International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://theaspd.com/index.php

3D Photogrammetry for Monitoring Architectural Deterioration: Insights from the Chennigaraya Temple

Sagar T S[1], Harshini M[2]
[1]Associate Professor, School of Architecture, Siddaganga Institute of Technology, Tumakuru
sagarts@sit.ac.in
[2]Undergraduate Student, School of Architecture, Siddaganga Institute of Technology, Tumakuru

Abstract: *To ensure the long-term viability of heritage monuments, which serve as crucial windows into past civilizations and cultural practices, advanced documentation and preservation methodologies are essential. Contemporary digital technologies, including photogrammetry and laser scanning, are instrumental in capturing minute details and producing precise three-dimensional models of invaluable cultural assets such as artifacts, architectural edifices, and entire heritage sites (Imtiaz et al. 2024) (Buldo et al. 2023). This research examines the utilization of photogrammetry as a non-destructive technique for the comprehensive documentation and condition evaluation of the Chennigaraya Temple, a significant historical edifice located in Turuvekere. The study's primary objective is to generate accurate 3D models and orthophotos that meticulously record intricate architectural features and pinpoint areas of degradation, thereby supplying critical data for conservation and restoration initiatives. This methodology is especially beneficial for cultural heritage sites globally, particularly in resource-constrained regions, offering an economical alternative to conventional surveying methods. Advances in both hardware and software, coupled with declining equipment costs, have positioned photogrammetry as a leading tool for archaeological surveying and the creation of detailed 3D models of historical artifacts and structures. This approach facilitates precise dimensional analysis and the visualization of complex geometries, which are vital for assessing structural integrity and informing conservation strategies. The increasing demand for comprehensive 3D models of historical monuments within archaeological and architectural applications underscores the need for highly detailed and dependable surface representations (Salonia et al. 2009). The paper details the process of data acquisition using close-range photogrammetry and subsequent processing to generate high-fidelity digital replicas of the temple. These digital representations not only enable a thorough condition assessment but also serve as a foundational resource for subsequent restoration projects and academic research. Furthermore, the integration of photogrammetric solutions with accurate surveying measurements permits the creation of fully functional three-dimensional models of architectural structures, which are indispensable for the protection and conservation documentation of cultural heritage*
Keywords: *Photogrammetry, 3D modeling, cultural heritage, condition assessment, Chennigaraya Temple, non-destructive testing*

1. INTRODUCTION

The long-term preservation of heritage monuments, which offer critical insights into past civilizations and cultural practices, necessitates sophisticated documentation and conservation techniques. Modern digital technologies, such as photogrammetry and laser scanning, are crucial for capturing intricate details and generating precise three-dimensional models of invaluable cultural assets, including artifacts, architectural structures, and entire heritage sites (Imtiaz et al. 2024) (Buldo et al. 2023). The Chennigaraya Temple, an exemplar of traditional Indian Hindu temple architecture, provides an excellent context for exploring advanced documentation and condition assessment methodologies (Singh et al. 2022). This research employs photogrammetry as a non-invasive and efficient method for creating detailed 3D models, which are vital for comprehensive structural health monitoring and preservation efforts (Heß et al. 2017). This approach enables precise spatial data acquisition, facilitating thorough analysis of architectural integrity and the identification of deterioration patterns crucial for heritage conservation (Tsilimantou et al. 2016). Such digital documentation not only aids in the meticulous recording of complex architectural features but also serves as an invaluable resource for future restoration planning and scholarly research (Yastikli 2007). The increasing accessibility and sophistication of 3D survey techniques, including close-range photogrammetry and laser scanning, have significantly enhanced the accuracy and efficiency of cultural heritage documentation (Zhang et al. 2020). These methods facilitate the creation of highly detailed digital models, essential for monitoring the condition of historical structures and supporting conservation initiatives (Cheng, Yang, and Yen 2015). The resulting 3D models are highly valuable for scientific study, conservation, and educational purposes, enabling efficient and precise measurement of relevant natural and architectural features (Zlot et al. 2013). This study focuses on using photogrammetry to document the architectural intricacies of the Chennigaraya Temple, highlighting how this technology promotes efficient documentation, enhances conservation practices, and ensures the preservation of this heritage for future generations.

