A Holistic Documentation and Restoration Framework for Heritage Structures: The Case of the Metropolitan Church of Saint Minas, Heraklion, Crete

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Abstract

The Metropolitan Church of Saint Minas in Heraklion, Crete, stands as one of the largest Orthodox churches in Greece and a land-mark of significant cultural and historical value. Constructed during the second half of the 19th century, the monument has endured decades of seismic activity and environmental degradation. Following the damaging effects of the 2021 Arkalochori earthquake, a comprehensive documentation and structural assessment project was undertaken to guide future conservation interventions. This paper presents the integrated approach adopted for this initiative, combining digital heritage documentation techniques—such as laser scanning and photogrammetry—with detailed structural diagnostics and conservation planning. The project not only sought to create a complete record of the monument’s current state but also to establish a methodological framework for seismic risk manage-ment in historic masonry churches. Emphasis is placed on the monument’s architectural features, construction history, identified pathologies, and the proposed interventions, which aim to preserve both the tangible and intangible values embedded in this heritage landmark.

1. Introduction

Cultural heritage protection and preservation in seismic zones poses significant technical and ethical challenges. Recent seismic events in Italy, Turkey, and Syria have highlighted the susceptibility of unreinforced masonry churches to significant structural failure during earthquakes. These buildings, often characterized by their lack of reinforcement techniques, face heightened risk of collapse or extensive damage when subjected to the forces generated by seismic activity. This underscores the urgent need to assess and retrofit vulnerable structures to enhance their resilience in the face of such natural disasters (Feilden, 2003; Roca et al., 2010). The Metropolitan Church of Saint Minas in Heraklion, Crete, a monumental example of 19th-century Orthodox architecture, represents both a liturgical centrepiece and a historical narrative of resilience. In light of the 2021 Arkalochori earthquake, which exacerbated pre-existing vulnerabilities, this paper addresses the urgency of a data-driven, multidisciplinary approach to documentation and structural assessment.

The project described herein stems from a collaborative research initiative commissioned by the Hellenic Ministry of Culture, with technical oversight by the National Technical University of Athens. The objective was to evaluate and meticulously document the building's structural and material deterioration, analyse its construction, and recommend sustainable conservation strategies. This paper synthesizes findings from the broader diagnostic campaign—including architectural documentation, structural modelling, and material analysis—to present a best-practice model for safeguarding similar monuments.

In particular, the focus lies on the integration of advanced recording methods with conventional engineering analysis. The dual goals were: (i) to preserve the historical and architectural integrity of Saint Minas and (ii) to enhance its seismic resilience in accordance with national conservation standards and international charters (ICOMOS, 2003; Letellier, 2007).

2. Historical and Architectural Significance of the Metropolitan Church of Saint Minas

The Metropolitan Church of Saint Minas is located at the heart of Heraklion and serves as the seat of the local Metropolis. The foundation stone was laid in 1862, and construction continued for more than three decades, culminating in its consecration in 1895. Dedicated to Saint Minas, the patron saint of Heraklion, the church holds immense religious, social, and historical significance (Chlepa, 2011). Its construction marked the emergence of Cretan architectural revivalism during the late Ottoman period, blending neoclassical motifs with Byzantine spatial typologies (Fig. 1).

Figure 1: The city of Heraklion on a postcard. The Church of Panagia of the Market and, in the background, Saint Minas. (Vikelaia Municipal Library, Heraklion), Tzompanaki Ch. (2000), Heraklion Within the Walls, p. 89

The monument features a cruciform plan with a prominent central dome, flanked by two symmetrical bell towers added at a later stage. The north and south bell towers—each exceeding

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30 meters in height—became iconic visual anchors in the city's skyline. The masonry of the structure is defined by a stratified design that alternates between meticulously carved ashlar and rubble infill. Within the internal framework, metal reinforcements have been incorporated as part of 20th-century retrofitting efforts to enhance structural integrity. The interior showcases an impressive array of iconographic and sculptural components, including intricate wall paintings, elaborate decorative plasterwork, and a finely crafted wooden iconostasis, all of which reflect the liturgical artistry characteristic of post-Ottoman Crete. The progression of time, along with environmental degradation and seismic occurrences, has resulted in a multifaceted array of structural pathologies. Previous remediation efforts, especially those undertaken after the restorations in 1953 and the 1960s, did not yield sustainable durability. This was frequently attributable to issues such as material incompatibility and insufficient seismic reinforcement measures.

