A Digital Layer of Memory: 3D Documentation, Art Historical Interpretation, and Web-Based Presentation of the Saint Michael Church

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Abstract

This paper presents the three-dimensional documentation and web-based dissemination of Saint Michael Church in Akçaabat, Trabzon, Türkiye. A high-resolution UAV photogrammetry survey consisting of 178 aerial images produced a detailed 3D model that was optimized for online delivery and exported in glTF format. The model is rendered in a browser through a Three.js viewer. An art-historical assessment accompanies the geometric record. The analysis identifies two construction phases: the medieval core dating to the 13th–14th centuries and the 1846 westward addition. Key formal features are described, including the nave dome on a high octagonal drum, the heptagonal exterior apse with arched niches, and the north and south entrances with their masonry treatments. The workflow allows close inspection of stonework and ornament while maintaining a faithful representation of the building fabric. The resulting dataset and viewer serve conservation documentation, research use, and broader access to a protected monument, and they align with international aims for heritage safeguarding, including Sustainable Development Goal 11.4. Potential extensions include semantic enrichment to link model elements with interpretive notes and scalable deployment using multi-LOD CityJSON for comparative studies.

1. Introduction

The preservation of cultural heritage has entered a new era, empowered by the transformative potential of digital technologies. From photogrammetric surveying to semantic three-dimensional (3D) modeling, the processes of documenting and presenting cultural assets in digital environments have moved beyond experimental stages to become integral components of contemporary conservation practices. As emphasized by Styliadis et al. (2009), Cultural Heritage Management (CHM) has evolved into a multidisciplinary field shaped by the convergence of imaging sensors, 3D modeling software, Geographic Information Systems (GIS) databases, and e-learning platforms.

In particular, 3D data acquisition and visualization techniques have emerged as powerful tools in the field of cultural heritage management. Methods such as drone photogrammetry, terrestrial laser scanning (TLS), and structured light scanning enable the creation of highly accurate digital twins of cultural assets. These models serve not only as valuable resources for physical conservation, but also as essential tools for public dissemination and scholarly research (Dang et al., 2023; Salonia et al., 2009).

At the same time, the documentation process is increasingly approached through a multi-scale and multidisciplinary perspective. Salonia et al. (2009) emphasize that a rigorous photogrammetric survey must encompass both the global context and microscopic details of the site. This includes scanning all components of the cultural heritage structure, as well as modeling finer elements such as column capitals and fresco fragments (Salonia et al., 2009). Such an approach aligns with developments in metadata-driven 3D modeling, in which spatial, temporal, stylistic, and semantic attributes are integrated to form layered information structures (Styliadis et al., 2009).

Recent developments in web-based 3D presentation platforms have significantly enhanced the ways in which cultural heritage models can be explored interactively and accessed remotely. These platforms support features such as high-resolution zooming, context-aware tagging, and timeline-based transitions, allowing digital geometry to be enriched with layers of historical interpretation (Tucci et al., 2019; Windhager et al., 2018). Stylianidis et al. (2022) emphasize that these emerging practices in digital curation are redefining how museums and archives engage with their audiences across both academic and informal learning environments. The nature of user interaction with digital heritage objects is shaped not only by the technical interface but also by the interpretive and narrative depth embedded in the model. As these digital environments evolve, they increasingly foster the integration of interpretive frameworks into the documentation and presentation process itself.

This study aims to contribute to the growing body of digital heritage scholarship through the case of Saint Michael Church, located in the Akçaabat district of Trabzon, Türkiye. Currently functioning as the Ortamahalle Museum, the building symbolizes the transformation of both religious architecture and urban cultural identity. Within the scope of this project, a high-resolution 3D model of the structure was produced using drone-assisted photogrammetry, while a formal and symbolic analysis was conducted in parallel from an art historical perspective. The final model was published through a web-based interactive platform, enabling users to engage with the site not only spatially and historically, but also through interpretive narrative layers.