LITERATURE REVIEW

The rapid advancements in computer vision and photogrammetry have made the creation of high-quality 3D models of Cultural Heritage sites more accessible, although the process remains time-consuming and requires specialized expertise and equipment (Shivottam and Mishra 2023). However, the development of Unmanned Aerial Vehicles has significantly streamlined data acquisition, offering unprecedented flexibility and cost-effectiveness for generating high-resolution spatial data, especially for large and complex heritage sites (Zhang et al. 2020) (Themistocleous et al. 2015). This integration of UAV-based imagery with terrestrial photography further enhances comprehensive documentation by capturing intricate details from various perspectives, thereby enabling the generation of highly detailed, textured 3D models (Bhardwaj and Muralidhar 2024). Moreover, photogrammetry, particularly Structure from Motion techniques, has emerged as a particularly flexible, affordable, and operable method for 3D modeling within cultural heritage contexts, effectively serving as a viable alternative to traditional laser scanning for capturing intricate details of historical monuments (Khalil 2020) (Zhang et al. 2020). This methodology substantially reduces the economic and logistical burden associated with remote expert consultation, as detailed virtual models enable comprehensive morphological and condition diagnoses from geographically distant locations (Prizeman and Barazzetti 2021). Furthermore, the adoption of photogrammetric workflows, especially those incorporating coded targets, allows for accurate measurements and precise 3D reconstructions of even large-scale archaeological sites, ensuring high fidelity in the digital representation of heritage assets (Sapirstein 2016). This development is crucial for transmitting cultural heritage to posterity through delicate documentation, which increasingly involves computerized or digital representations of objects in 2.5 or 3D (Jebur 2022).

This technological synergy, encompassing both hardware and software advancements, has significantly democratized the process of 3D model creation, transforming it from a niche, labor-intensive task into a more accessible and efficient workflow for cultural heritage professionals (Pepe, Alfio, and Costantino 2022). The integration of such technologies also mitigates the need for repeated on-site visits, allowing archaeologists and architects to extract data from 3D models as new research questions emerge (Wright, Conlin, and Shope 2020). Beyond documentation, these 3D models facilitate advanced structural analysis and monitoring, providing a robust framework for assessing the long-term stability and degradation of architectural elements (Mamani-Huaman, Rojas, and Inche 2022). This allows for the systematic tracking of changes over time, offering critical insights into the monument's structural health and informing proactive conservation strategies. The application of photogrammetry offers substantial advantages over traditional methods, particularly due to its capacity for non-contact data acquisition, high geometric accuracy, and the production of visually rich digital models that can be used for detailed metric analysis (Adamopoulos, Rinaudo, and Ardissono 2020).

The Chennigaraya Temple, a significant historical edifice showcasing regional architectural intricacies (Federman et al. 2018) (Banfi et al. 2023), was selected for this study. Its elaborate carvings and fine details render it an ideal subject for assessing photogrammetry's capacity to capture minute features and facilitate comprehensive condition evaluations. Many heritage sites, such as the Chennigaraya Temple, are vulnerable to deterioration due to funding or initiative deficits, underscoring the critical role of modern technologies like UAVs in their preservation through accurate and efficient documentation (Sestraş et al. 2020). The temple exemplifies the distinctive Hoysala architectural style, recognized for its intricate ornamentation and innovative structural designs. Architecturally, it features a Dravida ekakuta vimana, with a sanctum accessible via a square vestibule that opens into a hall. This hall is segmented into nine decorative ceiling bays, supported by four meticulously lathe-turned stone pillars. An awning, itself supported by intricately carved pillars and flanked by parapets, marks the entrance to the hall. Consistent with Hoysala architectural conventions, the mantapa is enclosed, lacking windows to foster an atmosphere of introspection. The temple's exterior walls are richly adorned with sculptural reliefs, prominently featuring numerous dancer figures, which highlights the integral relationship between architecture and the performing arts during the Hoysala period, mirroring the decorative richness found at the Chennakeshava Temple in Belur (“10_chapter 4.Pdf,” n.d.).