What makes Saint Minas architecturally significant is not only its scale but also its structural ingenuity and layered construction phases. For instance, the dome and barrel vaults are supported by an intersecting system of piers and arches, designed to distribute seismic forces across the load-bearing system. The recent documentation verified this spatial logic, while also revealing structural weaknesses at nodal intersections, particularly at the interfaces between dome supports and the longitudinal walls. In terms of heritage classification, the monument is listed as a protected structure under Greek national legislation, which mandates a rigorous process of study, documentation, and approval before any conservation work may proceed (Fig. 2). As such, this project was a critical first step in fulfilling both legal and ethical obligations toward the monument's long-term preservation.

Figure 2. The Metropolitan Church of Saint Minas (June 2020).

3. Diagnostic Approach and Methodology

The assessment of the structural integrity and conservation needs of the Metropolitan Church of Saint Minas was carried out using an interdisciplinary and layered diagnostic methodology. This approach ensured a comprehensive understanding of both the geometric configuration and the mechanical behavior of the monument under static and seismic loads. The strategy combined high-precision survey techniques, material analysis, and structural modelling, forming a robust framework for diagnosing vulnerabilities and planning effective restoration.

3.1 Geometric Documentation

To ensure spatial consistency and enable multi-source data integration, a geodetic control network was firstly established at the Church of Saint Minas. This reference network was crucial for aligning data from various acquisition methods and for generating outputs in a unified coordinate system (Fig. 3). The control network consisted of 8 fixed points strategically placed around and within the monument and measured using a PENTAX R-323NX total station and GNSS equipment. This setup allowed for precise georeferencing in the GGRS87 (Greek Geodetic Reference System). A total of 131 Ground Control and characteristic points were measured.

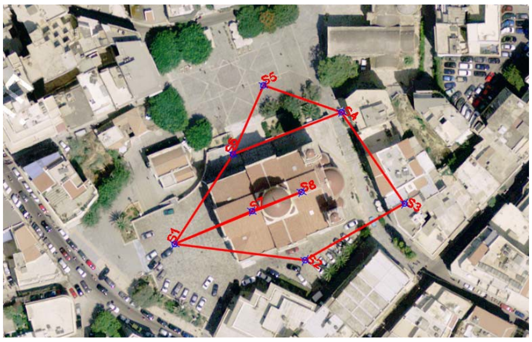

Figure 3: The established control network consisting of 8 network points.

The geometric documentation was carried out using a hybrid acquisition strategy that combined high-resolution terrestrial laser scanning with terrestrial and aerial photogrammetry. The laser scanner that was used was a Leica BLK360, known for its portability and accuracy. The scanning process attained a spatial resolution of roughly 6 mm at a distance of 10 meters and 8 mm at 20 meters, capturing the intricate architectural geometry of the dome, nave, bell towers, underground cistern, adjoining chambers and the outdoors. This comprehensive documentation was facilitated by a total of 205 individual scans. The point clouds were registered using Leica Cyclone REGISTER 360, maintaining sub-centimeter alignment errors while it was referenced using the coordinates of the measured control points (Fig. 4).

