

Artificial Intelligence–Assisted Digital Reconstruction for Heritage Conservation: A Study of Monument Restoration


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Abstract

South India represents one of the most culturally and architecturally rich regions in the world, hosting a wide array of UNESCO World Heritage Sites and historically significant monuments. The Indian subcontinent has multiple archaeological sites as well as historical monuments in different states of ruin. While conventional restoration techniques are in use at various locations but the process still needs more focus and improved methods leveraging technology for expediting the initiative. Many of the heritage structures have undergone degradation due to aging, weather and human intervention particularly in culturally rich regions of Southern India. This study explores the application of Artificial Intelligence (AI) in the restoration of these monuments and artifacts through digital techniques by augmentation of damaged or lost architectural elements of heritage structures. The research investigates how machine learning, computer vision, and generative AI models can analyze historical images, maps, and archival records to recreate missing architectural features with improved accuracy and efficiency. Using AI-based image reconstruction and 3D modeling tools, digital models are generated and compared with traditional archaeological drawings and expert interpretations to evaluate reliability and authenticity. The study aims to assess whether AI can predict original architectural styles and reduce subjectivity in reconstruction processes. By providing a non-invasive and sustainable approach to heritage conservation, AI-assisted digital reconstruction offers new possibilities for documentation, visualization, and educational engagement. The findings contribute to interdisciplinary research integrating artificial intelligence with archaeology and cultural heritage preservation, highlighting AI's potential as a supportive tool for future conservation practices in Southern India. We will take detailed case studies and explore step by step on the specific problem statement, the feasible remedial measures and an elaborate approach for optimum restoration of the heritage structure and artifacts

Keywords: Artificial Intelligence; Digital Reconstruction; Heritage Conservation; Archaeology; 3D Modeling; Cultural Heritage; Southern India.

Introduction

The Indian subcontinent, particularly its southern region, is globally renowned for its culturally and architecturally rich heritage, encompassing sprawling temple complexes, monolithic rock-cut structures, and royal palaces. Monuments built during the reigns of the Chola, Pallava, and Vijayanagara empires exhibit unparalleled craftsmanship, featuring intricate stone carvings, towering Vimanas, and ornate Mandapas. Unfortunately, these architectural marvels exist in varying states of ruin due to prolonged exposure to harsh tropical climates, natural disasters, and centuries of human activity. While conventional restoration initiatives are actively deployed across multiple archaeological sites, the complexity and sheer volume of the degradation demand innovative, scalable interventions. Heritage conservation must balance the preservation of structural integrity with the authentic representation of historical aesthetics, a task that increasingly requires interdisciplinary methodologies.

To address the growing urgency of heritage preservation, this study explores the integration of Artificial Intelligence as a mechanism for the digital restoration of monuments and artifacts. The scope of this research is defined by the objective to digitally augment and reconstruct lost or severely damaged architectural elements using non-invasive computational techniques. By leveraging computer vision and generative AI models, the proposed approach seeks to synthesize historical images, archival maps, and modern sensor data to create highly accurate 3D representations of ruined structures. This paradigm shift from physical reconstruction to digital preservation allows historians and conservationists to visualize original architectural states without permanently altering the physical ruins, thereby maintaining the archaeological authenticity of the site.

Despite the ongoing efforts in heritage conservation, existing conventional and basic digital approaches remain insufficient for several critical reasons. First, traditional physical restoration and conventional 3D modeling are highly manual, time-consuming processes that rely heavily on the subjective interpretations of individual archaeologists, often leading to inconsistent historical accuracy. Second, standard digital modeling techniques struggle to efficiently process the massive, dense point clouds generated by modern laser scanning of large-scale temple complexes, lacking the predictive capabilities required to infer missing geometrical features from highly fragmented data. Finally, conventional computer-aided design tools do not possess the semantic understanding of regional architectural styles necessary to automatically generate historically plausible textures and sculptural details when source material is completely lost.

To overcome these significant limitations, this paper presents a novel computational framework tailored for heritage conservation. The primary contributions of this research are as follows:

- We propose an end-to-end AI-driven pipeline that integrates generative adversarial networks and 3D computer vision to synthetically reconstruct and predict lost architectural features specific to South Indian monuments.
- We introduce a comprehensive, structured evaluation methodology designed to benchmark AI-generated 3D models against expert archaeological drawings, effectively quantifying the reduction of subjectivity in historical reconstructions.

