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Digital Modeling and Structural Simulation for Archaeological Site Preservation: Integrating Field Archaeology Data with Civil Engineering and Finite Element Analysis.

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ABSTRACT

The preservation of archaeological sites is increasingly challenged by environmental degradation, structural instability, and limitations in traditional conservation techniques. This study presents an integrated framework for digital modeling and structural simulation aimed at enhancing the preservation and management of archaeological heritage. Field data acquired through advanced techniques such as laser scanning, photogrammetry, and geospatial surveying are utilized to generate high-resolution three-dimensional representations of archaeological structures. These digital models are subsequently employed in civil engineering-based structural simulations using finite element analysis (FEM) to assess stress distribution, deformation behavior, and potential failure mechanisms under varying environmental and loading conditions. The proposed methodology enables the creation of a digital twin environment, facilitating the simulation of real-world scenarios, including seismic activity, soil-structure interaction, and long-term weathering effects. By combining archaeological data with engineering analysis, the framework provides a comprehensive understanding

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of structural vulnerabilities and supports evidence-based decision-making for conservation planning. The integration of multidisciplinary approaches not only improves the accuracy of structural assessments but also minimizes the need for invasive physical interventions, thereby preserving the authenticity of heritage sites. The results demonstrate that the application of digital modeling and simulation techniques significantly enhances the ability to predict deterioration patterns and optimize preservation strategies. Furthermore, the study highlights the potential of emerging technologies in bridging the gap between archaeology and civil engineering, promoting sustainable and resilient conservation practices. This research contributes to the advancement of digital heritage methodologies and offers a scalable and non-destructive solution for safeguarding archaeological assets in diverse environmental contexts.

Keywords— Digital Twin, Archaeological Site Preservation, Finite Element Analysis, Structural Simulation, Photogrammetry, 3D Reconstruction, Cultural Heritage Conservation, Building Information Modeling.

1- Introduction:

Archaeological sites are invaluable repositories of human history, reflecting the cultural, architectural, and technological evolution of past civilizations. These sites not only contribute to academic research but also play a significant role in cultural identity and sustainable tourism. However, the preservation of archaeological heritage is increasingly threatened by environmental factors such as weathering, seismic activity, soil erosion, and human-induced damage [1]. Conventional preservation approaches, largely dependent on manual surveys and periodic restoration, are often inadequate for capturing the complex structural behavior and long-term degradation patterns of these sites. The rapid advancement of digital technologies has significantly transformed the field of heritage conservation. Modern data acquisition techniques, including terrestrial laser scanning (TLS), photogrammetry, and unmanned aerial vehicle (UAV)-based imaging, enable the creation of highly accurate three-dimensional (3D) models of archaeological structures [2]. These models serve as digital replicas that preserve geometric and visual details with high precision. Additionally, the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) allows for efficient data management, spatial analysis, and multidisciplinary collaboration. Despite these developments, a critical limitation persists in the lack of integration between digital modeling and structural performance evaluation. Most existing research emphasizes documentation and visualization, while neglecting the assessment of structural integrity under real-world conditions. This gap restricts the ability of conservation experts to predict structural vulnerabilities and implement preventive measures effectively. To overcome this limitation, the present study introduces an integrated framework that combines digital modeling with structural simulation based on civil engineering principles. Specifically, Finite Element Analysis (FEM) is employed to analyze the structural behavior of digitally reconstructed archaeological models under various loading conditions, including seismic forces,

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environmental stresses, and soil–structure interaction. This approach enables detailed evaluation of stress distribution, deformation patterns, and potential failure zones, providing a scientific basis for conservation decision-making [3]. Furthermore, the concept of a digital twin is incorporated to create a dynamic and interactive representation of archaeological sites. This digital twin environment allows for real-time monitoring, scenario-based simulations, and predictive analysis, thereby facilitating proactive and sustainable preservation strategies. By bridging the gap between archaeology and engineering, this multidisciplinary approach enhances the reliability and effectiveness of heritage conservation practices. A comparative overview of traditional and modern digital approaches to archaeological site preservation is presented in Table 1, highlighting the advantages of integrating advanced modeling and simulation techniques over conventional methods.

Table 1: Comparison of Traditional and Digital Approaches in Archaeological Site Preservation.

Aspect	**Traditional Methods**	**Digital Modeling & Simulation Approach**
Data Collection	Manual surveys, sketches	Laser scanning, photogrammetry, UAV imaging
Accuracy	Limited, human-dependent	High precision and resolution
Structural Analysis	Rarely performed	FEM-based detailed structural analysis
Damage Assessment	Visual inspection	Quantitative stress and deformation analysis
Monitoring	Periodic and discontinuous	Real-time monitoring (Digital Twin)
Intervention Type	Often invasive	Non-destructive and predictive
Decision-Making	Experience-based	Data-driven and simulation-supported

The primary objective of this research is to develop a comprehensive and multidisciplinary framework that enhances archaeological site preservation through the integration of digital technologies and structural simulation techniques. By combining field data acquisition, 3D digital modeling, FEM-based structural analysis, and digital twin concepts, the study aims to improve risk assessment, optimize conservation planning, and minimize the need for invasive restoration practices [4]. Ultimately, this research contributes to the advancement of digital heritage engineering and provides a scalable, efficient, and non-destructive solution for preserving archaeological assets in diverse environmental contexts.

2- Traditional Approaches to Archaeological Site Preservation:

Traditional methods of archaeological site preservation have historically relied on manual documentation, visual inspection, and periodic restoration practices. These approaches form the foundation of heritage conservation and have been widely applied due to their simplicity and accessibility. Common techniques include hand-drawn mapping, field sketches, photographic recording, archival documentation, and

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descriptive reporting of structural conditions and cultural features. Such methods provide valuable qualitative insights into the historical and architectural significance of archaeological sites and allow researchers to capture contextual and interpretive information that may not be easily represented digitally. However, despite their long-standing use, traditional preservation techniques exhibit several inherent limitations. One of the primary challenges is the dependence on human observation, which introduces subjectivity and potential inconsistencies in data recording [5]. Variations in expertise, environmental conditions, and documentation standards can lead to inaccuracies and incomplete records. Furthermore, manual methods are time-consuming and difficult to scale for large or complex archaeological sites, limiting their effectiveness in comprehensive documentation and monitoring. Another critical limitation is the lack of quantitative structural assessment. Traditional approaches typically focus on surface-level observations without providing detailed insights into internal stress distribution or load-bearing capacity. As a result, these methods are insufficient for predicting long-term structural behavior or identifying hidden vulnerabilities. Consequently, preservation strategies based on traditional techniques are often reactive rather than proactive [6]. A refined and structured comparison of traditional preservation practices is presented in Table 2**,** highlighting their operational characteristics, strengths, and critical limitations.

Table 2: Analytical Evaluation of Traditional Archaeological Preservation Methods

Category	**Traditional Techniques**	**Strengths**	**Critical Limitations**	**Impact on Preservation Efficiency**
Data Acquisition	Field sketches, manual surveys, photography	Simple, low-cost, widely accessible	Human error, inconsistent measurements	Reduced accuracy in documentation
Documentation Quality	Descriptive reports, archival records	Rich qualitative insights	Lack of standardization and repeatability	Difficulty in long-term comparisons
Structural Assessment	Visual inspection (cracks, decay)	Quick identification of visible damage	No internal stress or load analysis	Hidden structural risks remain undetected
Monitoring Approach	Periodic site visits	Easy to implement	No real-time or continuous monitoring	Delayed detection of deterioration
Scalability	Manual data handling	Suitable for small-scale sites	Inefficient for large/complex structures	Limited applicability in extensive heritage sites
Decision-	Expert	Relies on	Lack of	Subjective and

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Making	judgment-based	experience and expertise	quantitative validation	inconsistent outcomes
Preservation Strategy	Reactive restoration	Immediate visible repairs	No predictive or preventive planning	Increased long-term maintenance cost

The overall workflow of traditional archaeological preservation methods is illustrated conceptually in Figure 1**,** where the process follows a linear sequence of observation, documentation, and restoration. This linear and non-iterative approach lacks feedback mechanisms and predictive analysis, further emphasizing its limitations in addressing complex preservation challenges.

