with libraries of reusable parametric elements containing geometric, semantic, and topological attributes, which are valuable in architecture, engineering, construction, and design (Watson 2011; Bozoglu 2016).

The HBIM approach (BIM applied to Heritage) enables the representation of the preservation state of historic buildings. However, the heterogeneous characteristics and irregular morphologies of archaeological, architectural, and artistic heritage (PA3) complicate virtual modelling. Integrating remote sensing point cloud data enables the accurate modelling of architectural heritage components (Fai et al. 2011; Hichri et al. 2013). Nonetheless, the lack of specific objects for certain architectural styles and the absence of full process automation are still limitations (Anil et al. 2013).

In this context, this research addresses the systematisation of the Scan-to-Mesh-to-BIM process to overcome challenges in the accurate parametric modelling of heritage components, especially in buildings with complex geometry where manual element modelling poses a significant challenge.

3 Research aim

This work addresses the analysis and implementation of semi-automatic modelling techniques for accurate heritage representation. Based on TLS data, this Scan-to-mesh-to-BIM workflow culminates in the programmed 3D element parameterisation. The methodological process developed explores two point cloud processing programmes, Cloudcompare (<https://www.danielgm.net/cc/>) and Leica Geosystems Cyclone 3DR (<https://leica-geosystems.com/es-es/products/laser-scanners/software/leica-cyclone/leica-cyclone-3dr>), for identifying characteristic architectural typologies, semantic segmentation, and meshing complex surfaces. These processes aim to automate the modelling of historical systems and reinforce the HBIM project.

4 Case study

The Church of the Company of Jesus is one of Quito's most iconic historic buildings. This Baroque temple is regarded as the most representative of the colonial era in the Americas. Its construction began in the early 17th century and spanned 160 years. The structure features a large central nave, two lateral aisles with interconnecting chapels, a transept connecting the north and south chapels, and a presbytery and sacristy. According to Navarro (2011), its dimensions and artistic features have been widely studied. The pulpit, dated 1675 (Escudero-Albornoz 2004), is one of the most valuable indoor artistic elements of the church. The main façade is the building's most outstanding exterior feature in architectural terms. In 1722, Father Leonardo Deubler began construction of the imposing grey volcanic stone portico, though work ceased in 1725, leaving it unfinished. Brother Venancio Gandolfi resumed the work in 1760, with completion on 24 July 1765 (Avilés Pino 2012). The façade exhibits various intricately decorated elements, including six Solomonic columns flanking the main entrance, with twisted shafts, vegetal motifs, prismatic plinths, and Corinthian capitals.



Fig. 1. a. Photograph of the main façade of the Church of the Company of Jesus in Quito; b. Leica Geosystems TruView TLS render.

5 Methodology

This section describes the methodological processes required to create the HBIM project for the Church of the Company of Jesus via the Scan-to-Mesh-to-BIM approach. Besides, the resulting geometry is validated for its integration into the HBIM project.

5.1 Data acquisition procedure

The TLS survey was conducted across five levels (Table 1) to cover most of the church's space and minimise occlusions.

Table 1. Number of scans across the survey levels.

Scans	Level 1 (+1.00)	Level 2 (+5.70)	Level 3 (+8.70)	Level 4 (+9.60)	Level 5 (+19.90)	Total
Valid	71	13	19	9	3	115
Void	2	0	0	0	0	2
Subtotal	69	13	19	9	3	113

The Leica BLK360 laser scanner used was configured at 6 mm resolution at 10 metres with HDR imaging. The scan distribution was even, ensuring that distances did not exceed 5 metres and details of vaults and elevated areas were covered. To do this, mobile scaffolding was used to scan the upper cornices, intrados of vaults, and the main façade at various heights. The exterior portal was scanned from two levels, with seven positions relative to the pavement and six additional positions at 8.10 m.

5.2 Post-processing

Scans were processed in Cyclone Register 360 (<https://leica-geosystems.com/es-es/products/laser-scanners/software/leica-cyclone/leica-cyclone-register-360>) to obtain point clouds into a single coordinate system (registration) in .e57 format. Nieto et al. (2022) detailed the TLS capture, post-processing, and referencing procedures, along with a report validating the results. Thus, the segmented point clouds were exported (e57, ptx, or xyz formats) for integration into the HBIM project (ArchiCAD) (Fig. 2).



Fig. 2. Global point cloud in the ArchiCAD HBIM project. Isometric view.

5.3 Segmentation and classification by typologies

The façade of the Church of the Company of Jesus presented a significant challenge due to its artistic and temporal imprints. The unstructured TLS point cloud could be subjected to manual, semi-automatic, or algorithmic classification procedures for semantic segmentation. This facilitates subsequent modelling to generate HBIM parametric objects, which must define the components of the studied architectural style. The difficulty in automating this process increases when techniques resulting from later repair actions and deterioration overlap. Consequently, the TLS cloud of the temple's

façade was imported into Leica Cyclone 3DR software, a processing, classification, and analysis environment for 3D point clouds and meshes. The point cloud segmentation took place in the original project coordinates (0,0,0), around which the different component typologies were identified, and building parts were automatically located in the HBIM project (Fig. 3).



Fig. 3. Façade point cloud of the Church of the Company of Jesus with sectoring boxes for the Solomonian columns. Leica Cyclone 3DR software.

5.4 Point cloud-based HBIM reconstruction

The obtained point cloud allowed for 3D modelling of the church using BIM tools. A basic model (LOD < 200) was developed in ArchiCAD (<http://www.graphisoft.com/archicad/>), focusing on the identification of structural elements. BIM parametric objects, based on Graphisoft's Geometric Description Language (GDL) programming language, can be incorporated into the ArchiCAD object library.

