Digital Architectural Heritage in Saudi Arabia: An Integrated Model for Documentation and Preservation

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Abstract:

The Kingdom of Saudi Arabia boasts a rich architectural heritage encompassing traditional Najdi mud houses, Islamic-era structures, and modern historical landmarks. Documenting and preserving this heritage are vital for understanding Saudi cultural identity and ensuring sustainable conservation. This paper introduces an integrated model for the digital documentation and preservation of architectural heritage, leveraging technologies such as Heritage Building Information Modelling (HBIM), 3D laser scanning, and Geographic Information Systems (GIS). Case studies include Al-Balad Historic Jeddah, Diriyah's At-Turaif District, and the mud-built structures of Al-Qassim. The model emphasizes a holistic approach that integrates high-resolution 3D documentation, heritage analysis, and stakeholder collaboration. By bridging gaps between digital tools and conservation strategies, this study contributes to the broader discourse on how digital methodologies can protect Saudi Arabia's architectural heritage for future generations.

1. Introduction

Saudi Arabia's architectural heritage stands as a profound representation of its rich cultural history, offering a window into the diverse influences that have shaped its built environment over centuries. From the early Islamic structures to the intricate mud-brick designs of the Najdi region and other significant architectural styles, the Kingdom's built environment reflects the confluence of local traditions, religious influences, and foreign cultural interactions. This heritage is not merely a collection of buildings but a tangible manifestation of the historical, social, and environmental dynamics that have defined the Kingdom's evolution (Ghazala, 2021). However, this invaluable heritage is under increasing threat due to rapid urbanization, environmental degradation, and the pressures of modernization. Many historical sites are facing the risk of irreversible damage from natural and man-made factors. To preserve these structures for future generations, it is crucial to adopt innovative strategies that align with both technological advancements and the principles of conservation. Recent developments in digital technologies present an opportunity to revolutionize how architectural heritage is documented and preserved, making it more accessible for study, restoration, and public engagement.

This paper introduces an integrated model for the digital documentation and preservation of Saudi Arabia's architectural heritage. The model incorporates cutting-edge digital tools, such as Heritage Building Information Modelling (HBIM), 3D laser scanning, and Geographic Information Systems (GIS), all of which are transforming the field of heritage conservation. These technologies provide precise, high-resolution data that can capture the intricate details of historic buildings, allowing for virtual reconstructions, condition assessments, and restoration simulations (A. H. Baik, 2020). Aligned with the goals of Saudi Vision 2030, which emphasizes the importance of cultural sustainability, tourism, and heritage preservation, this model is designed to support the Kingdom's strategic vision. Vision 2030 outlines the preservation of cultural heritage as a cornerstone for building a sustainable future, particularly by leveraging digital tools for the conservation of historical sites. The integration of digital documentation methods enables a more holistic approach to heritage conservation, ensuring that Saudi Arabia's architectural legacy is not only preserved but also celebrated as part of a vibrant cultural tourism initiative. This paper explores the application of these technologies through several case studies, such as the historic districts of Al-Balad in Jeddah, At-Turaif in Diriyah, and the mud-built structures in Riyadh and Al-Qassim. Examples of Saudi Heritage sites (see Figure 1and Figure 2). These case studies demonstrate how digital documentation can preserve architectural details, facilitate restoration, and engage the public in the heritage preservation process. Moreover, the paper argues that by bridging the gap between digital technologies and traditional conservation practices, it is possible to ensure the sustainable safeguarding of Saudi Arabia's architectural heritage for the benefit of future generations.

Figure 1. Al-Masookf Market is one of the popular markets in the city of Unaizah in Al-Qassim (Ref. Heritage Commission)

Figure 2. Masmak Palace in the center of Riyadh (Ref. Heritage Commission)

Figure 3. Shebra Palace, Taif (Ref. Heritage Commission).