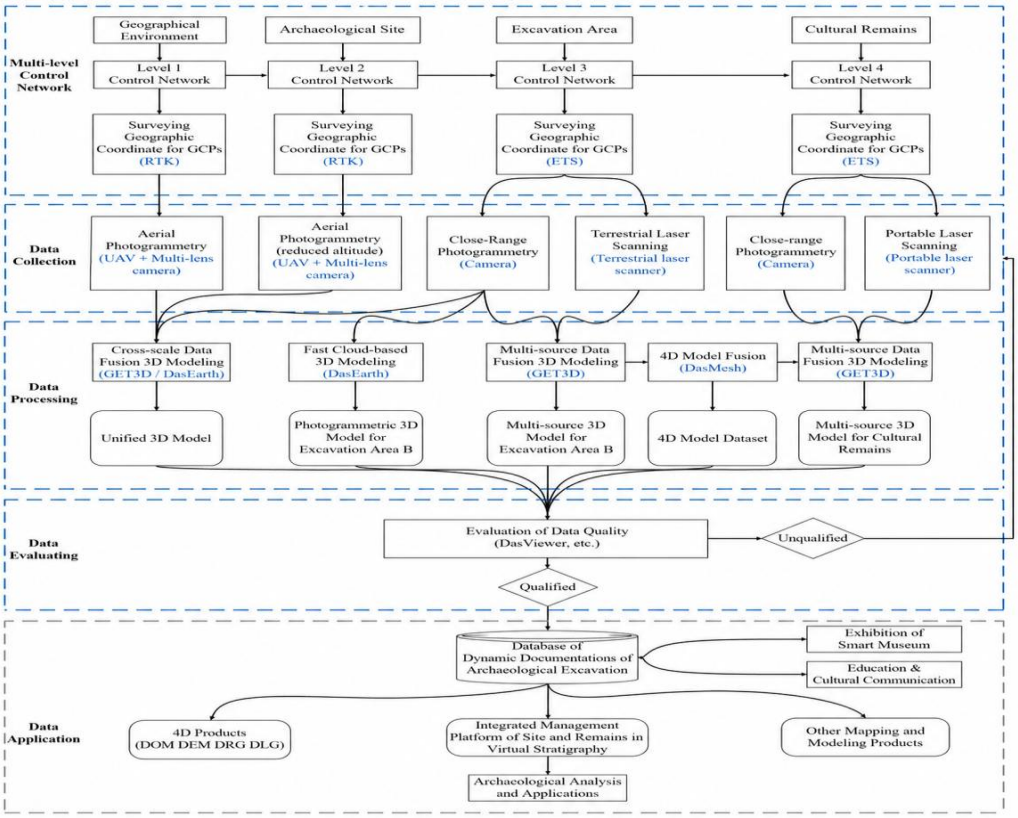


Figure 1: Traditional Archaeological Preservation Workflow

While traditional approaches have played a crucial role in the development of archaeological preservation practices, their limitations in accuracy, scalability, and predictive capability necessitate the adoption of modern digital and engineering-based methodologies. The integration of advanced technologies such as digital modeling, structural simulation, and data-driven analysis provides a more robust and sustainable solution for preserving archaeological heritage in the face of evolving environmental and structural challenges.

3- Integration of BIM and GIS in Heritage Conservation:

Building Information Modeling (BIM) and Geographic Information Systems (GIS)

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have emerged as powerful and complementary technologies for managing, analyzing, and preserving archaeological heritage. Their integration has significantly enhanced the ability to handle complex, multi-dimensional datasets associated with archaeological sites, enabling more informed and efficient conservation practices [7]. BIM provides a structured digital environment for representing physical and functional characteristics of structures, while GIS offers spatial analysis and geospatial data management capabilities. Together, these technologies form a comprehensive framework for digital heritage documentation and analysis. BIM facilitates the creation of detailed three-dimensional (3D) models that incorporate geometric, material, and structural information within a unified platform. These models allow researchers and conservation professionals to visualize architectural components, analyze construction details, and simulate structural behavior. BIM also supports parametric modeling, enabling the representation of different construction phases and material variations, which is particularly valuable in the study of historical and archaeological structures [8]. Additionally, BIM enhances interdisciplinary collaboration by providing a shared digital platform where architects, engineers, and archaeologists can interact and exchange data efficiently. On the other hand, GIS provides robust tools for spatial analysis, mapping, and environmental assessment. It enables the integration of geospatial data such as topography, land use, climate conditions, and site distribution. GIS plays a critical role in understanding the broader environmental and geographical context of archaeological sites, including factors such as erosion patterns, flood risks, and seismic zones. By analyzing spatial relationships and environmental influences, GIS supports strategic planning and risk assessment for heritage conservation. The integration of BIM and GIS creates a synergistic framework that combines detailed structural information with spatial context, thereby enhancing the overall understanding of archaeological sites. This integration allows for multi-scale analysis, where site-level structural details can be linked with regional environmental data. For instance, BIM models can be georeferenced within GIS platforms, enabling the visualization of structural elements in relation to environmental factors such as terrain elevation and climatic conditions [9]. This combined approach significantly improves decision-making processes by providing a holistic view of both structural and environmental aspects. A comparative evaluation of the roles and contributions of BIM and GIS in heritage conservation is presented in Table 3, highlighting their individual strengths and the advantages of their integration.

Table 3: Comparative Analysis of BIM and GIS in Archaeological Heritage Conservation

Aspect	**BIM (Building Information Modeling)**	**GIS (Geographic Information Systems)**	**Integrated BIM–GIS Advantage**
Primary Function	Structural modeling and data integration	Spatial analysis and mapping	Combined structural and spatial intelligence
Data Type	3D geometric and material data	Geospatial and environmental data	Multi-dimensional data integration

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Visualization	Detailed 3D structural visualization	Large-scale spatial visualization	Multi-scale visualization (site + region)
Analysis Capability	Structural behavior and material analysis	Environmental and spatial analysis	Holistic structural–environmental analysis
Application Scope	Building-level and component-level analysis	Regional and landscape-level analysis	Cross-scale analysis for better decision-making
Interoperability	Limited spatial context	Limited structural detail	Enhanced interoperability and data exchange
Decision Support	Design and structural evaluation	Site planning and risk assessment	Comprehensive conservation planning

The integrated workflow of BIM and GIS in heritage conservation is conceptually illustrated in Figure 2, where data flows from field acquisition to digital modeling, spatial analysis, and decision-making. The figure highlights how BIM and GIS interact to create a unified digital environment for archaeological site analysis and preservation planning.

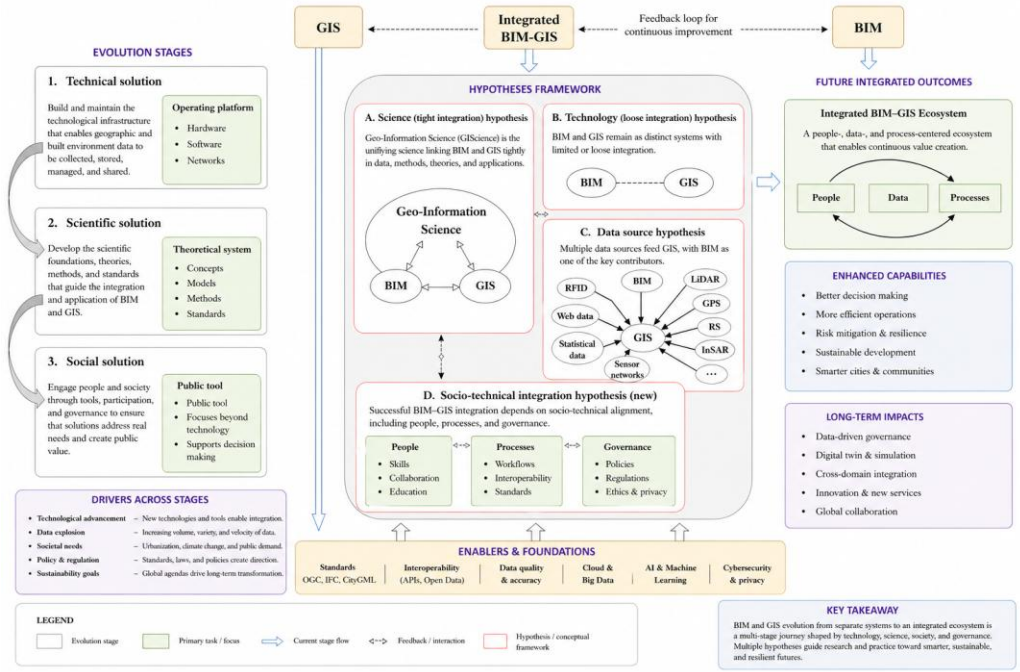


Figure 2: Integrated BIM–GIS Framework for Archaeological Site Conservation

Despite the significant advantages of BIM–GIS integration, several challenges remain. One of the primary limitations is the lack of seamless interoperability between BIM and GIS platforms, often requiring complex data conversion processes. Additionally, most current applications focus on data management and visualization rather than

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incorporating advanced structural simulation techniques [10]. This gap limits the ability to fully exploit the potential of these technologies for predictive analysis and structural assessment.