2. Study Object

Saint Michael Church, located in the Akçaabat district of Trabzon (Figure 1), was constructed by the Empire of Trebizond in the 13th–14th centuries and stands among the most significant cultural monuments of the Black Sea region's historical and cultural landscape (Ballance, 1960; Kaya, 2021). In 1846 the church was expanded into its present basilica-plan form, set on a rectangular footprint oriented along the east–west axis (Bekar and Kutlu, 2021).

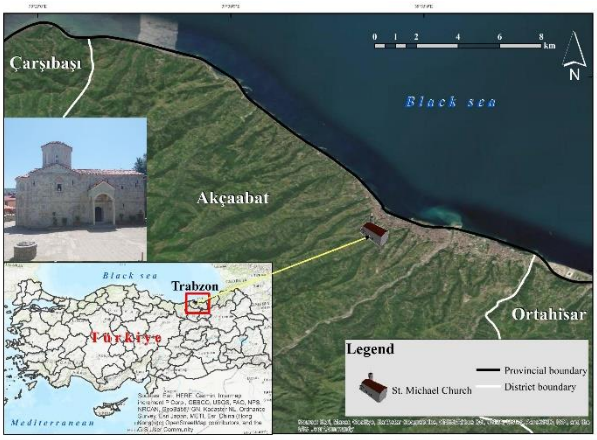

Figure 1. Location of the study object: Saint Michael Church (coordinates: 41.019° N, 39.562° E) in Akçaabat, Trabzon, Türkiye (Map from ArcGIS World Imagery, Sources: Esri, Maxar, Earthstar Geographics, and the GIS User Community.)

The naos is covered by a high drum supporting a conical dome, while the apse is executed internally as a semicircular recess and externally in a polygonal plan. Although the church's design reflects the influences of late Byzantine art, it was built in a manner sensitive to local architectural traditions (Ballance, 1960).

The ornamented window openings on the exterior facade, the lofty drum of the naos dome, the semicircular blind niches set into the bearing walls, and the dynamic, polygonal apse all attest to a restrained yet powerful sense of proportion. Despite its overall simplicity of decoration, the apse, the bearing walls, the dome, and the windows feature occasional stone reliefs and geometric-vegetal motifs. The stonework is particularly noteworthy: ashlar and rubble masonry are combined within the wall fabric to reinforce the structure's integrity.

As one of the rare examples of rural church architecture surviving from the Empire of Trebizond, Saint Michael Church has retained a remarkable degree of original fabric. Its main structural elements remain largely unaltered, having been reinforced and expanded only by selective restoration interventions (Bekar and Kutlu, 2021).

Digitally capturing the architectural details of Saint Michael Church facade in three dimensions and describing these sections in an art-historical register will greatly enhance the building's presentation. In this study, the exterior architectural elements, such as stone carvings, ornamental features and related details, will be meticulously visualized through 3D modeling. By employing not only technical documentation but also an art-historical narrative, the project will convey the church's regional and historical significance in a manner that combines scholarly interpretation with accessibility for cultural-heritage tourism.

3. Methodology

Figure 2 illustrates the overall workflow. The photogrammetric modeling process was conducted using an unmanned aerial vehicle (UAV) equipped with an FC6310 (8.8 mm) sensor, capturing a total of 178 high-resolution images at an average flight altitude of 56.4 meters. The resulting dataset yielded a ground sampling distance (GSD) of approximately 8.74 mm/pixel (Table 1).

Parameter	Value
Flight Altitude	56.4 m
Image Overlap (Front/Side)	80% / 70%
Ground Sampling Distance	8.74 mm/pixel
Point density	2.79 points/cm²
Number of Images	178
Reconstruction Method	Structure from Motion (SfM)
Dense Cloud Quality	High
Mesh Generation	Arbitrary
Texturing Mode	Mosaic