Literature Review

The application of digital technologies in cultural heritage preservation has expanded significantly in recent years, driven by the urgent need to document and restore historically significant sites that are vulnerable to environmental degradation and human impact. Existing literature highlights three major domains relevant to this study: digital reconstruction and storytelling, 3D scanning and point cloud processing, and generative artificial intelligence for synthetic reconstruction.

Digital Reconstruction and Cultural Heritage Visualization

Digital reconstruction has emerged as a powerful non-invasive tool for preserving and presenting cultural heritage. Studies such as Zacho et al. (2026) demonstrate how integrating archival data with 3D visualization techniques enables the recreation of historically suppressed or deteriorated sites. Their work on immersive storytelling platforms shows that combining historical narratives with 360-degree visualization enhances public engagement and supports cultural memory preservation.

Similarly, Ye et al. (2020) explored the digital reconstruction of heritage landmarks using large-scale point cloud datasets. Their approach enabled the development of mobile-based virtual reality environments, allowing users to interact with reconstructed heritage structures. While these methods are effective in visualization and accessibility, they are primarily dependent on existing physical and archival data. A key limitation identified across these studies is the lack of predictive capabilities when dealing with severely damaged or missing architectural components.

3D Scanning and Point Cloud Processing Techniques

Accurate geometric documentation forms the backbone of digital reconstruction. Techniques such as LiDAR scanning and photogrammetry have been widely used to generate dense point clouds representing the physical state of heritage structures. Mikkelsen and Kristiansen (2023) discuss advanced methods for aligning and merging point cloud data using registration algorithms and nonlinear optimization, followed by surface reconstruction techniques such as Poisson surface reconstruction.

These approaches provide high geometric fidelity and are widely adopted in engineering and industrial applications. However, when applied to archaeological contexts, they reveal critical limitations. Point cloud processing techniques lack semantic understanding, making it difficult to infer missing or damaged structural elements. Additionally, the processing of large-scale datasets requires substantial computational resources, limiting their practical application in heritage conservation without further optimization.

Generative Artificial Intelligence in Reconstruction

Recent advancements in generative AI, particularly Generative Adversarial Networks (GANs) and diffusion models, have significantly improved the ability to generate high-quality synthetic data. Goyal et al. (2026) demonstrated the effectiveness of combining GANs and diffusion models for enhancing digitally reconstructed medical images, treating reconstruction as a complex image-to-image translation problem.

Similarly, Zhang et al. (2020) introduced domain adaptation techniques to bridge the gap between synthetic and real-world data, improving the reliability of AI-generated outputs. These methods highlight the potential of AI to learn complex patterns and generate realistic textures and structures. However, a major concern associated with generative AI is the risk of producing plausible yet historically inaccurate outputs, often referred to as “hallucinations.”

Digital Reconstruction and Storytelling in Cultural Heritage

The application of digital technologies to reconstruct and preserve cultural heritage has gained substantial traction, primarily driven by the need to document sites that are vulnerable to destruction or decay. Previous research has demonstrated the profound impact of combining archival research with 3D modeling to preserve historically suppressed or degraded sites (Zacho et al., 2026). For example, immersive platforms have been developed to visualize the temporal transformation of historical locations, utilizing 360-degree photography and digital storytelling to engage the public and support memory work (Zacho et al., 2026). Similarly, the digital reconstruction of significant global landmarks, such as UNESCO World Heritage sites, has successfully utilized large, dense point clouds to create interactive virtual reality environments (Ye et al., 2020). The core strength of these approaches lies in their ability to provide non-invasive preservation and broad educational access. However, a notable weakness is that they often rely entirely on existing physical data and manual archival interpretation, lacking the automated predictive capabilities needed when significant portions of a structure are entirely missing. Our work builds upon these foundational concepts by integrating AI to actively predict and generate these missing elements, specifically tailoring the approach to the unique architectural vocabularies of South India.

Method/Approach

Data Acquisition and Preprocessing Module

The foundational step in our proposed framework involves the comprehensive aggregation of multi-modal data from selected South Indian heritage sites. This module combines contemporary spatial data with historical archives to create a robust ground-truth foundation. High-resolution LiDAR scanners and drone-based photogrammetry are deployed to capture the current state of the monument, generating dense, millimeter-accurate 3D point clouds. Simultaneously, historical data comprising colonial-era photographs, traditional architectural blueprints (Agama Shastras), and early archaeological sketches are digitized. The raw point clouds undergo rigorous preprocessing, utilizing noise reduction

filters and alignment algorithms to merge overlapping scans into a unified coordinate system (Mikkelstrup & Kristiansen, 2023). Historical 2D images are enhanced using computer vision techniques to correct fading, enhance contrast, and extract structural edges, serving as critical priors for the subsequent generative phases.