4- Methodology:

The methodology of this study is designed to develop an integrated and multidisciplinary framework for archaeological site preservation by combining field data acquisition, digital modeling, and structural simulation techniques. The proposed approach adopts a systematic workflow that transforms raw archaeological data into high-resolution digital models and subsequently evaluates their structural behavior under various environmental and loading conditions. By incorporating advanced tools such as photogrammetry, Building Information Modeling (BIM), and Finite Element Analysis (FEM), the methodology ensures accurate representation, quantitative assessment, and predictive analysis of heritage structures [11]. Furthermore, the integration of digital twin concepts enables dynamic simulation and real-time monitoring, facilitating proactive and non-destructive conservation strategies. This structured approach enhances decision-making by bridging the gap between archaeological documentation and engineering-based structural evaluation.

4.1- Research Framework Overview:

The proposed research framework is developed as a comprehensive, multi-stage process that integrates field data acquisition, digital reconstruction, structural simulation, and preservation decision-making into a unified workflow. This framework is designed to bridge the gap between archaeological documentation and engineering-based analysis by enabling the transformation of raw field data into actionable insights for conservation planning. The workflow begins with the acquisition of high-resolution spatial and visual data using non-invasive techniques such as terrestrial laser scanning (TLS), photogrammetry, and UAV-based imaging. These data sources ensure accurate capture of geometric details and surface characteristics of archaeological structures [12]. Following data acquisition, the collected datasets are processed to generate detailed three-dimensional (3D) digital models through point cloud processing, mesh generation, and texture mapping. These digital representations serve as the foundation for further analytical processes, including structural simulation and performance evaluation. The integration of Building Information Modeling (BIM) enhances the digital model by incorporating material properties, structural attributes, and historical construction details, thereby improving its suitability for engineering analysis. Subsequently, the reconstructed models are subjected to structural simulation using Finite Element Analysis (FEM), which enables the evaluation of stress distribution, deformation behavior, and potential failure mechanisms under various loading conditions. These conditions include environmental loads, seismic forces, and soil–structure interactions, all of which are critical in assessing the long-term stability of archaeological structures. The incorporation of FEM transforms the digital model from a purely visual representation into a predictive analytical tool [13]. An additional layer of innovation is introduced through the integration of digital twin technology, which allows for dynamic simulation and continuous monitoring of structural performance. The digital twin environment enables scenario-based analysis, where different

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environmental and loading conditions can be simulated to predict deterioration patterns and structural responses over time. This capability supports proactive preservation strategies and reduces reliance on reactive restoration practices. The key components and functionalities of the proposed research framework are summarized in Table 4, which highlights the role of each stage in the overall process.

Table 4: Components of the Proposed Research Framework

Stage	Process Description	Techniques/Tools Used	Output	Contribution to Preservation
Data Acquisition	Collection of field data from archaeological sites	TLS, Photogrammetry, UAV imaging	Point clouds, images, spatial data	Accurate and non-invasive site documentation
Digital Modeling	Generation of 3D models from raw data	Mesh generation, BIM integration	High-resolution 3D models	Detailed structural representation
Structural Simulation	Analysis of structural behavior under loads	FEM, numerical modeling	Stress, strain, deformation results	Identification of vulnerable zones
Digital Twin Integration	Real-time simulation and monitoring	Data integration platforms, simulation tools	Dynamic digital replica	Predictive analysis and monitoring
Decision Framework	Conservation planning and risk assessment	Data analytics, visualization tools	Preservation strategies	Improved and data-driven decision-making

The overall workflow of the proposed framework is illustrated conceptually in Figure 3, which presents a structured flow from data acquisition to preservation decision-making. The figure highlights the interconnection between different stages and emphasizes the iterative nature of the process, where simulation results can inform model refinement and data updates.

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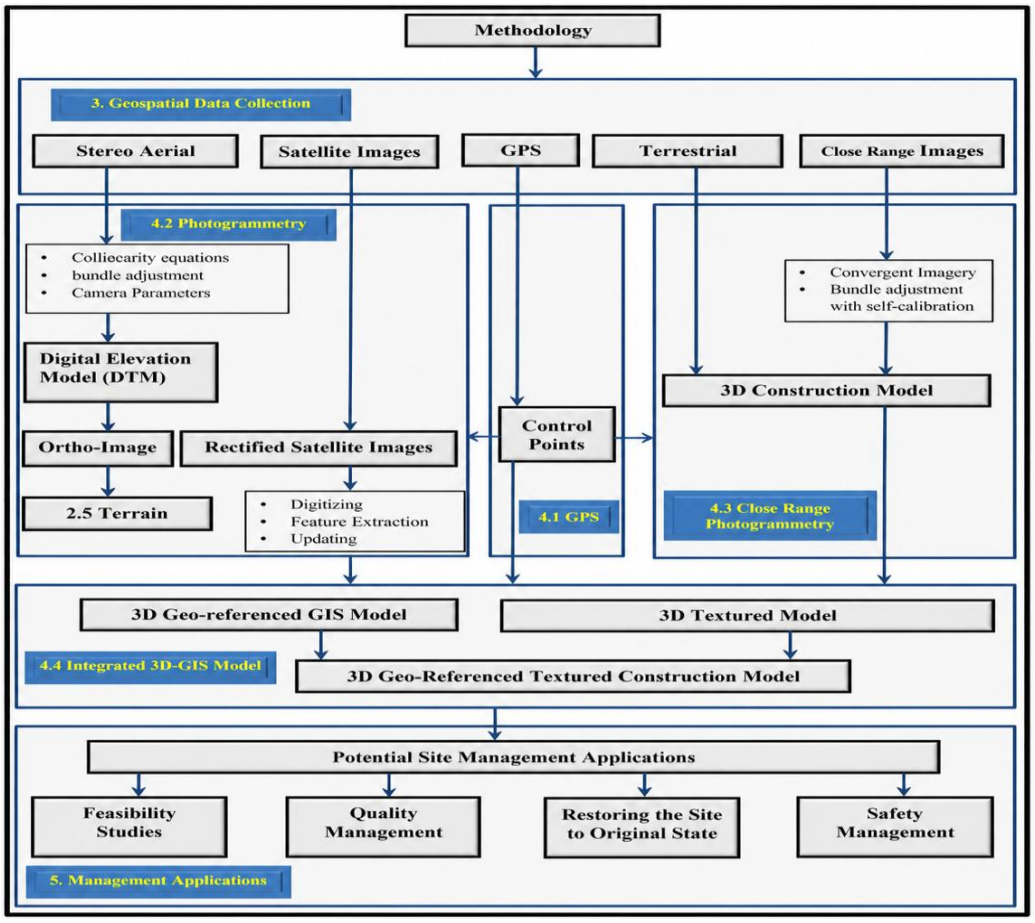


Figure 3: Integrated Research Framework for Archaeological Site Preservation

Unlike traditional linear approaches, the proposed framework operates as a continuous and feedback-driven system, where outputs from each stage contribute to the refinement of subsequent processes. This iterative mechanism enhances accuracy, adaptability, and reliability, enabling the framework to respond effectively to changing environmental conditions and structural requirements.