Table 1. Flight and modeling parameters

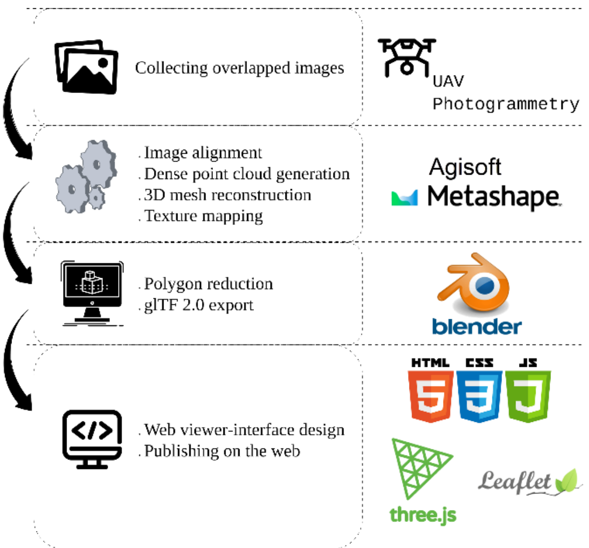

Figure 2. The overall workflow of the study

To ensure sufficient image redundancy and modeling accuracy, forward and side overlaps were planned to exceed 75%, enabling robust feature matching and image alignment. The average number of tie points was recorded as 140,625, and the reprojection error was measured at 0.448 pixels.

The entire modeling workflow was performed using Agisoft Metashape Professional (v1.5.2, build 7838). The processing steps included:
– Image alignment at the highest accuracy setting,
– Dense point cloud generation with mild filtering,
– 3D mesh reconstruction from depth maps, and
– Texture mapping using interpolated surface data.

The final mesh consisted of over 6.5 million faces and was textured using high-resolution imagery, ensuring accurate representation of architectural details and surface materials. The model was georeferenced using the TURKEY TUREF / TM39 projection system (EPSG:5257), providing both spatial coherence and compatibility with GIS-based analysis.

3.1 3D Modeling and Visualization Process

Following the photogrammetric reconstruction, the raw 3D model was optimized for the web and its level of detail (LOD) was adjusted in Blender. The model was imported in OBJ format, and its polygon count was reduced using the Decimate modifier. Polygon reduction was performed to shorten loading times, improve real-time rendering, and ensure compatibility with browsers and devices with limited processing power. Parameters were selected to preserve photorealism. Once optimized, the model was exported in glTF 2.0 format, which is widely used for web-based 3D applications. Figure 3 shows the web-optimized model from multiple viewing angles.

Figure 3. Web-optimized 3D model viewed from multiple angles. The model was processed in Blender using mesh decimation and exported in glTF 2.0 format for web compatibility

Following the glTF export, the file was integrated into a web environment using HTML, JavaScript and the Three.js library. Three.js rendered the 3D model interactively in the browser and allowed users to rotate, pan and zoom to explore the geometry in real time. The entire setup was embedded within a standard HTML page, enabling access across platforms without additional plugins.

3.2 Art Historical Evaluation

The building known as Saint Michael Church is located in Ortamahalle, Akçaabat district, Trabzon Province, and is registered under parcel 979 block 2. The Ortamahalle neighborhood was designated an urban conservation area by the Trabzon Cultural and Natural Heritage Preservation Board on 24 August 1988, and the church itself was officially registered by the same board's decision No. A1771 on 13 July 1979. After serving as a place of worship for many centuries, the structure now functions as a museum.

Saint Michael Church was constructed in two phases by the Empire of Trebizond. An inscription on the church's restoration ledger records that on 20 May 1846, the devout inhabitants of Pulathane (the earliest known name for Platana) enlarged and restored the building (Ballance, 1960; Bryer and Winfield, 1985). The church was most recently included in a conservation program in 2018, and its restoration works were completed in 2021.

Saint Michael Church began as a square-plan structure with a single nave and apse, its original phase defined by finely dressed ashlar masonry on the north, south and east bearing walls, the apse, the dome drum, the ciborium-style north entrance and the triangular pediments. In 1846 a western addition transformed the plan into its present longitudinal transept form; the later phase contrasts the earlier work by employing river-smoothed stone, rubble and roughly hewn ashlar on its south and west walls (Figure 4).