2. Literature Review

2.1 Heritage Building Information Modelling (HBIM)

Heritage Building Information Modelling (HBIM) has emerged as a pivotal methodology in the digital preservation and management of architectural heritage. Extending the principles of traditional Building Information Modelling (BIM), HBIM incorporates the unique complexities inherent in historical structures—such as irregular geometries, non-standardized materials, and rich cultural narratives—into a robust digital framework that supports both documentation and conservation. The origins of HBIM can be traced back to the early adaptations of BIM technology for heritage contexts, where researchers recognized that conventional BIM systems were insufficient for capturing the nuanced details of historical edifices. Early work by Murphy et al. (2013) laid the groundwork by proposing a tailored framework that integrated historical research with digital modelling techniques. This approach not only emphasized the geometric and material attributes of heritage structures but also sought to incorporate contextual information critical for informed conservation decisions. Subsequent studies (e.g., A. Baik et al., 2013; Dore et al., 2015) have further refined the HBIM process, advocating for an interdisciplinary methodology that brings together architects, historians, conservationists, and IT specialists.

A significant trend in HBIM literature is the integration of advanced digital data acquisition methods, such as terrestrial laser scanning, UAV photogrammetry, and photogrammetric reconstruction. These technologies provide the high-resolution spatial data necessary for creating precise 3D models of complex heritage structures (Alshawabkeh & Baik, 2023). For instance, laser scanning has been instrumental in capturing intricate details of historical facades and decorative elements, while UAV-based imaging has facilitated the documentation of large-scale sites with minimal physical intervention. The fusion of these technologies with HBIM has not only enhanced the accuracy of digital reconstructions but also enabled dynamic simulations of deterioration processes, thereby informing proactive conservation strategies (Abdelhafiz, 2009; Alshawabkeh et al., 2024).

Numerous case studies have demonstrated the efficacy of HBIM in diverse heritage contexts. In Europe, HBIM has been successfully applied to the restoration of Gothic cathedrals and medieval castles, where detailed digital archives have aided in both structural analysis and heritage interpretation. In the Middle East, projects focused on traditional vernacular architecture have leveraged HBIM to preserve unique cultural identities while accommodating modern conservation needs. These applications underscore HBIM's versatility in addressing the multifaceted challenges of heritage documentation—from preserving fine architectural details to integrating intangible cultural values into digital records (Alshawabkeh & Baik, 2023).

Despite its promising applications, HBIM faces several critical challenges. One major hurdle is the management and standardization of the vast and heterogeneous datasets generated during the documentation process. The lack of universally accepted protocols for data capture, processing, and integration often leads to interoperability issues between different software platforms. Moreover, capturing the intangible aspects of heritage—such as historical context, cultural significance, and traditional construction techniques—remains a significant challenge, necessitating enhanced collaboration between technical experts and heritage scholars. Future research is expected to focus on developing standardized frameworks, improving data interoperability, and advancing semantic enrichment techniques that better capture the full spectrum of heritage values (Smith, 2007).

HBIM represents a transformative evolution in the digital documentation and preservation of architectural heritage. By combining precise digital modelling with rich historical and cultural data, HBIM not only facilitates detailed conservation planning but also enhances public engagement with cultural heritage. Continued advancements in data acquisition technologies and the development of standardized protocols will be essential in overcoming current challenges and fully realizing the potential of HBIM in safeguarding our shared cultural legacy.

2.2 3D Laser Scanning

3D laser scanning has emerged as a transformative technology in the field of heritage documentation, offering unparalleled precision and efficiency in capturing the intricate geometries of historical structures and archaeological sites. This section reviews the evolution, methodologies, applications, and challenges associated with 3D laser scanning in heritage documentation, drawing insights from a growing body of literature. The advent of 3D laser scanning marked a significant departure from traditional documentation methods such as hand-drawn surveys and photogrammetry. Early research (e.g., El-Hakim et al., 2005; Remondino et al., 2009) demonstrated the potential of laser scanning to generate dense point clouds that capture both macro- and micro-structural details of heritage assets. Terrestrial Laser Scanning (TLS) and Mobile Laser Scanning (MLS) have since become standard tools, providing high-resolution spatial data with sub-centimetre accuracy. These systems emit laser pulses that reflect off surfaces to produce precise distance measurements, which are then compiled into 3D point clouds. Advances in sensor technology and data processing algorithms have further enhanced the efficiency and reliability of these methods, enabling the documentation of complex geometries even in challenging environmental conditions.