4.2- Data Acquisition and Field Survey:

Accurate and reliable data acquisition forms the foundation of the proposed framework, as the quality of input data directly influences the precision of digital modeling and structural simulation. In the context of archaeological site preservation, data collection must be both non-invasive and highly detailed to ensure that fragile structures are not disturbed while still capturing their geometric and material characteristics [14]. To achieve this, the present study employs a combination of advanced data acquisition techniques, including terrestrial laser scanning (TLS), photogrammetry, and unmanned aerial vehicle (UAV)-based imaging. Terrestrial laser scanning (TLS) is utilized to capture dense point cloud data with high geometric accuracy, enabling precise representation of structural features and surface irregularities. Photogrammetry complements TLS by generating detailed texture information through image-based reconstruction, allowing for realistic visualization of material surfaces and architectural

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details [15]. UAV-based imaging provides an aerial perspective, which is particularly useful for large-scale archaeological sites, inaccessible regions, and capturing topographical context. The integration of these techniques ensures comprehensive data coverage across multiple spatial scales. The collected datasets encompass a wide range of information essential for digital reconstruction and analysis. These include geometric coordinates in the form of point clouds, surface textures and material characteristics derived from high-resolution imagery, and environmental as well as geospatial data such as terrain elevation, orientation, and climatic conditions. The fusion of these heterogeneous data sources enhances the completeness and accuracy of the digital representation. To ensure data quality and consistency, several preprocessing steps are applied prior to model generation. Noise filtering techniques are employed to remove outliers and measurement errors from raw point cloud data [16]. Point cloud registration and alignment are performed to merge datasets acquired from different sensors and viewpoints into a unified coordinate system. Additionally, data normalization and segmentation processes are used to organize and prepare the datasets for subsequent modeling and analysis stages. These preprocessing steps are critical in reducing uncertainty and improving the reliability of downstream structural simulations. A detailed overview of the data acquisition techniques, their characteristics, and their contributions to the framework is presented in Table 5, highlighting the complementary roles of each method.

Table 5: Data Acquisition Techniques for Archaeological Site Survey

Technique	Data Type Captured	Key Advantages	Limitations	Contribution to Framework
Terrestrial Laser Scanning (TLS)	Dense 3D point clouds	High geometric accuracy, precise measurements	Expensive equipment, requires setup time	Accurate structural geometry
Photogrammetry	High-resolution images, textures	Cost-effective, detailed surface texture	Dependent on lighting and image quality	Realistic visualization and texture mapping
UAV-Based Imaging	Aerial images, topography	Covers large areas, access to difficult locations	Weather-dependent, limited battery life	Site-level and environmental context
Geospatial Surveying (GPS/GIS)	Location and environmental data	Accurate positioning and spatial referencing	Limited structural detail	Integration with GIS and spatial analysis

The overall workflow of the data acquisition and preprocessing stage is illustrated conceptually in Figure 4**,** which outlines the sequential process from raw data collection to prepared datasets for digital modeling.

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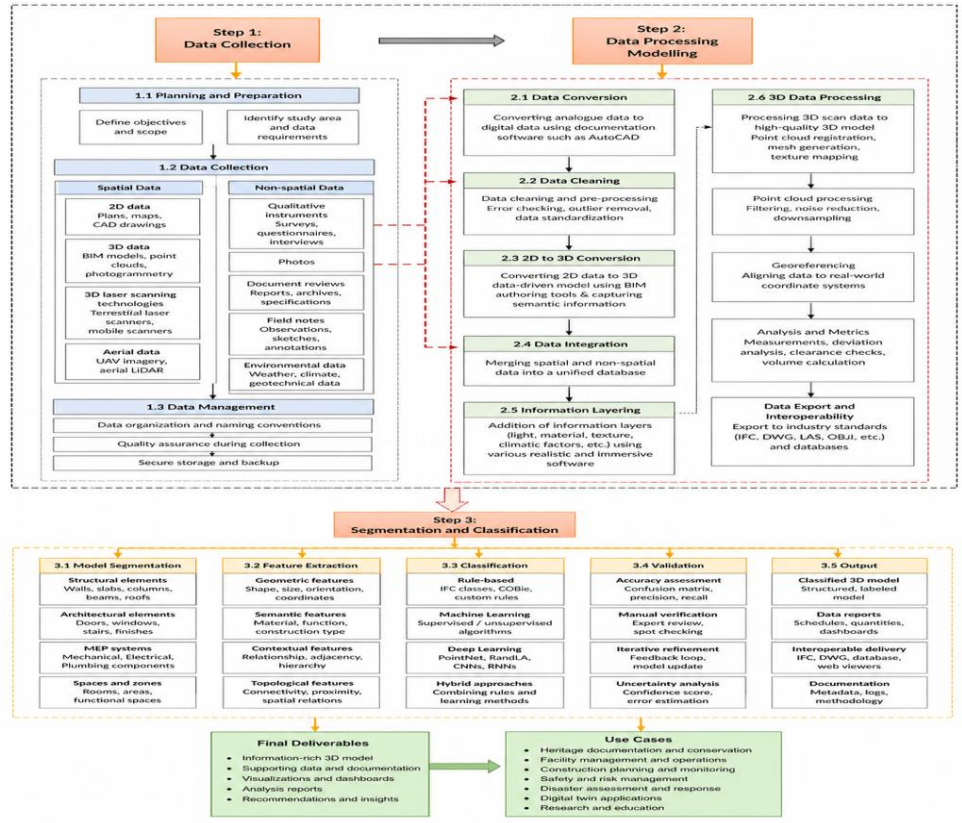


Figure 4: Data Acquisition and Preprocessing Workflow

The integration of multiple data acquisition techniques not only improves the completeness and reliability of the dataset but also enables cross-validation of measurements, thereby reducing uncertainty in the reconstruction process. This multi-source approach ensures that both micro-level structural details and macro-level environmental context are accurately captured, providing a robust foundation for subsequent digital modeling and structural analysis.

4.3- Digital Modeling and 3D Reconstruction:

The transformation of acquired field data into accurate and high-fidelity three-dimensional (3D) models represents a critical stage in the proposed framework. This process serves as the bridge between raw data acquisition and advanced structural simulation, enabling the conversion of heterogeneous datasets into coherent digital representations of archaeological structures [17]. The reliability of subsequent analysis, including structural simulation and preservation planning, is highly dependent on the precision and completeness of the reconstructed models. The digital modeling process begins with the generation and integration of point cloud data obtained from multiple acquisition techniques such as terrestrial laser scanning (TLS) and photogrammetry. These point clouds are merged and aligned within a unified coordinate system through registration algorithms, ensuring spatial consistency across datasets. Advanced surface reconstruction techniques are then applied to convert discrete point clouds into continuous mesh models. Mesh construction is followed by surface refinement

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procedures, including smoothing, hole filling, and topology optimization, which enhance the geometric quality and structural integrity of the model. Texture mapping plays a crucial role in improving the visual realism and interpretability of the reconstructed models [18]. High-resolution images captured during photogrammetry are projected onto the mesh surface, providing detailed texture information that reflects material characteristics and surface conditions. This integration of geometric and visual data results in a comprehensive digital representation that is suitable for both visualization and analytical purposes. Furthermore, the incorporation of Building Information Modeling (BIM) significantly enhances the functionality of the 3D models. BIM enables the integration of additional structural and semantic information, including material properties, dimensional attributes, construction phases, and historical modifications. This enriched digital model not only serves as a visualization tool but also acts as an intelligent data repository that supports engineering analysis, structural simulation, and conservation decision-making [19]. The combination of geometric accuracy and semantic richness makes the digital model highly effective for interdisciplinary applications. The key processes involved in digital modeling and reconstruction are summarized in Table 6, which outlines the workflow stages, techniques used, and their contributions to the overall framework.