Figure 4: Different views and sectional representations of the unified point cloud of the Metropolitan Church of Saint Minas

In parallel, terrestrial photogrammetry was performed using a Sony A7RIII full-frame camera equipped with a 28–75 mm lens at a fixed local length. Emphasis was placed on capturing key architectural details and areas that presented reflective or complex surfaces difficult to scan, such as decorative frescoes, transition zones, and tight internal corners. A DJI Mavic 2 Pro UAV was deployed to perform aerial photogrammetry of the roof, upper cornices, bell towers and surrounding urban context. Automated image acquisition missions were executed incorporating sufficient overlap parameters, specifically a minimum of 80% forward overlap and 60% side overlap, in conjunction with manual flight operations. A total number of 4399 aerial and 3040 terrestrial images were acquired.

The resulting datasets were processed using Agisoft Metashape for the orientation via the automated Structure from Motion (SfM) process (Fig. 5). The dense cloud generation using the Multi-View Stereo (MVS) reconstruction algorithms, and finally the mesh reconstruction and orthophoto production concluded the photogrammetric processing. The point clouds from both TLS and photogrammetry were integrated and optimized using CloudCompare, where noise filtering and deviation analysis were conducted. The integrated point cloud formed the basis for advanced analyses such as deformation monitoring, material condition evaluations, and the creation of orthogonal projections. The high geometric fidelity of the documentation allows for accurate longitudinal monitoring of structural movements and conservation interventions, ensuring the project complies with international principles of reliability and long-term reproducibility.

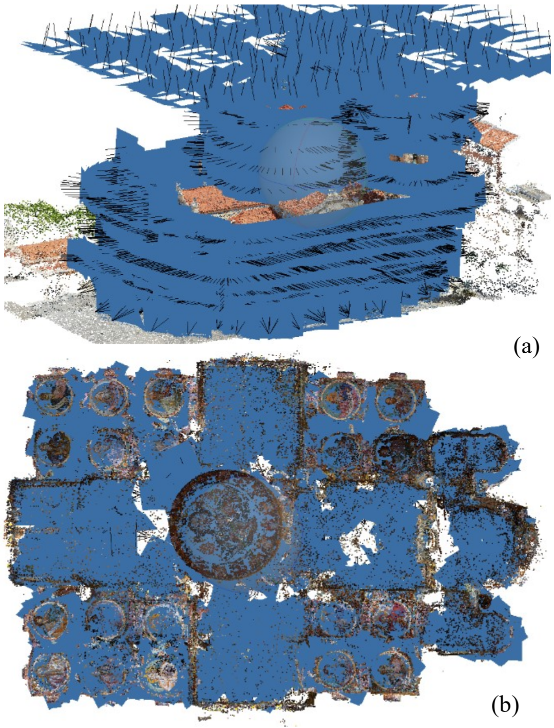

Figure 5: Snapshots from the oriented digital images of the church's exterior (a) and interior (b).


Figure 6: The orthophoto of the North Façade of the Metropolitan Church of Saint Minas.

For the production of the orthophotos, a ground sampling distance (GSD) of 2 mm was selected in order to preserve all the recorded information from the original digital images (Fig. 6). The orthophotos were geometrically verified using the measured points that were not included in the bundle adjustment process for image orientation in order to be used as check points. The unified 3D point cloud and the high-resolution orthophotos served as the foundational dataset for generating all necessary architectural drawings. These included detailed plans, sections, elevations, and façade drawings (Fig. 7 & 8). The integration of both 2D and 3D outputs ensured the production of geometrically accurate and visually comprehensive documentation, suitable for conservation planning and further analysis.

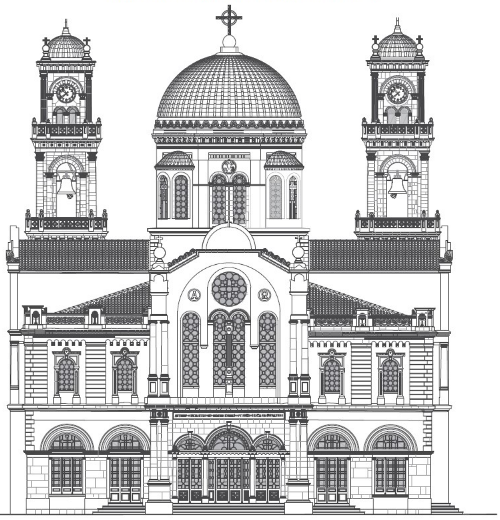
Figure 7. The architectural drawing of the West Façade (main façade) of the Metropolitan Church of Saint Minas.