AI-Assisted Feature Prediction and Generative Reconstruction

Once the spatial and historical data are aligned, the system identifies structural gaps—regions where the monument has suffered severe degradation or loss. We propose the use of a dual-pathway generative AI architecture combining 3D geometric deep learning and 2D texture generation. For geometric reconstruction, a modified 3D Convolutional Neural Network (CNN) is utilized to predict the volumetric shape of missing elements, such as broken pillars or eroded deities. This network is trained on a specialized, curated database of intact South Indian architectural components, allowing it to infer missing geometry based on the stylistic context of the surviving surrounding structure. Concurrently, a Diffusion-based generative model is employed to synthesize high-fidelity surface textures (Goyal et al., 2026). By treating the mapping of historical sketches to photorealistic textures as an image-to-image translation task, the model generates realistic stone weathering and intricate carving details that match the specific geological materials of the site, such as granite or sandstone.

Detail Transfer and Digital Assembly

The final stage of the pipeline focuses on the efficient assembly and rendering of the reconstructed elements into a cohesive digital twin. Processing massive, fully reconstructed point clouds for interactive visualization often exceeds the memory and computational limits of standard hardware. To address this, we implement a detail transfer technique where high-frequency geometric and textural details from the AI-generated point clouds are mapped onto optimized, low-polygon base meshes (Ye et al., 2020). This approach preserves the intricate visual quality of the synthetic carvings while maintaining a highly efficient computational footprint. The digitally reconstructed components are seamlessly integrated with the actual scanned data of the existing ruins. Domain adaptation algorithms are applied during this phase to harmonize the lighting, shadows, and material properties between the real and synthetic elements, ensuring a visually continuous and realistic final model (Zhang et al., 2020).

Evaluation Plan

To systematically assess the reliability and authenticity of the proposed AI-assisted reconstructions, we outline a comprehensive evaluation protocol. Given the absence of standardized benchmarks for South Indian architectural reconstruction, we propose the creation of a hypothetical "Dravidian Heritage Scan Dataset (DHSD)." This dataset would comprise paired samples of intact structures (ground truth) and artificially degraded versions of those structures (inputs). The quantitative evaluation of 2D texture generation will be measured using the Fréchet Inception Distance (FID) to assess visual fidelity, while the 3D geometric accuracy will be evaluated using the Chamfer Distance between the predicted meshes and the ground truth. Crucially, a qualitative evaluation framework will be established involving a panel of expert archaeologists and art historians. In a series of blind tests, these experts will compare the AI-generated digital reconstructions against traditional, manually drawn archaeological interpretations, scoring them on stylistic accuracy, proportional correctness, and historical plausibility. This dual-faceted evaluation ensures that the AI models not only achieve mathematical optimization but also meaningfully reduce subjectivity and adhere to domain-specific archaeological standards.

Discussion

Practical Implications and Deployment Considerations

The successful deployment of AI-assisted digital reconstruction holds transformative implications for the field of heritage conservation in South India and beyond. By establishing a robust, non-invasive digital pipeline, conservationists can extensively study and document deteriorating sites without the immediate need for physical interventions that risk altering the original fabric of the monuments. This methodology directly supports the creation of highly detailed digital twins, which serve as invaluable resources for virtual tourism, democratizing access to global heritage for individuals unable to travel. Furthermore, the generated 3D models can be integrated into educational

curricula and interactive museum exhibits, fostering a deeper public appreciation for regional history (Zacho et al., 2026). From a logistical standpoint, deploying this framework requires collaborative ecosystems where computer scientists, government archaeological bodies, and local historians share secure access to multi-modal data repositories. Future deployment must also prioritize the development of user-friendly software interfaces that allow archaeologists lacking deep programming expertise to intuitively guide and constrain the AI generation process.

Research Gap and Contribution

While prior studies have successfully utilized digital tools for documentation and visualization, they largely depend on manual interpretation and lack automated mechanisms for reconstructing missing architectural elements. Additionally, existing approaches do not adequately incorporate regional architectural knowledge, which is crucial for preserving the stylistic authenticity of heritage structures.