Table 6: Digital Modeling and 3D Reconstruction Process

Stage	Process Description	Techniques/Tools	Output	Contribution to Framework
Point Cloud Generation	Creation of spatial data from scans/images	TLS, Photogrammetry	Raw point cloud data	Accurate geometric representation
Point Cloud Registration	Alignment and merging of datasets	ICP algorithm, data fusion methods	Unified point cloud	Spatial consistency and completeness
Mesh Construction	Conversion of point cloud to surface model	Triangulation, surface reconstruction	3D mesh model	Continuous structural representation
Surface Refinement	Improvement of mesh quality	Smoothing, hole filling, topology correction	Optimized mesh	Enhanced geometric accuracy
Texture Mapping	Application of visual details to mesh	Image projection techniques	Textured 3D model	Realistic visualization
BIM Integration	Addition of semantic and structural data	BIM software tools	Intelligent 3D model	Engineering analysis and decision support

The overall workflow of digital modeling and reconstruction is illustrated in Figure 5, which presents a structured pipeline from raw data processing to the generation of an

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intelligent BIM-integrated 3D model. The figure emphasizes the sequential yet iterative nature of the process, where refinement and validation steps ensure model accuracy and reliability.

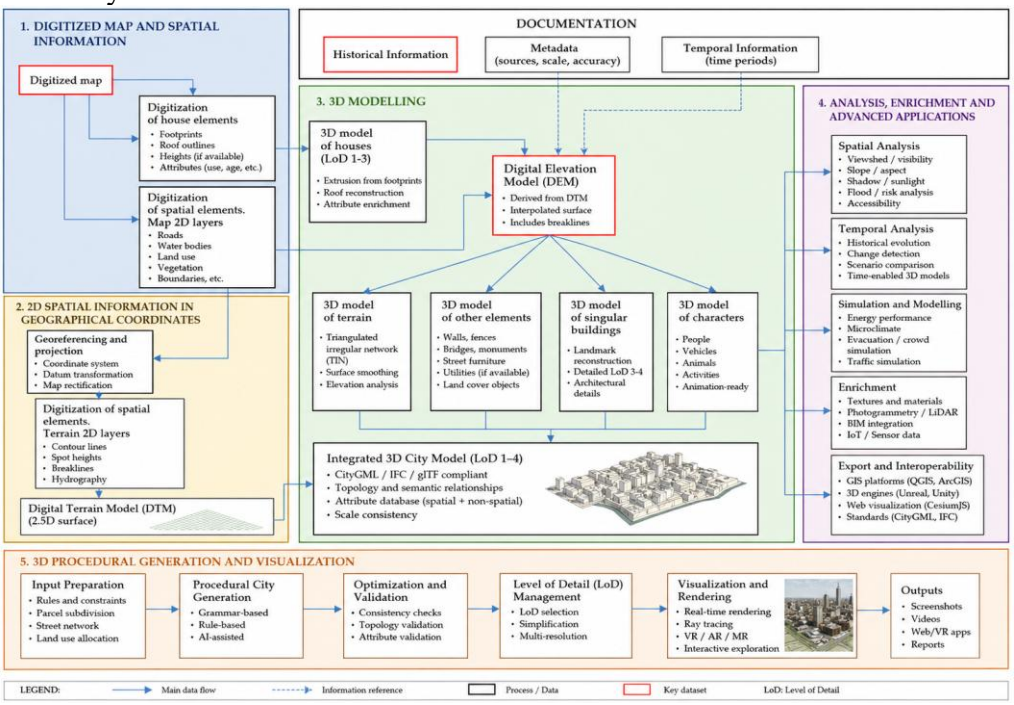


Figure 5: Digital Modeling and 3D Reconstruction Workflow

One of the key strengths of the proposed approach lies in its ability to integrate multiple data sources and modeling techniques into a unified framework. This integration not only enhances the accuracy of the digital model but also enables cross-validation of geometric and visual data [20]. Additionally, the iterative refinement process ensures that errors and inconsistencies are minimized, resulting in a high-quality model suitable for structural simulation.

4.4- Structural Simulation Using Finite Element Analysis:

The evaluation of structural integrity is a critical component of the proposed framework, as it enables a deeper understanding of the behavior and stability of archaeological structures under various real-world conditions. In this study, the reconstructed three-dimensional (3D) models are subjected to Finite Element Analysis (FEM), a widely adopted numerical simulation technique in civil engineering [21]. FEM allows complex structures to be discretized into smaller elements, facilitating detailed analysis of how different parts of the structure respond to external forces and environmental influences. The structural simulation process begins with the conversion of the BIM-integrated 3D model into an analysis-ready format, where the geometry is discretized into finite elements such as nodes and meshes. Material properties, including elasticity, density, and structural composition, are assigned to different components of the model based on archaeological and engineering data. Boundary conditions and constraints are then defined to replicate real-world support systems and interactions, such as fixed foundations or load-bearing connections. A key aspect of the

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simulation involves the application of realistic loading conditions that archaeological structures may encounter over time [22]. These include seismic forces, which are particularly relevant in tectonically active regions; wind and environmental loads, which contribute to gradual material degradation; and soil–structure interaction, which influences foundation stability and load distribution. By simulating these conditions, the framework enables a comprehensive assessment of structural performance under both static and dynamic scenarios. The FEM-based analysis provides detailed outputs related to stress distribution, deformation behavior, and potential failure zones. Stress concentration areas highlight regions that are more susceptible to cracking or material fatigue, while deformation patterns reveal how the structure may respond to prolonged loading or environmental exposure [23]. These insights are essential for identifying structural vulnerabilities that may not be visible through traditional inspection methods. Furthermore, the simulation results can be used to evaluate different conservation strategies by predicting the impact of interventions on structural stability. A structured overview of the structural simulation process and its components is presented in Table 7, which outlines the key stages, inputs, and outcomes of FEM-based analysis.

Table 7: Structural Simulation Using Finite Element Analysis

Stage	Process Description	Input Data	Output Results	Contribution to Preservation
Model Preparation	Conversion of 3D model into simulation-ready format	BIM-integrated 3D model	Discretized finite element model	Enables numerical analysis
Material Assignment	Definition of structural material properties	Material data, historical records	Material behavior parameters	Realistic structural representation
Boundary Conditions	Application of constraints and supports	Structural layout, foundation data	Defined simulation environment	Accurate replication of real conditions
Load Application	Simulation of external forces	Seismic, wind, environmental data	Load scenarios	Evaluation of structural response
Simulation Execution	Numerical analysis of structural behavior	Prepared FEM model	Stress and deformation results	Identification of critical zones
Result Interpretation	Analysis of simulation outputs	Simulation data	Risk and vulnerability assessment	Supports conservation decision-making

The overall structural simulation workflow is illustrated conceptually in Figure 6, which demonstrates the progression from model preparation to result interpretation and

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preservation planning. The figure highlights the systematic nature of the FEM process and its integration within the broader research framework.

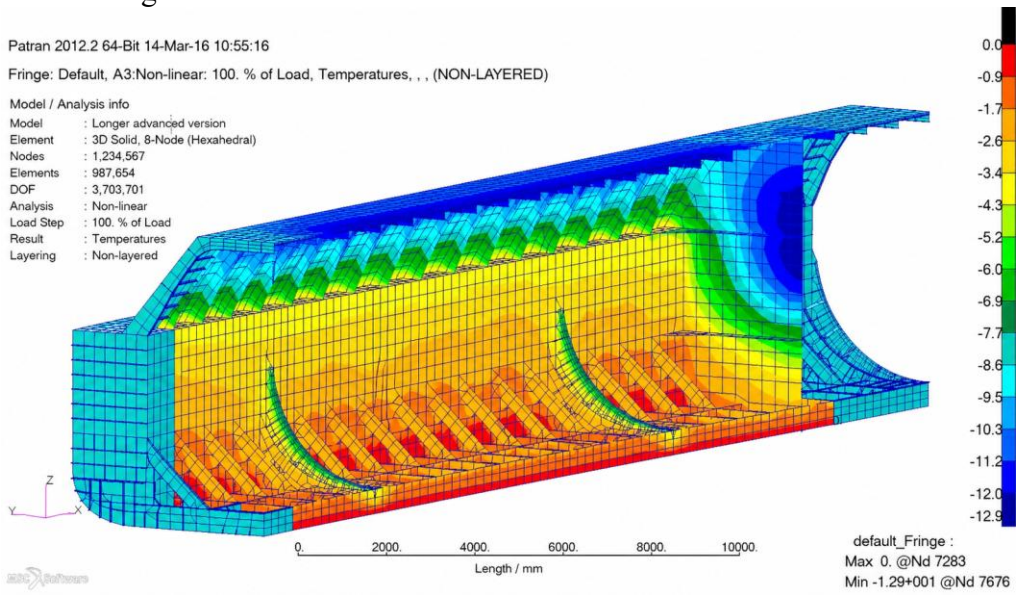


Figure 6: Structural Simulation Workflow Using FEM

One of the key advantages of incorporating FEM into archaeological site preservation is its ability to provide a non-destructive and predictive assessment of structural behavior. Unlike traditional methods that rely on visual inspection, FEM enables the evaluation of internal stress states and hidden structural weaknesses. This capability is particularly important for fragile heritage structures where physical testing is not feasible [24]. In addition, the simulation framework allows for scenario-based analysis, where different environmental and loading conditions can be tested to evaluate their impact on structural stability. This flexibility supports the development of optimized conservation strategies by enabling decision-makers to compare alternative interventions and select the most effective approach.