The application of 3D laser scanning in heritage documentation is diverse and multifaceted. Notable applications include Structural Analysis and Conservation Planning: Detailed 3D models facilitate the assessment of structural integrity and the identification of areas affected by degradation. For example, studies by Beraldin, (2004) have shown how laser-scanned models of historical monuments enable conservation experts to monitor deterioration processes over time. Digital Preservation and Virtual Reconstruction: Laser scanning serves as the backbone for creating digital archives of heritage sites. The resultant 3D models can be integrated into Heritage Building Information Modelling (HBIM) systems and Geographic Information Systems (GIS), which support virtual reconstructions and simulations of restoration scenarios (A. Baik et al., 2015). Such integrations not only

assist in conservation planning but also promote public engagement through virtual tourism and interactive exhibits. Comparative and Quantitative Analysis: The precision of 3D laser scanning allows for quantitative comparisons between different time periods. This is particularly useful in monitoring the impacts of environmental factors and human interventions on heritage sites, thereby informing sustainable preservation strategies.

Moreover, a key trend in recent literature is the integration of 3D laser scanning with complementary digital technologies. Combining laser scanning data with UAV photogrammetry, for instance, enables comprehensive surveys of both exterior and hard-to-reach areas. Moreover, the fusion of point clouds with historical records and archival materials enriches the contextual understanding of heritage sites. This integrated approach not only improves the accuracy of the digital models but also enhances their utility in multidisciplinary research, ranging from architectural history to conservation science (Alshawabkeh & Baik, 2023).

Furthermore, despite its many advantages, 3D laser scanning is not without challenges. One of the primary issues is the management of massive datasets generated during scanning sessions. Effective data processing, storage, and visualization require significant computational resources and specialized software. Additionally, scanning in complex environments—such as densely vegetated sites or structures with reflective surfaces—can lead to data gaps or inaccuracies. There is also an ongoing need for standardized protocols to ensure interoperability between different scanning systems and software platforms. Addressing these challenges is critical for maximizing the potential of laser scanning in heritage documentation and for facilitating broader adoption across the conservation community (Ebrahim, 2015).

3D laser scanning has revolutionized heritage documentation by providing a precise, efficient, and versatile means of capturing the physical details of historical structures and archaeological sites. While challenges related to data management and environmental complexities remain, ongoing technological advancements and interdisciplinary collaborations are poised to address these limitations. As such, 3D laser scanning continues to be a critical tool in the digital preservation of cultural heritage, offering valuable insights for both current conservation efforts and future research endeavours (Gado et al., 2024).

Figure 5. using 3D laser scanning (Leica RTC360) on site(Ref. A.Baik).

2.3 UAV Photogrammetry

UAV photogrammetry has emerged as a transformative tool in the field of heritage documentation, providing a flexible, efficient, and cost-effective means of capturing high-resolution aerial imagery and generating accurate three-dimensional (3D) models of cultural heritage sites. This section reviews the evolution, methodologies, applications, challenges, and future directions of UAV photogrammetry within the context of heritage documentation. The integration of Unmanned Aerial Vehicles (UAVs) with advanced photogrammetric techniques marks a significant evolution from traditional aerial photography and ground-based survey methods. Early studies demonstrated that UAVs, equipped with high-resolution digital cameras, could capture extensive overlapping imagery required for robust Structure-from-Motion (SfM) processing (Berra & Peppa, 2020). This method reconstructs detailed 3D models by correlating features across multiple images. The typical workflow involves: Flight Planning: Designing optimal flight paths to ensure adequate coverage and image overlap. Data Acquisition: Capturing high-resolution images under suitable lighting and environmental conditions. Data Processing: Utilizing photogrammetric software to process images into dense point clouds, textured meshes, and orthophotos. Model Generation and Analysis: Creating accurate 3D reconstructions that serve as digital proxies for the heritage sites (Berra & Peppa, 2020; Livox, 2019).

Figure 4. Auto flight path using the Dji drone (Ref. A.Baik).

This workflow not only enhances spatial accuracy but also enables the documentation of sites that are logistically challenging to survey using traditional methods. Moreover, UAV photogrammetry has been applied to a wide range of heritage documentation scenarios, with significant benefits demonstrated in several key areas: Mapping Large-Scale and Inaccessible Sites: UAVs can efficiently document expansive areas, such as archaeological landscapes and ancient urban environments, that are otherwise difficult to access. This capability is particularly useful for sites with complex topographies or those located in rugged terrains. 3D Reconstruction and Virtual Heritage: The high-resolution 3D models generated through UAV photogrammetry provide invaluable digital archives for virtual reconstructions. These models allow for immersive virtual tours and simulations, enhancing both research and public engagement with heritage sites. Moni-

toring and Conservation: Periodic UAV surveys enable the monitoring of structural changes and degradation over time. This temporal data is critical for assessing the impacts of environmental factors and human activities, thereby informing proactive conservation strategies. Complementary Integration with Other Technologies: UAV photogrammetry often operates in synergy with other digital documentation techniques, such as terrestrial laser scanning and Heritage Building Information Modelling (HBIM). This integration facilitates comprehensive multi-scale documentation and analysis, bridging the gap between aerial and ground-level data (James et al., 2017).