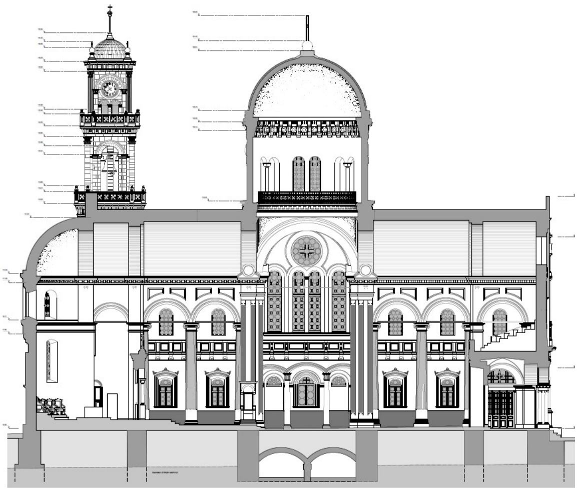
Figure 8. The architectural drawing of the longitudinal section along the central nave of the church.

3.2 Pathology Mapping and Material Analysis

The evaluation of structural pathology was based on visual inspections correlated with geometric data. Crack patterns, material degradation, and deformation signs were meticulously documented and classified. Special attention was given to the dome and the lateral vaults, as well as the twin bell towers, which exhibited asymmetric behavior and heightened vulnerability. Detailed mapping helped establish the spatial distribution and potential origins of damage, facilitating a targeted response strategy (Fig. 9).

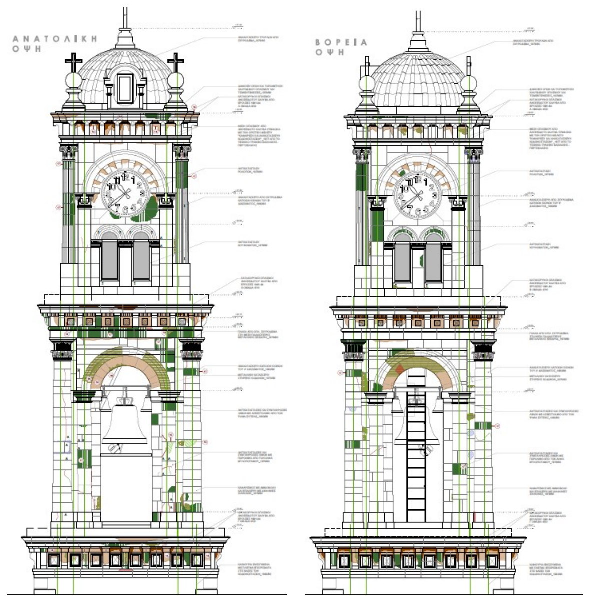

Figure 9: Pathology of the North Bell Tower (East and North Façade).

In parallel, material characterization was performed to assess the mechanical properties and decay mechanisms affecting the masonry. Samples were analyzed for compressive strength following ASTM standards (ASTM, 1984), and the correlation between point load index and uniaxial compressive strength was applied to interpret results (Singh et al., 2012). The deterioration of porous building materials was evaluated using methodologies grounded in established conservation science principles (Stambolov, 1985), offering insights into deterioration due to moisture ingress, salt crystallization, and biological growth.

3.3 Structural Modelling and Seismic Analysis

Numerical modelling played a central role in diagnosing structural weaknesses and forecasting seismic behavior. A finite element model (FEM) of the church was constructed to simulate the load-bearing performance under gravitational and lateral loads (Fig. 10). The model incorporated data from the 3D survey and was calibrated using modal identification techniques (Brincker et al., 2000; Pioldi et al., 2014). Special attention was given to the dynamic behavior of the main dome and the structural articulation with adjoining elements.