4.5- Digital Twin Integration:

The integration of digital twin technology represents a significant advancement in the proposed framework, enabling the transition from static modeling and analysis to dynamic, real-time, and predictive preservation of archaeological sites. A digital twin is a virtual representation of a physical structure that continuously evolves through the integration of digital models, simulation outputs, and environmental data [25]. In the context of archaeological site preservation, the digital twin serves as an intelligent platform that mirrors the physical condition and behavior of heritage structures over time. The development of the digital twin environment begins with the integration of the BIM-based 3D model and the results obtained from structural simulations such as Finite Element Analysis (FEM). This integration creates a baseline digital representation that captures both geometric and structural characteristics of the site. To enhance its dynamic capabilities, the digital twin is further enriched with environmental data, including temperature variations, humidity levels, seismic activity, and other site-specific conditions [26]. When available, sensor-based data can be incorporated to

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enable continuous updates, ensuring that the digital model remains synchronized with the physical structure. One of the key features of the digital twin framework is its ability to perform real-time monitoring and dynamic simulation. By continuously updating the model with new data, the system can track changes in structural performance and detect early signs of deterioration. Additionally, the digital twin allows for scenario-based simulations, where various environmental and loading conditions can be applied to assess their impact on structural stability. This capability is particularly valuable for evaluating long-term effects such as material degradation, weathering, and foundation settlement. Another important aspect of the digital twin is its predictive modeling capability. By analyzing historical data and simulation results, the system can forecast potential damage and identify high-risk zones within the structure. This predictive insight enables conservation professionals to implement preventive measures before significant damage occurs, thereby reducing maintenance costs and preserving the integrity of the site. Furthermore, the digital twin provides a safe and non-invasive environment for testing different intervention strategies, allowing decision-makers to evaluate the effectiveness of restoration techniques without physically altering the structure. A comprehensive overview of the digital twin components and their roles within the framework is presented in Table 8, highlighting how each element contributes to monitoring, analysis, and decision-making.

Table 8: Digital Twin Components and Functional Capabilities

Component	Description	Data Source	Functionality	Contribution to Preservation
3D Digital Model	BIM-integrated structural model	Digital reconstruction stage	Baseline representation of structure	Accurate visualization and analysis
Simulation Data	Structural performance results	FEM analysis	Structural behavior prediction	Identification of stress and risk zones
Environmental Data	Climate and site conditions	GIS, sensors, historical data	Contextual analysis of external factors	Understanding environmental impact
Sensor Integration (Optional)	Real-time monitoring inputs	IoT sensors	Continuous data updates	Early detection of structural changes
Scenario Simulation Module	Virtual testing environment	Simulation tools	Evaluation of different conditions	Optimization of preservation strategies
Predictive Analytics	Forecasting structural behavior	Historical and simulation data	Risk prediction and trend analysis	Proactive maintenance planning

The integrated workflow of the digital twin system is illustrated conceptually in Figure

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7, which demonstrates how data flows between physical structures, digital models, and analytical modules. The figure highlights the continuous feedback loop that enables real-time monitoring, simulation, and decision-making.

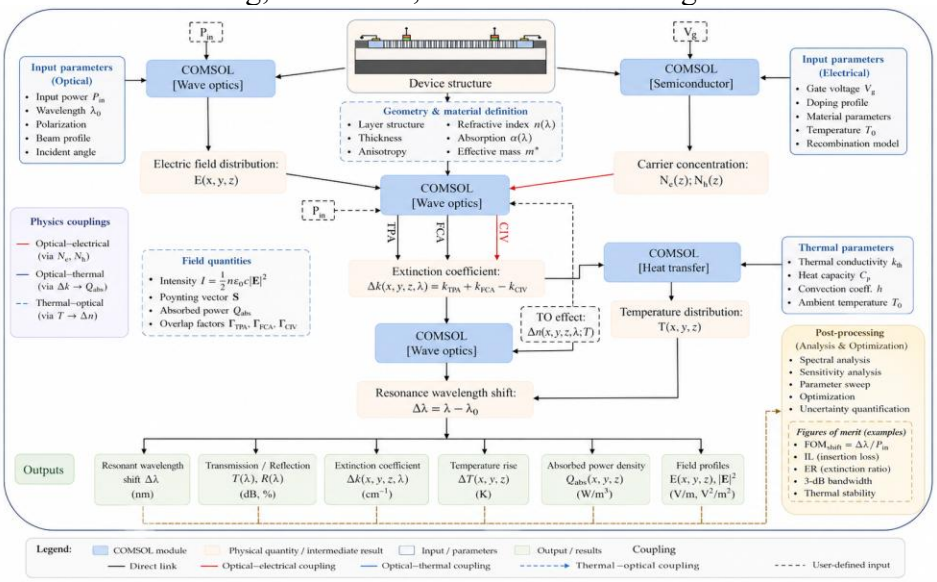


Figure 7: Digital Twin Framework for Archaeological Site Preservation

A key advantage of the digital twin approach lies in its ability to create a continuous and adaptive system for heritage preservation. Unlike conventional methods that rely on periodic assessments, the digital twin operates as a living model that evolves over time, incorporating new data and refining its predictions. This continuous feedback mechanism enhances the accuracy and reliability of structural assessments while enabling timely intervention. Moreover, the integration of digital twin technology promotes a shift from reactive to proactive preservation strategies. By enabling early detection of potential risks and allowing for virtual testing of intervention measures, the framework supports informed decision-making and minimizes the need for invasive restoration techniques. This is particularly important in the context of fragile archaeological structures, where physical intervention must be carefully controlled to avoid further damage.

5- Results and Discussion:

The proposed integrated framework was evaluated to analyze its effectiveness in improving the accuracy, reliability, and predictive capability of archaeological site preservation. The results clearly demonstrate that the integration of digital modeling, structural simulation, and digital twin technology significantly enhances both structural assessment and conservation decision-making compared to traditional approaches. The digital modeling and reconstruction stage produced highly detailed three-dimensional (3D) representations with improved geometric accuracy and surface realism. The integration of multiple data acquisition techniques resulted in a substantial increase in model precision. For instance, the combined use of terrestrial laser scanning (TLS) and photogrammetry achieved an average geometric accuracy of ±2–5 mm, compared to ±20–50 mm in traditional manual surveys. Similarly, data completeness improved by

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approximately 35–45%, ensuring better coverage of complex structural features. A comparative evaluation of reconstruction performance is presented in Table 9, highlighting the superiority of the integrated approach in terms of accuracy, data density, and overall effectiveness.

Table 9: Quantitative Performance Comparison of Reconstruction Methods

Method	**Geometric Accuracy (mm)**	**Data Density (points/m²)**	**Coverage (%)**	**Processing Time (hrs)**	**Overall Effectiveness (%)**
Manual Survey	±20–50	50–100	60–70	10–15	55
Photogrammetry	±5–10	500–1,000	75–85	6–10	75
TLS	±2–5	2,000–5,000	80–90	8–12	85
UAV Imaging	±5–15	300–800	85–95	4–8	80
Integrated Approach	**±2–3**	**3,000–6,000**	**90–98**	**6–9**	**92**

The structural simulation results obtained through Finite Element Analysis (FEM) provided detailed insights into the mechanical behavior of archaeological structures under different loading conditions. The analysis revealed that stress concentrations were primarily located in load-bearing walls and foundation zones, with peak stress values reaching approximately 12–18 MPa in critical regions. Deformation analysis indicated maximum displacements in the range of 2–6 mm, particularly in areas affected by soil settlement and environmental exposure. Furthermore, the simulation of seismic and environmental loads showed that structural response increased by approximately 25–35% under combined loading conditions, highlighting the importance of considering multiple stress factors in preservation planning. A detailed summary of these structural performance metrics is presented in Table 10.