METHODOLOGY

The Chennigaraya Temple's architectural details were meticulously documented and analyzed using photogrammetry. The process commenced with a comprehensive site visit to capture high-resolution images from multiple viewpoints, systematically recording all structural and ornamental features. Following a quality review to exclude suboptimal images, the selected photographs were processed in RealityCapture. Photogrammetric techniques were employed to align the images, generate a dense point cloud, and construct a detailed, textured 3D model. This model underwent refinement for enhanced geometric accuracy and photorealism before an in-depth analysis of the temple's architectural attributes, structural integrity, and ornamental elements. The resulting digital model facilitated a non-invasive condition assessment, enabling the precise identification and categorization of material degradation, structural anomalies, and areas requiring conservation intervention without direct physical contact (Abdelalim 2025).

3.1 Reconnaissance Survey

The initial phase of the project involved a reconnaissance survey to optimize the data collection process. This survey was essential for understanding the site's layout, accessibility, and general conditions, including an evaluation of the Chennigaraya Temple's geographical setting and surroundings to identify optimal vantage points and plan the photogrammetric workflow. Observations regarding the temple's architectural components, lighting conditions, and potential challenges such as access restrictions or obstructed views were recorded. Logistical considerations, including entry permissions, equipment placement, and safety protocols, were also reviewed. This preliminary visit ensured an efficient and disruption-free image capture phase, contributing to the accuracy and quality of the 3D model.

3.2 On-Site Interventions

The on-site interventions were the most critical phase, requiring a systematic approach to data acquisition at the Chennigaraya Temple.

3.2.1 Site Visit

A detailed site visit was conducted to implement the findings from the reconnaissance survey. Preparations included gathering all necessary equipment, such as DSLR cameras, drones, and measuring instruments, for capturing high-resolution imagery and data.

3.2.2 Image Capturing Process

Images were captured using various techniques:

Wide-Angle Captures: Documented the overall structure and complete temple architecture from multiple perspectives to provide contextual information and continuity.

Detailed Close-Ups: Captured high-resolution images of intricate carvings, ornamental details, and distinctive architectural elements.

Part Images: Documented specific components like the mantapa, ceilings, pillars, and shikhara individually for precise detailing within the 3D model.

3.2.3 Drone Captures

Drones were utilized to capture aerial perspectives and top-down views, offering comprehensive coverage of the temple's layout, spatial orientation, and surrounding environment, thereby supplementing ground-based data. This diverse range of image capture techniques ensured meticulous documentation of all architectural and ornamental aspects, forming the basis for an accurate and detailed 3D model.

3.3 Generating the 3D Model

The 3D model was generated using RealityCapture software, a process that involved several systematic steps:

3.3.1 Uploading Images and image alignment

High-resolution images acquired on-site, including wide-angle, close-up, and drone imagery, were imported into the software as the foundational dataset. The software identified common features across the uploaded images to align them spatially, resulting in a sparse point cloud that represented the initial geometric framework of the Chennigaraya Temple.

3.3.2 Mesh Model Creation and cleaning

A dense point cloud was generated from the sparse point cloud and subsequently converted into a mesh model, accurately representing the temple's detailed geometry, from macroscopic forms to microscopic intricacies. Unwanted artifacts and extraneous elements were systematically removed from the mesh to ensure a pristine, accurate, and data-integrity-focused 3D model. Figure 1 shows the image of work flow of mesh model creation and cleaning.

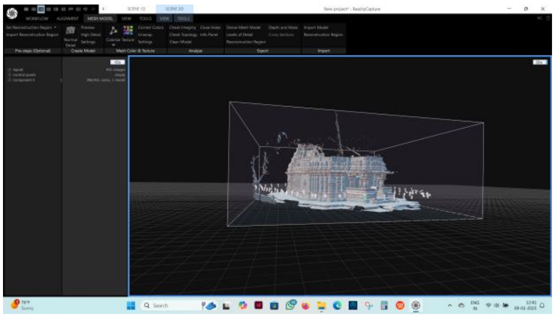
Figure 1: Screenshot of mesh model creation

3.3.3 Texturing and Unwrapping

High-resolution textures, replicating the original captured images, were applied to the cleaned mesh to enhance realism and visual fidelity. The unwrapping process ensured correct texture alignment with the geometric structure, preserving the temple's authentic appearance. This rigorous workflow resulted in a precise and photorealistic 3D model, forming the core of the project's documentation and analytical efforts. Figure 2 presents orthographic images generated.