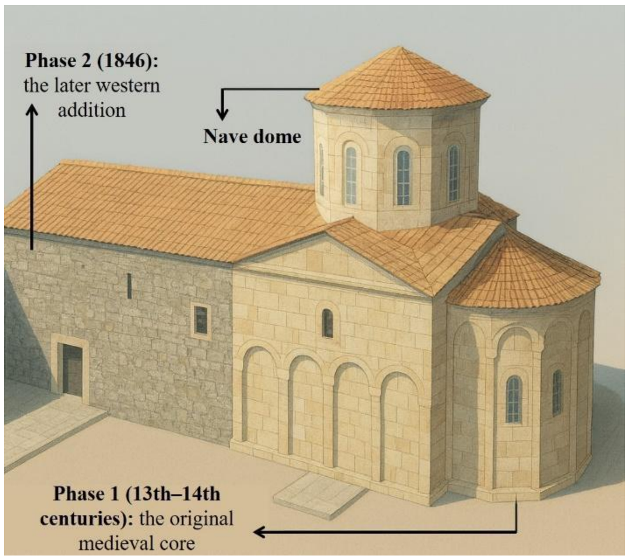

Figure 4. Phased construction of Saint Michael Church, Akçaabat: original medieval core (13th–14th centuries) and westward expansion (1846)

The nave is crowned by a dome set upon an octagonal drum and capped by a conical spire. Each face of the drum is articulated with pronounced moldings that frame rectangular panels and stucco-lattice window openings. These vertical, rectangular windows are bordered by three bands of substantial moldings, while the spaces between the drum faces and the spire form recessed horizontal rectangles. A bold spiral-grooved border marks the seam between the church's two construction phases.

On the east facade, the apse presents a semicircular interior and a heptagonal exterior. Plaster bands divide the exterior into seven vertical facets, and continuous moldings create three horizontal registers. In the upper register each facet ends in a round arch, while the middle and lower registers each contain a single arched niche; three of the middle-register niches house vertical, stucco-lattice windows. The upper facets also feature paired niches within round arches. All niches and arches are edged with convex rope moldings that underscore the church's decorative restraint.

The north entrance sits centrally in the bearing wall within a simple vertical frame. Its plain lintel is gently recessed to suggest an arch, topped by a small relieving arch. A projecting canopy supported by two free-standing piers and two engaged pilasters shelters the doorway, with a double-pitched roof and a triangular pediment completing the ensemble. Like the original masonry, the entire entrance is executed in precisely cut ashlar.

A richly ornamented window on the north facade further enlivens the elevation. Set beneath a shallow round arch, the vertical rectangular opening is surrounded by multiple moldings; the ashlar surround's inner frame carries a decorative tooth-mold motif, and a semi-circular arched tympanum crowns the opening. Additional moldings flank the window, and the outermost are linked by a rope-mold arch. The surround incorporates ashlar blocks in varying tones of green, brown and yellow, providing a final flourish to the church's exterior.

The south entrance is positioned near the western corner of the south facade and occupies a vertical rectangular opening beneath a plain lintel. Directly above the lintel, a small horizontal tabula ansata frames an inscribed panel, itself surmounted by a pointed relieving arch. The doorway is crowned by a triangular pediment that projects slightly forward to form a shallow eave. While the surrounding bearing wall is built of roughly hewn ashlar and rubble masonry, the door opening itself is executed in finely dressed ashlar.

4. Results and Discussion

The UAV survey yielded 178 images at an average flight altitude of 56.4 m with an estimated ground sampling distance of 8.74 mm per pixel. Overlaps exceeding 75 percent support robust feature matching. Image alignment reached a mean reprojection error of 0.448 pixels, which demonstrates internal consistency of the bundle adjustment. The dense reconstruction produced a mesh of more than 6.5 million faces, which provides sufficient detail to resolve small-scale architectural features while remaining suitable for web optimization. Georeferencing enables integration with GIS-based workflows.