Despite its advantages, UAV photogrammetry faces several challenges in heritage documentation: Environmental Constraints: Weather conditions such as wind, rain, and varying light intensities can adversely affect image quality and, consequently, the accuracy of the generated 3D models. Regulatory and Operational Issues: Navigating airspace regulations and obtaining necessary permits can limit UAV operations, especially in urban or protected heritage areas. Data Processing Demands: The large datasets generated by UAV photogrammetry require substantial computational resources and advanced processing algorithms to ensure timely and accurate model reconstruction. Integration Complexities: Merging UAV-derived data with other datasets, such as laser scans or archival records, presents challenges related to data interoperability and standardization across different platforms (Fiz et al., 2022).

UAV photogrammetry stands as a critical innovation in the documentation of cultural heritage. Its ability to rapidly capture detailed aerial imagery and reconstruct precise 3D models has transformed the way heritage sites are recorded, monitored, and preserved. While challenges remain—particularly regarding environmental conditions, data processing, and regulatory constraints—ongoing technological advancements and methodological improvements promise to further enhance the capabilities and applications of UAV photogrammetry. As such, it is an indispensable component of integrated digital heritage documentation strategies, contributing significantly to the conservation and sustainable management of cultural heritage in Saudi Arabia and beyond (Gado et al., 2024).

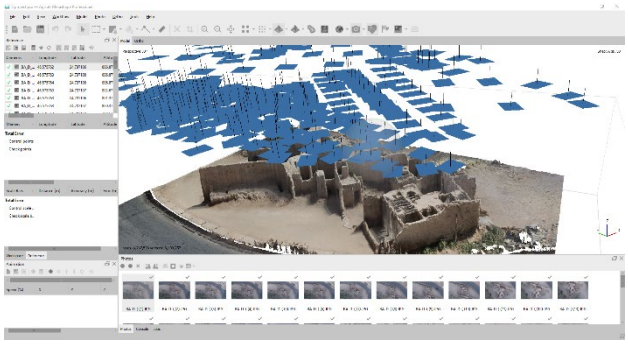

Figure 6. using aerial photogrammetry via Agisoft Metashape (Ref. A.Baik).

2.4 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) have emerged as an indispensable tool in the field of heritage documentation, offering an integrated platform to collect, manage, analyse, and visualize spatial and temporal data related to cultural heritage sites. In recent years, GIS has evolved from a basic mapping tool into a comprehensive system that supports multidisciplinary approaches in heritage conservation. This section provides an overview of the evolution, applications, integration with other digital tools, challenges, and prospects of GIS in the documentation and preservation of cultural heritage (Box, 1999).

The application of GIS in heritage documentation began with the digitization of historical maps and the georeferencing of cultural sites. Early implementations were primarily concerned with spatial localization and the creation of thematic maps that displayed the distribution of heritage assets. Over time, GIS methodologies have incorporated more sophisticated spatial analyses and data integration techniques. Modern GIS platforms now support the integration of high-resolution remote sensing data, 3D spatial datasets, and temporal information, thereby enabling researchers to construct detailed, multi-layered representations of heritage landscapes. This evolution has been driven by advances in remote sensing technologies, increased computational power, and the development of standardized data formats that facilitate interoperability among diverse data sources (Çakici Alp & Şahin Güçhan, 2017).

GIS serves multiple roles in the documentation and preservation of heritage, including Spatial Analysis and Mapping: GIS allows for precise mapping of heritage sites, enabling the analysis of spatial relationships and patterns. For instance, proximity analysis can be used to assess the impact of urban encroachment on historical landmarks, while terrain analysis aids in understanding the environmental context of archaeological sites. Data Integration and Visualization: One of the key strengths of GIS lies in its ability to integrate heterogeneous datasets—ranging from historical documents and archival photographs to modern sensor data from UAV photogrammetry and 3D laser scanning. This integration provides a holistic view of heritage sites, facilitating both macro- and micro-scale analyses. Monitoring and Management: GIS enables continuous monitoring of heritage sites by tracking changes over time. Time-series analyses can reveal trends in structural degradation or landscape alteration, providing critical data that informs conservation strategies and emergency response planning. Public Engagement and Education: Interactive GIS applications, such as web-based mapping platforms and virtual tours, enhance public accessibility to heritage information. These tools promote community engagement by allowing the public to explore and contribute to heritage documentation efforts, thereby fostering a greater appreciation for cultural heritage (A. Baik et al., 2015).