Figure 2: Orthographic images of the temple

3.3.4 Extracting and Drafting Drawings

Following the 3D model creation in RealityCapture, detailed drawings were extracted and drafted for further assessment. The 3D model was transformed into CloudCompare to derive accurate orthographic views, which were exported for refinement. These extracted images were imported into AutoCAD as references, scaled to their actual dimensions, and used to draft precise 2D representations. The comprehensive suite of drawings included plans, elevations, sections, reflected ceiling plans, and detailed renderings of architectural elements, providing an accurate, scaled depiction of the temple's complex design for thorough analysis and condition assessment. This step ensured meticulous documentation of significant architectural elements, preserving the temple's spatial and structural integrity and providing an invaluable resource for conservation planning and academic research. Further, condition assessment of the heritage structure was carried out. Figure 3 presents process of drawing.

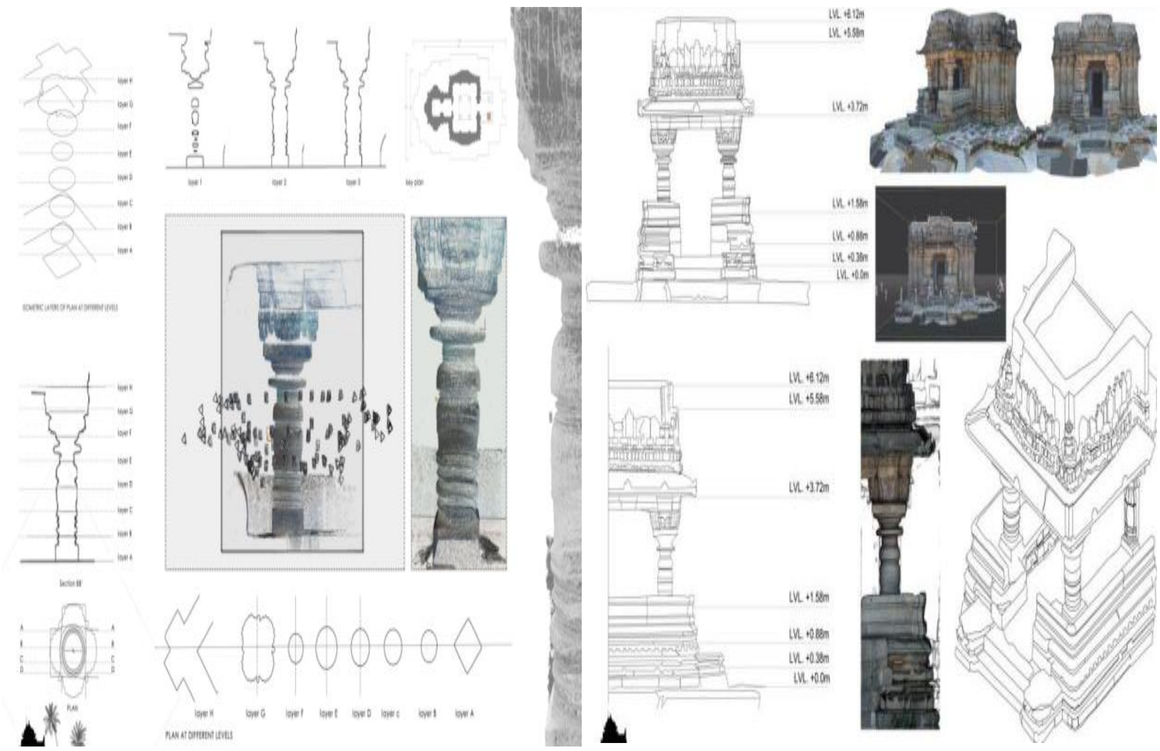

Figure 3: Samples workflow from 3D mesh model to drawing creation

RESULTS

The photogrammetric methodology facilitated the creation of a precise and dimensionally accurate 3D model of the Chennigaraya Temple, establishing a digital replica essential for thorough condition evaluation and future conservation initiatives (Patrucco, Perri, and Spano 2021). This model serves as a fundamental dataset for monitoring potential structural alterations over time and is instrumental for obtaining exact measurements of architectural features, thereby aiding in restoration planning (Patrucco, Perri, and Spano 2021). Specifically, the 3D model enabled detailed mapping of areas affected by material deterioration, including erosion, fissures, and biological colonization, allowing for precise quantification of damage to guide targeted conservation efforts (Doria, Galasso, and Morandotti 2022). Furthermore, this comprehensive digital archive supports advanced visualization techniques, such as transparent rendering, to expose concealed structural elements and intricate internal geometries, which are vital for holistic preservation strategies (Pan et al. 2020). The resultant point clouds and textured meshes function as accurate benchmarks for continuous monitoring, facilitating the identification and measurement of subtle volumetric changes attributable to environmental stresses or human activities (Curto, Garzulino, and Malik 2023). Additionally, the generated orthophotos offer a scientifically validated foundation for the precise localization of cultural artifacts and the planning of site protection measures, enhancing the method's applicability to extensive archaeological contexts (Zhang, Zhang, and Zhang 2017).