The exterior-focused model demonstrates geometric fidelity adequate to differentiate the two construction periods. Finely dressed ashlar on the north, south and east walls, the apse and the dome drum indicate the medieval core, whereas river-smoothed stone, rubble and roughly hewn ashlar on the south and west walls support the identification of the 1846 western addition. The octagonal drum capped by a conical top, the heptagonal exterior apse with arched niches and the masonry treatments at the north and south entrances are legible in the textured mesh. Close-up inspection shows the spiral-grooved border at the junction of phases and the molded frames of the window openings, which together support the art-historical reading with measurable geometry.

Alongside the 3D view, there is a left-side information panel implemented with HTML and JavaScript. The panel presents the historical background, architectural details and site information in an accordion layout that supports topic-by-topic navigation. It also embeds an interactive map created with the Leaflet library and an OpenStreetMap basemap, which identifies the location of the church. The interface provides bilingual content in English and Turkish. Figure 5 shows the published web interface with the interactive 3D model, the information panel and the embedded location map.

Figure 5. The published web interface displays the interactive 3D model with QR code, accompanied by an information panel and integrated map showing the church's location (© OpenStreetMap contributors).

The dataset and viewer together support several uses. For conservation documentation, the model provides a repeatable baseline for condition monitoring and for comparing masonry treatments between periods. For research, the model enables examination of drum proportions, apse geometry, niche rhythm and entrance composition within a consistent spatial frame. For broader access, the browser-based presentation supports engagement without additional plugins.

There are also limitations. The survey relied on aerial imagery, and no independent checkpoint set was reported, so absolute accuracy was not quantified against external references. The scope of work focused on exterior architecture; therefore, interior surfaces were not captured. Further refinement could include additional close-range imagery for undercut elements, independent accuracy assessment using ground control or checkpoints and semantic enrichment of the glTF to associate model parts with interpretive attributes within the 3D scene.

5. Conclusion and Recommendations

The preservation of cultural heritage has entered a new era empowered by the transformative capabilities of digital technologies. This transformation encompasses not only the documentation of physical assets but also the enhancement of accessibility and sustainability of cultural values. In alignment with the United Nations Sustainable Development Goal (SDG) 11.4, digital tools strengthen efforts to safeguard cultural and natural heritage, contributing to its transmission to future generations.

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As future work, it is planned to enrich the 3D model with semantic surfaces, each carrying descriptive attributes such as historical background, architectural function, or cultural relevance. These attributes will be integrated into the glTF structure using the EXT_structural_metadata and EXT_feature_metadata extensions, allowing semantic information to be directly associated with specific geometric elements. This will enable users to interact with the model in a more meaningful way, such as selecting a facade or window to reveal related cultural or historical details, enhancing both educational value and user engagement. In this study, such information is served in the information panel, but future versions aim to embed it directly into the 3D geometry. Additionally, a 3D globe-enhanced interface is planned, where the model will be geographically visualized on a virtual globe, enabling users to explore the cultural asset in relation to its global location and surrounding landmarks.

The current model only represents the exterior boundary of the object. Therefore, there is a need to extend it with interiors to enable a more informative representation. The authors intend to capture 360-degree panoramic images of the interiors as a first step. These images can be mapped onto a series of spheres placed on the floor plan to create a virtual tour, allowing users to navigate between successive 360-degree viewpoints. A globe-based interface is also planned, in which the model will be positioned on a virtual globe to contextualize the monument within its wider geography. The described enhancement is also a part of future work directions.

As another future direction, the use of generalized LOD2 or LOD3 CityJSON models can be considered for large-scale projects that include dense clusters of cultural assets. These models can be generated using building footprints and point cloud data as input. Aerial imagery can be utilized to wrap textures onto the low-poly, generalized models, providing a visually rich and lightweight representation. This approach would facilitate the presentation of multiple levels of detail (LODs) for the same model, allowing users to switch between simplified geometry and high-resolution textures depending on the context and performance needs.

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