This study addresses these gaps by proposing an AI-driven framework that integrates computer vision, generative modeling, and domain-specific architectural knowledge to enable predictive reconstruction. Unlike conventional methods, the proposed approach emphasizes reducing subjectivity, improving scalability, and ensuring historical plausibility through structured evaluation and expert validation.

Despite its substantial potential, the proposed methodology presents several limitations and potential failure modes that must be critically addressed.

- **Architectural Hallucination:** Generative AI models, by their probabilistic nature, are prone to "hallucinating" features. In the context of heritage reconstruction, the model might invent ornamental carvings or structural proportions that look stylistically plausible but are historically inaccurate, thereby creating a false historical record.
- **Complex Material Properties:** Accurately replicating the exact material properties and localized weathering states of ancient stone presents a significant challenge. The AI may struggle to differentiate between the subtle erosion patterns of distinct geological materials like soapstone versus basalt, leading to digital reconstructions that appear synthetically uniform or texturally incongruous with the physical ruins.
- **Computational Overhead:** The processing of massive, dense point clouds capturing sprawling South Indian temple complexes—some spanning dozens of acres—demands immense computational resources. Although optimization techniques like differentiable rendering can accelerate specific pipelines (Gopalakrishnan & Golland, 2022), the end-to-end training and inference of high-resolution 3D generative models remain prohibitively expensive for widespread, local deployment at remote archaeological sites.

Ethical Considerations or Risks

The integration of advanced AI into cultural heritage preservation introduces profound ethical considerations that must be navigated with care.

- **Risk of Digital Falsification:** There is a substantial risk that highly realistic AI-generated reconstructions could be mistaken for definitive historical truths. If these digital models are disseminated without clear annotations distinguishing between authentic surviving structures and AI-synthesized predictions, it could inadvertently rewrite historical narratives and mislead future generations of researchers.
- **Cultural Insensitivity and Iconographic Misrepresentation:** South Indian temple architecture is deeply intertwined with specific religious iconographies and sacred geometric principles (Vastu Shastra). If the AI model misinterprets or inappropriately alters the posture, attributes, or proportions of a deity's sculpture, it can result in cultural insensitivity and offend the religious sentiments of the local communities for whom these sites remain active places of worship.

Future Work

To advance the capabilities and safety of AI in heritage conservation, several avenues for future research are identified.

- **Multi-Modal Text-to-3D Generation:** Future iterations of the framework should integrate Large Language Models (LLMs) capable of analyzing ancient texts, localized inscriptions, and historical scriptures. By feeding explicit textual descriptions of lost structures as conditioning prompts to the 3D generative models, researchers can significantly constrain the AI, reducing hallucinations and anchoring the visual output to documented historical facts.
- **Real-Time Augmented Reality (AR) Integration:** Another critical direction is the transition of these digital reconstructions into immersive, on-site experiences. Future work should focus on optimizing the AI-generated low-polygon meshes for real-time rendering on mobile and wearable AR devices (Ye et al., 2020). This would allow site visitors and conservationists to stand directly in front of a ruined monument and view the historically accurate, AI-reconstructed architectural elements dynamically overlaid onto the physical environment.

Conclusion

The preservation of South India's architectural heritage requires innovative strategies that transcend the limitations of traditional, manual conservation techniques. This study has proposed a comprehensive methodological framework leveraging artificial intelligence, computer vision, and generative modeling to digitally reconstruct damaged or lost structural artifacts. By synthesizing archival records, historical photographs, and dense 3D point clouds, the proposed AI pipeline offers a scalable, non-invasive solution for predicting and recreating intricate Dravidian architectural features.

While the application of deep learning in this domain presents challenges regarding computational cost, the potential for digital falsification, and material accuracy, the structured implementation of expert-led evaluation and strict stylistic constraints can mitigate these risks. Ultimately, the integration of AI into archaeological practices represents a pivotal advancement in sustainable heritage conservation. It not only enhances the accuracy and efficiency of structural documentation but also opens entirely new paradigms for interactive historical education and the global digital preservation of human history. This approach aligns with recent advances in efficient 3D reconstruction from point clouds, which significantly reduce computational time and cost while maintaining high visual fidelity for heritage preservation applications (Ye et al., 2020).

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