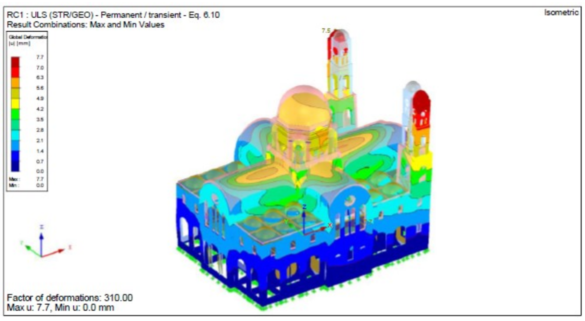

Figure 10: Displacements under static loads in the Ultimate Limit State (ULS) condition.

Nonlinear analysis techniques were utilized in accordance with the Eurocode 8 provisions and the KADET guidelines (OASP, 2019) to simulate potential failure scenarios. The model highlighted zones of stress concentration, especially in the foundation system and the bell towers, and informed the prioritization of intervention measures. The integration of these simulations with pathology data allowed for a holistic understanding of the monument's seismic vulnerability.

4. Proposed Conservation and Strengthening Interventions

The proposed conservation and structural reinforcement strategy for the Metropolitan Church of Saint Minas is the outcome of a detailed interdisciplinary evaluation that respected both the architectural heritage and the structural pathologies of the monument. The approach was carefully aligned with international principles for conservation and structural restoration of built heritage (ICOMOS, 2003; Feilden, 2003), emphasizing minimal intervention, reversibility, compatibility of materials, and respect for historical authenticity. All interventions were developed alongside 3D modelling and structural simulations that guided decision-making.

A key intervention proposed is the reinforcement of the building's foundations. Given the monument's seismic vulnerability and the observed settlement and crack patterns, micro-piles are to be implemented in strategically critical zones to enhance foundation stability without significantly disturbing the existing structural fabric. To complement this, drainage improvement works around the perimeter are planned, incorporating vapor-permeable cementitious mortars and HDPE layers to mitigate rising damp and reduce hydrostatic pressure on the foundations.

The masonry walls will undergo selective grouting with lime-based hydraulic mortars chosen for their mechanical compatibility with the original stone and brickwork. The grouts are formulated to ensure high workability and low shrinkage, complying with EN 998-2 specifications for M15-class mortars. The injection aims to restore structural cohesion, reduce porosity, and strengthen the walls while preserving their breathability. In locations with deep cracks, pre-cleaning procedures using pressurized air, water, and hydrogen peroxide solutions will ensure effective penetration of the injection materials. Vaults and domes, critical to the structural behaviour of the monument under seismic loads, are to be reinforced with concealed stainless-steel or composite ties, offering internal confinement with minimal visual impact. In particular, titanium rods are recommended in select zones due to their superior resistance to chloride-induced corrosion, which is a relevant consideration in the coastal environment of Heraklion. The bell towers, structurally vulnerable due to their height and asymmetric response during dynamic loading, will undergo localized dismantling and reconstruction using salvaged original materials where feasible. Interior metallic frameworks will be minimally intrusive and concealed, ensuring the towers' visual coherence is preserved while enhancing their lateral stability (Fig. 11).

To address surface deterioration, stone consolidation with injection-compatible mineral consolidants, selective replacement of irreversibly damaged elements, and deep repointing with compatible mortar are included. The monument's ornamental features, such as plaster decorations, joinery, and mosaic flooring, will be conserved using material-specific methods that prioritize reversibility and minimal intervention.

5. Structural Vulnerabilities and Restoration Strategies

The structural assessment of the Metropolitan Church of Saint Minas revealed multiple vulnerabilities that, if left unaddressed, could compromise the long-term stability of the monument. Primary among these are issues associated with seismic risk, foundational settlement, the cracking of masonry elements, and degradation in key load-bearing structural components such as domes, arches, and vaults.