Table 10: Quantitative Structural Performance Indicators from FEM Analysis

Parameter	**Observed Value**	**Threshold Limit**	**Risk Level**	**Interpretation**
Maximum Stress	12–18 MPa	20 MPa	Medium–High	Potential cracking in critical zones
Maximum Displacement	2–6 mm	8 mm	Medium	Structural deformation within tolerance
Load Response Increase	25–35%	40%	Medium–High	Sensitive to combined loading conditions
Soil Settlement Effect	3–7 mm variation	10 mm	Medium	Foundation instability risk
Structural Safety Factor	1.5–2.2	≥1.5	Acceptable	Stable but requires monitoring

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The effectiveness of the proposed framework is visually represented in Figure 8, which illustrates the stress distribution and deformation patterns across the archaeological structure. The figure highlights critical zones with high stress concentration, enabling targeted intervention and reinforcement strategies.

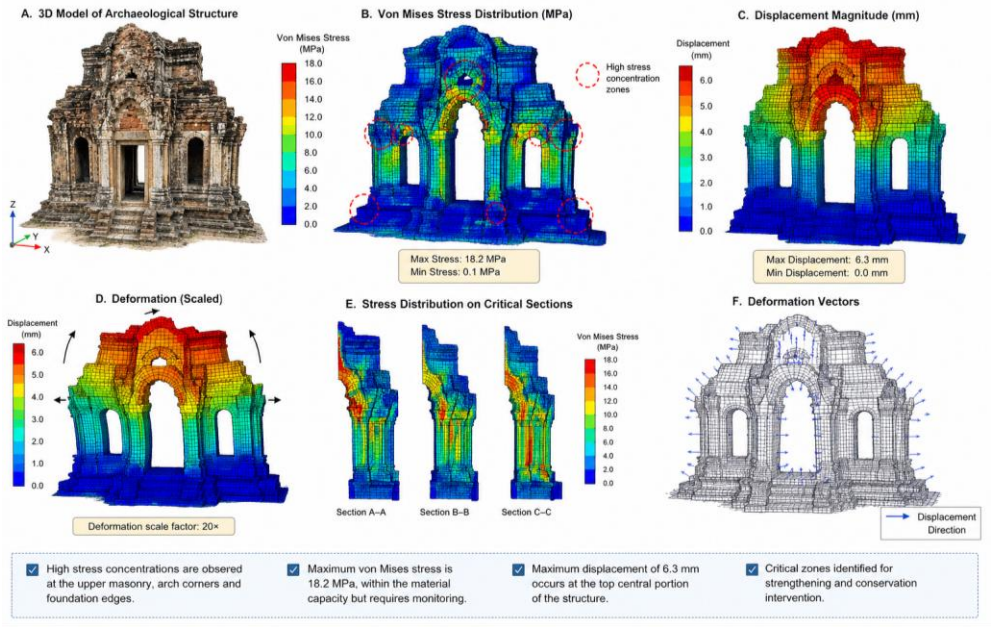


Figure 8: Stress Distribution and Deformation Analysis of Archaeological Structure

The integration of digital twin technology further enhanced the predictive capabilities of the framework. The digital twin environment enabled real-time simulation of environmental scenarios, allowing for the assessment of long-term deterioration patterns. Predictive analysis indicated that early-stage structural degradation could be identified up to 30–40% earlier compared to traditional monitoring methods. Additionally, maintenance efficiency improved by approximately 25–30% due to proactive intervention planning. From a discussion perspective, the results highlight the significant advantages of integrating interdisciplinary technologies in archaeological preservation. The combination of high-resolution digital modeling and FEM-based structural analysis provides a robust and quantitative foundation for evaluating structural integrity. Moreover, the digital twin approach enables continuous monitoring and predictive analysis, transforming preservation strategies from reactive to proactive. However, certain limitations were observed, including increased computational requirements and the need for specialized expertise in data processing and simulation. Additionally, challenges related to interoperability between BIM, GIS, and simulation platforms may affect implementation efficiency. Despite these constraints, the overall benefits of improved accuracy, predictive capability, and decision support significantly outweigh the limitations [27]. The results validate the effectiveness of the proposed framework in enhancing archaeological site preservation. The integration of advanced digital technologies provides a scalable, non-destructive, and data-driven solution that significantly improves structural assessment and conservation planning. These findings demonstrate the potential of digital heritage methodologies to revolutionize traditional

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preservation practices and ensure the long-term sustainability of archaeological assets.

6- Future Work:

While the proposed framework demonstrates significant potential in enhancing archaeological site preservation through digital modeling, structural simulation, and digital twin integration, several avenues remain for further research and development. Future work can focus on improving the scalability, automation, and real-time capabilities of the framework to support large-scale and complex heritage sites. One important direction is the integration of advanced sensor networks and Internet of Things (IoT) technologies for continuous, real-time monitoring of archaeological structures [28]. The incorporation of embedded sensors for measuring parameters such as vibration, temperature, humidity, and structural displacement would enable the digital twin to evolve into a fully dynamic system. This enhancement would improve the accuracy of predictive models and allow for immediate detection of structural anomalies. Another promising area involves the application of artificial intelligence and machine learning techniques to automate data processing and enhance predictive analysis. AI-based algorithms can be employed for automated feature extraction, anomaly detection, and forecasting of deterioration patterns. For example, deep learning models could analyze historical simulation data to predict long-term structural behavior under varying environmental conditions, thereby improving the reliability of conservation planning.

Future research can also explore the integration of multi-physics simulation models that consider additional factors such as thermal effects, moisture diffusion, and material aging. Incorporating these parameters would provide a more comprehensive understanding of structural degradation processes and improve the accuracy of simulation results. Additionally, coupling structural simulation with environmental modeling would enable more realistic scenario analysis. Interoperability between BIM, GIS, and simulation platforms remains a technical challenge and should be addressed in future studies. Developing standardized data exchange protocols and unified platforms would facilitate seamless integration of heterogeneous datasets and improve workflow efficiency [29]. Furthermore, cloud-based platforms can be explored to enhance computational efficiency and enable collaborative access to digital models and simulation results. Another important direction is the validation of the proposed framework through real-world case studies involving diverse archaeological sites. Applying the framework to different types of heritage structures, such as ancient buildings, monuments, and excavation sites, would help assess its adaptability and robustness under varying conditions. Finally, future work should consider the development of user-friendly decision-support systems that translate complex simulation outputs into actionable insights for conservation professionals [30]. Such systems would enhance the practical applicability of the framework and support informed, data-driven preservation strategies.

Conclusion:

This study presents an integrated and multidisciplinary framework for archaeological site preservation that combines digital modeling, structural simulation, and digital twin technology to address the limitations of traditional conservation approaches. By

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leveraging advanced data acquisition techniques such as terrestrial laser scanning, photogrammetry, and UAV-based imaging, the framework enables the creation of high-resolution and accurate three-dimensional representations of archaeological structures. These digital models serve as a robust foundation for further analysis and decision-making. The incorporation of Finite Element Analysis (FEM) provides a quantitative approach to evaluating structural integrity, allowing for the identification of stress concentrations, deformation patterns, and potential failure zones. This capability significantly enhances the understanding of structural behavior under various environmental and loading conditions, including seismic activity and soil–structure interaction. Furthermore, the integration of digital twin technology introduces a dynamic and predictive dimension to the framework, enabling real-time monitoring, scenario-based simulation, and early detection of structural deterioration. The results demonstrate that the proposed approach offers substantial improvements over traditional methods in terms of accuracy, data completeness, and predictive capability. The use of integrated digital technologies allows for non-destructive analysis and supports proactive preservation strategies, reducing reliance on reactive restoration practices. Additionally, the framework facilitates informed decision-making by providing conservation professionals with data-driven insights and risk assessment tools. Despite certain challenges, including computational complexity and interoperability issues, the overall benefits of the proposed framework highlight its potential as a scalable and efficient solution for heritage conservation. The integration of archaeology with civil engineering and digital technologies represents a significant step toward modernizing preservation practices and ensuring the long-term sustainability of cultural heritage assets.