Regarding the building's envelope, the complex geometry of the façade's Baroque decoration, in addition to the deformations caused by the ongoing seismic movements the building experienced, needed to be addressed. Therefore, the TLS data constituted a crucial reference for accurate 3D reconstruction.

5.5 The Scan-to-mesh process

The Scan-to-Mesh-to-BIM process requires the identification and segmentation of the elements in the global point cloud. Leica Cyclone 3DR was chosen for reverse engineering work while ensuring interoperability with the HBIM project environment. This work shows the process applied to a Solomonian column sample (Fig. 4): i) Manual boxes to segment identified semantic entities; ii) Noise (points) removal (1%); and iii) 3D meshing to avoid extreme triangulation rates for suitable mesh quality acquisition.

In this case study, meshing was conducted after noise reduction, given the occlusions caused by the prominent decorations on the façade. Next, a two-step refinement process was applied, avoiding the creation of a highly precise mesh with minimal noise reduction. Mesh interpolation refinement was preferred to the by-points option to smooth the mesh amidst the point cloud noise. This was implemented with a 0.1-mm deviation

error, 5-mm minimum mesh triangle size, and 30-mm point spacing. In addition, hole filling and smoothing enabled a more continuous mesh while preserving the outer edge.

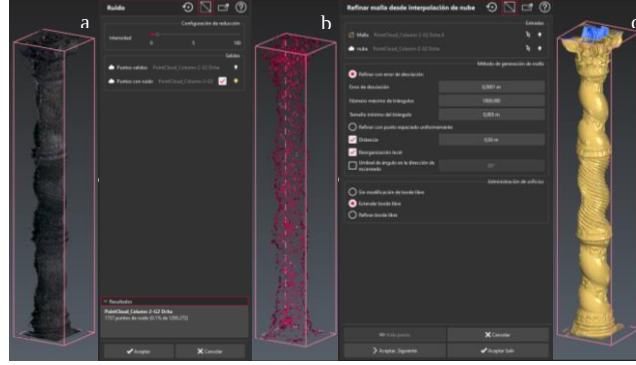


Fig. 4. a. Box fencing for segmentation; b. Noise removal; c. Mesh refinement. Cyclone 3DR.

5.6 Geometry validation

To validate the suitability of the 3D meshing process for HBIM, the accuracy of 3D objects produced in the Leica Cyclone environment was compared to that of the TLS-based 3D reconstruction. CloudCompare was used to triangulate TLS data of a column sample through the Screened Poisson surface reconstruction algorithm (Kazhdan and Hoppe 2013), as seen in (Antón et al. 2023), but with a level-9 smoothing degree to reduce surface noise. With this 3D mesh as the reference, a point-to-mesh deviation analysis was conducted on the geometry generated using Cyclone 3DR. This validation yielded a mean distance of 0.3 mm, a standard deviation of 4 mm, and a histogram of absolute distances between the two geometries (Fig. 5.a). A simplified version (65% reduction) of the Cyclone 3DR mesh, with approximately 170,000 triangles, was also compared, yielding a mean distance of 0.6 mm and a standard deviation above 4 mm (see histogram in Fig. 5.b). Scale remains constant to ease comprehension.

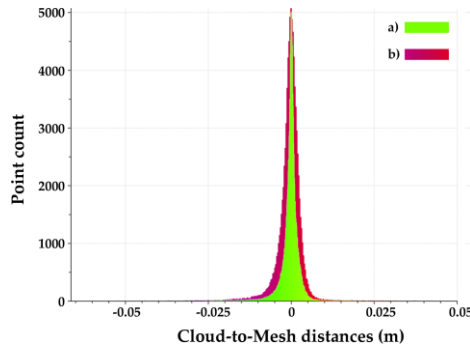


Fig. 5. Meshing validation against the reference geometry: a. Cyclone 3DR mesh; b. Simplified Cyclone 3DR mesh (65% de reduction). Point-to-mesh deviation analysis in CloudCompare.

The amount of information in 3D meshes has a direct impact on their handling within the HBIM environment, making it essential to consider file sizes. The CloudCompare reference mesh, also with an appropriate LOD for HBIM, contained approximately 150,000 polygons, compared to the nearly 500,000 faces in the Cyclone 3DR mesh.

5.7 HBIM implementation

The Cyclone 3DR mesh was included in the BIM environment through the Interoperability/Merge option. This ensured that the original coordinates of the 3D objects were preserved in the HBIM project, unlike standard data importation. The column was converted into an ArchiCAD parametric object, ready to be classified and enriched with properties of its historical-construction semantics. As a result of the interoperability process from Cyclone 3DR to ArchiCAD, the library manager includes the two library objects created in the HBIM project (those meshes created in CloudCompare and Cyclone 3DR, with a similar amount of geometrical data) with the same file size (18 MB).

6 Results and discussion

Showcasing the Church of the Company of Jesus in Quito, this study addresses the challenge of adopting the HBIM approach for geometrically complex heritage sites. To mitigate the limitations of current hardware, where the integration of parametric objects with numerous polygons into a single HBIM project often hinders data handling and visualisation capabilities, a 3D modelling systematic approach balances geometric accuracy and operational efficiency. The methodology integrates simplified parametric elements with semantically segmented point clouds derived from TLS data, thus producing sufficiently representative models of heritage components. Simplified 3D meshes, validated through both qualitative (graphic quality) and quantitative (geometric deviation and file size) analyses, emerge as an effective LOD to manage and visualise complex geometries within HBIM environments.

These findings serve as a reference for future applications in the conservation and management of heritage sites, contributing to the development of efficient, scalable HBIM workflows for historically significant architecture.

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