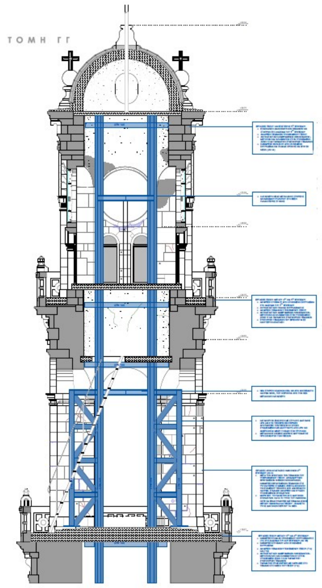

Figure 11: The proposed structural interventions on the Southern Bell Tower.

5.1 Structural Degradation Patterns and Seismic Vulnerability

The diagnostic assessment indicated significant deformation in the central dome and crossing arches, along with diagonal and vertical cracking in masonry walls, suggesting issues related to differential settlement or seismic activity. Notable pathology included delamination of stone masonry, detached mortar, and decayed lime plasters, with concerns for lateral stability in the bell towers and side aisles. FEM analysis revealed stress concentrations in critical areas and classified the building as high-risk under Eurocode 8 and Greek Seismic Codes, due to inadequate stiffness distribution and torsional vulnerability.rs.

5.2 Strengthening Interventions

A series of strengthening interventions was proposed to enhance structural resilience:

- Foundation Improvement: Jet grouting was recommended around the perimeter foundations to address differential settlement and to homogenize soil conditions.

- Masonry Strengthening: Compatible lime-based injection grouts were designed for the consolidation of internal voids and delaminated masonry. These grouts, developed according to EN 998-2 and tested for mechanical compatibility, were selected for their low modulus of elasticity and breathability.

- Steel Tie-Rods: New steel tie-rods will be inserted at the clerestory level and between dome piers to reduce thrust and stabilize horizontal forces. These rods are designed to be minimally invasive and reversible.

- Fibre-Reinforced Mortars: For selected vaults and arches, fibre-reinforced lime mortars will be applied to the intrados and extrados surfaces to mitigate crack propagation.

- Anchoring of Detached Elements: Structural anchors will secure parts of the cornices, balustrades, and decorative pediments currently at risk of falling.

5.3 Reversibility and Compatibility

A guiding principle in the intervention strategy is reversibility, as promoted by international charters such as the Venice Charter and the Nara Document on Authenticity. All added materials—particularly the injection grouts and tie-rods—were selected for chemical and mechanical compatibility with existing historic materials, avoiding Portland cement or resin-based solutions that might hinder moisture diffusion or induce salt crystallization. This integrative restoration plan responds to both structural safety needs and conservation ethics. The ultimate goal is not merely stabilization but the extension of the monument's functional and symbolic role as a living part of the city's cultural identity.

6. Sustainable Conservation Approaches

The proposed restoration of the Metropolitan Church of Saint Minas was shaped by a core philosophy grounded in internationally recognized conservation principles, including reversibility, minimal intervention, and compatibility with original materials (Brandi, 1963; ICOMOS, 2003). These principles guided both the architectural and structural strategies, ensuring that the interventions preserve the monument's authenticity while enhancing its resilience.

A primary focus was placed on material compatibility. Lime-based mortars, devoid of cement, were chosen for grouting and crack injection to avoid long-term incompatibilities with the original porous stone masonry (Feilden, 2003). Hydraulic lime mortars, compliant with EN 998-2 standards, were utilized for their favourable mechanical and hygroscopic properties, as well as their proven durability in saline and humid environments. Where replacement of deteriorated stone elements was deemed necessary, matching lithotypes from nearby historic quarries, such as those in Katsampas and Xiropotamos, were selected, maintaining material continuity and minimizing visual disturbance.