After the development of detailed drawings, a comprehensive condition assessment of the Chennigaraya Temple was performed to evaluate its current state and identify areas requiring intervention, a crucial step in documenting the structural and material integrity of heritage sites for conservation purposes. Observations included microbial vegetation in areas prone to moisture and the presence of black crusts on various surfaces, indicative of pollution and weathering. Discoloration of stone elements was also noted and attributed to environmental factors and aging. These findings were correlated with specific temple sections that had undergone restoration using concrete to enhance structural stability and mitigate water seepage, with these restored areas marked in red. While no significant structural damage or cracking was detected, suggesting overall stability, a minor northward inclination of approximately 3 degrees was recorded, potentially due to long-term subsidence. All identified conditions were meticulously documented on the drafted drawings, establishing a critical baseline for future conservation endeavors (Doria, Galasso, and Morandotti 2022). Figure 4 presents condition assessment drawing samples.

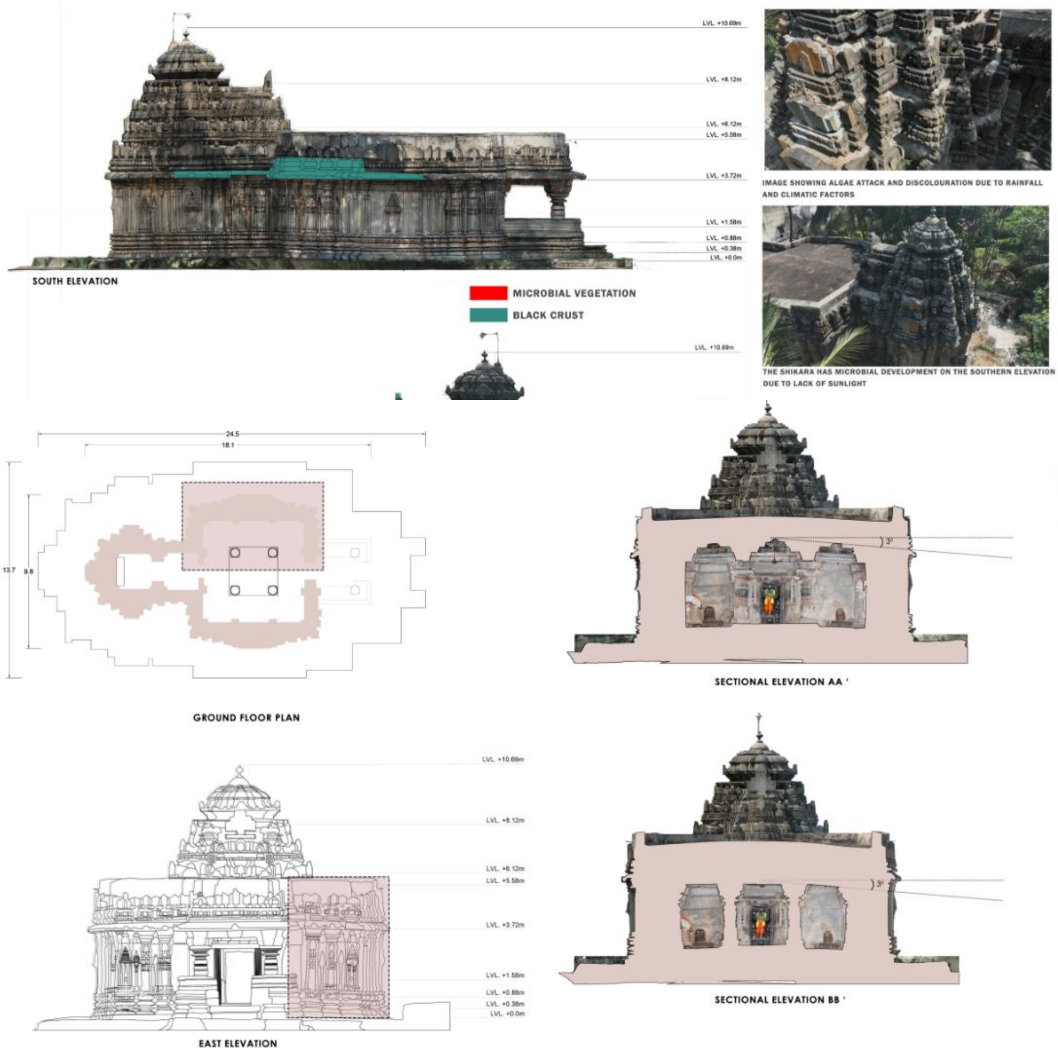

Figure 4: Condition assessment of the temple

DISCUSSION

Compared to the traditional manual documentation techniques , photogrammetry offers superior accuracy, cost-effectiveness, and the ability to capture complex geometries in a non-invasive manner, providing a significant improvement for the recording and archiving of archaeological features (Reu et al. 2012). Moreover, the rapid data acquisition inherent in photogrammetric workflows dramatically reduces the time spent on-site, minimizing potential disturbance to fragile structures (Zaragoza, Caroti, and Piemonte 2021). This efficiency also allows for more frequent data capture, creating a dynamic archive that reflects ongoing changes in the monument's condition. The integration of photogrammetry with other advanced techniques, such as laser scanning, further enhances the comprehensive nature of the captured data, allowing for the fusion of superior radiometric information from images with highly accurate geometric data from scanners, creating richer and more complete models (Alshawabkeh 2020). This synergy ensures an unparalleled level of detail and precision in the digital twin, critical for advanced heritage BIM applications (Alshawabkeh, Baik, and Miky 2021).

Some of the challenges include the substantial computational resources required for processing large datasets and the expertise needed for accurate data acquisition and interpretation (Solla et al. 2020). Additionally, the success of photogrammetric documentation heavily relies on optimal lighting conditions and meticulous camera calibration, which can be challenging to achieve in diverse field environments (Patrucco et al. 2023). Furthermore, while