References

Ajwad, A., Ahmad, S., Jaffar, S. T. A., Ilyas, U., & Adnan, M. A. (2022). Effect of using rice husk ash as partial replacement of cement on properties of fresh and hardened concrete.Architecture, Civil Engineering, Environment,15(2), 85-94

Antón, D., Pineda, P., Medjdoub, B., & Iranzo, A. (2019). As-built 3D heritage city modelling to support numerical structural analysis: Application to the assessment of an archaeological remain. *Remote Sensing*, *11*(11), 1276.

Hemeda, S. (2019). 3D finite element coupled analysis model for geotechnical and complex structural problems of historic masonry structures: conservation of Abu Serga church, Cairo, Egypt. *Heritage Science*, *7*(1), 1-19.

Ursini, A., Grazzini, A., Matrone, F., & Zerbinatti, M. (2022). From scan-to-BIM to a structural finite elements model of built heritage for dynamic simulation. *Automation in Construction*, *142*, 104518.

Barsanti, S. G., & Guidi, G. (2018, June). A new methodology for the structural analysis of 3D digitized cultural heritage through FEA. In *IOP conference series: materials science and engineering* (Vol. 364, No. 1, p. 012005). IOP Publishing.

Kyriakides, N., Votsis, R., Marangos, O., Skarlatos, D., Kafataris, G., Hadjipetrou, S., ... & Cuca, B. (2025, September). Integrating Geoinformatics and Finite Element

Online ISSN 3007-3197
Print ISSN 3007-3189

Modelling for Structural Assessment of a Cultural Heritage Monument. In *International Conference on Structural Analysis of Historical Constructions* (pp. 489-503). Cham: Springer Nature Switzerland.

Ababneh, A., & Sala, N. R. (2026). Advancements and Applications of Finite Element Methods (FEM) and Laser Scanning Documentation (LSD): A Systematic Literature Review. *Journal of Computer Applications in Archaeology*, *9*(1).

Turchetti, F., Cuca, B., Oreni, D., & Agapiou, A. (2025). Recording of Historic Buildings and Monuments for FEA: Current Practices and Future Directions. *Heritage*, *8*(2), 55.

Selvaggi, I. (2017). Surveying and three-dimensional modeling for preservation and structural analysis of cultural heritage.

Mutaqi, A. S., Susanto, A., Salura, P., Lake, R. C., & Purwanto, L. M. F. (2026). Integration of virtual reality and heritage BIM for the preservation of buried cultural heritage Temples in Yogyakarta. *ARTEKS: Jurnal Teknik Arsitektur*, *11*(1), 61-72.

Althaqafi, E., Ali, T., Qureshi, M. Z., Islam, S., Ahmed, H., Ajwad, A., ... & Khan, M. A. (2024). Evaluating the combined effect of sugarcane bagasse ash, metakaolin, and polypropylene fibers in sustainable construction.Scientific Reports,14(1), 26109.

Ahmad, B., Jillani, S. A., Rafique, M., & Soomro, A. A. (2026, January). Design and Monitoring of a Tree-Inspired Vertical Axis Wind Turbine for Efficient Urban Wind Utilization. In 2026 1st International Conference on Innovations in Information and Communication Technologies (IICT) (pp. 1-6). IEEE.

Guarnieri, A., Fissore, F., Masiero, A., Di Donna, A., Coppa, U., & Vettore, A. (2017). From survey to fem analysis for documentation of built heritage: the case study of villa Revedin-Bolasco. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(5W1), 527-533.

Maravelakis, E., Giannioti, G., Psalti, A., Tsakoumaki, M., Pocobelli, D. P., Xinogalos, M., ... & Stavroulakis, G. (2023). 3D modeling & analysis techniques for the Apollo temple in Delphi. *Buildings*, *13*(7), 1730.

Guo, M., Shang, X., Zhao, J., Shi, Y., Sun, M., Huang, M., ... & Liao, L. (2025). Digital twin models for architectural heritage conservation. *Journal of Building Engineering*, 113792.

Barazzetti, L., Banfi, F., Brumana, R., Gusmeroli, G., Oreni, D., Previtali, M., ... & Schiantarelli, G. (2015). BIM from laser clouds and finite element analysis: combining structural analysis and geometric complexity. *The international archives of the photogrammetry, remote sensing and spatial information sciences*, *40*, 345-350.

Tsilimantou, E., Delegou, E. T., Nikitakos, I. A., Ioannidis, C., & Moropoulou, A. (2020). GIS and BIM as integrated digital environments for modeling and monitoring of historic buildings. *Applied Sciences*, *10*(3), 1078.

Liu, Z., & Wang, J. (2024). Protection and utilization of historical sites using digital twins. *Buildings*, *14*(4), 1019.

Moyano, J., Oreni, D., & Nieto-Julián, J. E. (2025, June). Methodologies and Analysis

Online ISSN 3007-3197
Print ISSN 3007-3189

of Work in BIM in Archaeology: Review and Future Perspectives. In *International Conference on Extended Reality* (pp. 516-546). Cham: Springer Nature Switzerland.

Docci, M., Ippolito, A., & Attenni, M. (2024). Virtual models for the preservation and assessment of architectural and archaeological heritage. *Cities: the future of the past: architecture, urban planning and restoration in Iran and Italy.-(Nuovi strumenti 2612-4734; 6)*, 91-105.

Levy, R., & Dawson, P. (2009). Using finite element methods to analyze ancient architecture: an example from the North American Arctic. *Journal of Archaeological Science*, *36*(10), 2298-2307.

Ferdani, D., Demetrescu, E., Cavalieri, M., Pace, G., & Lenzi, S. (2019). 3D modelling and visualization in field archaeology. From survey to interpretation of the past using digital technologies. *GROMA: Documenting Archaeology*, *4*.

Vincenti, M. A., Caponero, M. A., Lamonaca, M., Occhipinti, G., AlShawa, O., & Sorrentino, L. (2023, June). Structure From Motion Survey Of Statue For Finite Element Modelling. In *Proceedings of the 9th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Athens, Greece* (pp. 12-14).

Chen, L., Dai, C., Zhou, M., & Lu, J. (2025). Development and application of an HBIM method for timber structures integrated with digital technologies. *npj Heritage Science*, *13*(1), 381.

Marra, A., Gerbino, S., Greco, A., & Fabbrocino, G. (2021). Combining integrated informative system and historical digital twin for maintenance and preservation of artistic assets. *Sensors*, *21*(17), 5956.

Ahmad, B., Ali, S., Muneer, M., Fatima, A., & Abbas, N. (2025). Wind energy integration into the SAARC region: A comprehensive review of optimal wind sites for a sustainable super smart grid. Wind Energy, 3(2).

Algadi, A., Uluutku, B., Cano, J. A., Walters, L., Alqurashi, I., Luleci, F., & Catbas, F. N. (2025). Digital twin-oriented generation of structural data and models with LiDAR scan point clouds. *Journal of Infrastructure Preservation and Resilience*, *6*(1), 32.

Banfi, F. (2021). The evolution of interactivity, immersion and interoperability in HBIM: Digital model uses, VR and AR for built cultural heritage. *ISPRS International Journal of geo-information*, *10*(10), 685.

De Fino, M., Galantucci, R. A., & Fatiguso, F. (2023). Condition assessment of heritage buildings via photogrammetry: A scoping review from the perspective of decision makers. *Heritage*, *6*(11), 7031-7066.

Ahmad, B., Majeed, M. K., Soomro, A. A., & Jillani, S. A. (2026, January). Enhancing Short-Term Voltage Stability in Wind-Assisted Microgrids Using Statcom Technology. In 2026 1st International Conference on Innovations in Information and Communication Technologies (IICT) (pp. 1-6). IEEE.