The project further emphasized passive environmental performance. Enhancements to thermal-hygrometric conditions were proposed through improved drainage and ventilation, avoiding energy-intensive mechanical systems. This approach reflects a broader commitment to sustainable conservation and resource efficiency (Waldhauser, 2007). Sustainability also informed the structural retrofitting strategy. Interventions were designed to be as non-invasive as possible, incorporating composite materials only where necessary and avoiding large-scale metal insertions that could disrupt the masonry's structural behaviour. Concealed ties and micro-piles were favoured over visible elements, safeguarding the aesthetic and physical integrity of the church (Roca et al., 2010; Remondino & Campana, 2014). Wherever feasible, interventions followed the principle of reversibility. For example, temporary shoring and monitoring systems were used to observe structural behaviour before committing to permanent changes. This reflects a precautionary approach consistent with best practices in heritage conservation.

The use of local materials, traditional craftsmanship, and low-impact techniques not only upheld the monument's cultural significance but also supported knowledge transfer and local community engagement—elements critical for the long-term sustainability of the site (Letellier, 2007; Osman & Moropoulou, 2019).

7. Conclusion and Broader Impact

The Metropolitan Church of Saint Minas holds a place of paramount importance within the social, cultural, and spiritual context of Heraklion. As the cathedral of the city and the seat of the Archbishop of Crete, it serves not only as a liturgical centre but also as a symbolic landmark of the city's identity and resilience. Beyond its architectural majesty and religious function, the church operates as a living monument that mediates between the past and present of the local community.

Saint Minas is widely venerated as the patron saint of Heraklion, and the church is deeply embedded in local traditions and popular religiosity. Religious festivals, particularly the annual celebration of Saint Minas Day on November 11, draw thousands of attendees and demonstrate the continuity of intangible heritage practices. These events reinforce communal identity and constitute a key vector for intergenerational transmission of cultural values.

The conservation and documentation project of the Metropolitan Church of Saint Minas in Heraklion stands as a multifaceted example of holistic heritage preservation. Through the integration of advanced recording technologies, meticulous structural analysis, material diagnostics, and cultural engagement, the initiative transcended the conventional boundaries of architectural restoration. It emerged not only as a technical endeavour but also as a cultural, educational, and social mission.

The restoration and documentation initiatives undertaken at the church have fostered significant public interest and engagement. Through public announcements, media coverage, and educational presentations, the project was able to stimulate awareness around the challenges of heritage conservation in seismically active regions like Crete. Moreover, the collaboration between scientific institutions and the Ministry of Culture encouraged participatory dialogue between heritage professionals, ecclesiastical authorities, and the local population. This multi-stakeholder dynamic echoes international recommendations for inclusive heritage management (Feilden, 2003; ICOMOS, 2003). Furthermore, the church's restoration is anticipated to have a positive effect on local tourism. Saint Minas is among the most visited monuments in Heraklion, frequently featured in tourist itineraries and cultural heritage trails. Improved preservation and interpretation of the site, supported by digital documentation, are expected to enhance the visitor experience, thereby supporting cultural tourism and local economic development. In this way, the project aligns with broader sustainable heritage management objectives, fostering both protection and promotion of cultural assets (Letellier, 2007; Remondino & Campana, 2014).

Despite logistical challenges—including limited timeframes, accessibility constraints, and the complexity of coordinating a multi-partner operation—the project successfully delivered a comprehensive and scientifically grounded documentation and assessment of one of Crete's most significant ecclesiastical monuments. The results will inform future restoration works, disaster preparedness strategies, and long-term monitoring, ensuring that the Church of Saint Minas continues to serve its community for generations to come. As a fundamental component of heritage management, geometric documentation ensures that conservation planning is informed by accurate, measurable data, fostering interventions that respect the integrity and complexity of historic structures.

Summarizing, the Church of Saint Minas is more than a religious monument; it is a cultural cornerstone of Heraklion. The integrated conservation and documentation campaign did not merely aim at physical repair but sought to reaffirm the monument's societal role, bridging technical restoration with community relevance. By situating the intervention within a broader cultural and educational framework, the project has laid the groundwork for long-term heritage stewardship rooted in public participation and awareness.

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