photogrammetry excels in chromatic data retrieval, it can suffer from short baselines in narrow scenes, necessitating a large number of images for sufficient overlap, which increases both on-site labor and computational burden (Sun and Zhang 2019). Moreover, the interpretation of results from complex photogrammetric models demands a nuanced understanding of potential distortions and occlusions, requiring specialized training for accurate assessment and defect identification. However, ongoing developments in automated processing pipelines and artificial intelligence algorithms are progressively mitigating these limitations, promising more accessible and robust photogrammetric solutions for heritage documentation (Alshawabkeh 2020). Nevertheless, the significant benefits of photogrammetry in cultural heritage preservation, particularly in providing detailed and non-invasive documentation, continue to drive its adoption and refinement (Donato and Giuffrida 2019). The digitization of cultural heritage, as facilitated by photogrammetry and other advanced geomatic tools, also presents opportunities for wider accessibility and public engagement through virtual tours and interactive platforms, fostering a deeper appreciation for historical landmarks.

CONCLUSION

In conclusion, the application of photogrammetry and other geomatic techniques to heritage documentation, exemplified by the Chennigaraya Temple, demonstrates a transformative shift in conservation methodologies, enabling unprecedented levels of detail and analytical depth. This approach not only facilitates precise condition assessment and long-term monitoring but also provides a robust digital archive for future generations, crucial for addressing challenges like digital obsolescence and data security. Furthermore, the creation of highly accurate 3D models through photogrammetry and other low-cost acquisition methods offers significant advantages for the knowledge, enhancement, and communication of cultural heritage, moving beyond traditional descriptive sheets and photographic images.

The condition assessment of chennigaraya temple suggests that it exhibits a combination of structural stability with minor surface deterioration, primarily due to weathering and biological growth, necessitating targeted conservation interventions. The architectural features of the temple are unique and hence demands meticulous documentation and preservation efforts to maintain their historical and artistic integrity. Future research will focus on developing predictive models for deterioration patterns, leveraging historical climate data and material science to forecast future conservation needs. This forward-looking approach will enable proactive interventions, moving from reactive repair to preventative maintenance, thus ensuring the long-term resilience of the monument against environmental stressors.

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