GIS does not operate in isolation; it is increasingly integrated with other digital documentation tools to enhance the quality and utility of heritage data. For example, the integration of 3D laser scanning data into GIS systems allows for the creation of highly detailed, geospatially accurate 3D models of heritage structures. Similarly, combining GIS with Heritage Building Information Modelling (HBIM) provides a dynamic environment where both spatial and semantic data can be analysed simultaneously. This interoperability not only improves the precision of heritage documentation but also supports comprehensive conservation planning by linking physical, historical, and environmental data (Bruno et al., 2020).

Despite its many advantages, the application of GIS in heritage documentation faces several challenges: Data Standardization and Interoperability: The integration of diverse datasets often leads to issues with data consistency, differing coordinate systems, and varying spatial resolutions. Establishing standardized

protocols and metadata guidelines is essential for ensuring data interoperability across projects and platforms. Technical and Resource Constraints: High-quality GIS applications require advanced hardware, specialized software, and skilled personnel. These requirements can be a barrier, particularly in regions with limited resources or technical expertise. Data Management and Preservation: The vast amount of data generated by GIS-based heritage documentation necessitates robust data management strategies. Long-term digital preservation, including secure storage and regular data updates, is critical to maintaining the integrity and accessibility of heritage records (Çakici Alp & Şahin Güçhan, 2017).

Geographic Information Systems have revolutionized the documentation and preservation of cultural heritage by providing a comprehensive platform for the integration and analysis of spatial data. Through advanced mapping, data integration, and dynamic visualization, GIS has enhanced the capacity to monitor, manage, and engage with heritage sites. Although challenges related to data standardization, technical resource constraints, and data management persist, ongoing advancements in GIS technology and interdisciplinary collaboration are set to further solidify its role as a cornerstone of heritage documentation in the modern era.

3. The method

3.1 An Integrated Model for Documentation and Preservation

The proposed model represents a unified workflow designed to capture, integrate, and contextualize heritage data for comprehensive documentation and preservation. This model synergistically combines advanced data acquisition techniques, robust data integration processes, and spatial contextualization through Geographic Information Systems (GIS) to produce a multi-layered digital record of heritage sites. The following subsections detail each phase of the workflow.

3.2 Data Acquisition

Data acquisition forms the foundational step in the integrated model and is achieved through the combined use of terrestrial laser scanning (TLS) and UAV photogrammetry.

3.2.1 Terrestrial Laser Scanning (TLS):

TLS is employed to capture high-resolution, dense point clouds of heritage structures. This method is particularly effective for documenting intricate architectural details, surface textures, and structural geometries. The laser scanner emits pulses that reflect off the surfaces of the heritage asset, allowing for the generation of accurate 3D models with sub-centimetre precision.

Figure 7.The output of the 3D laser scanning (Ref. A.Baik).

3.2.2 UAV Photogrammetry:

Complementing TLS, UAV photogrammetry is used to acquire aerial imagery of heritage sites. This technique is especially useful for large-scale sites or areas that are difficult to access on foot. By planning optimal flight paths and ensuring adequate image overlap, high-resolution images are captured and subsequently processed using Structure-from-Motion (SfM) algorithms to create detailed 3D reconstructions. Together, these techniques provide a comprehensive dataset that encompasses both macro-scale spatial layouts and micro-scale architectural details, forming a robust basis for further analysis.

Figure 8. 3D model from the Arial Photogrammetry (Ref. A.Baik).

3.3 Data Integration

Following data acquisition, the next phase involves the consolidation of the generated 3D models into a Heritage Building Information Modelling (HBIM) platform.

3.3.1 Model Consolidation:

The point clouds and 3D reconstructions obtained from TLS and UAV photogrammetry are imported into the HBIM environment. This integration involves aligning datasets spatially and temporally to ensure consistency and accuracy.

3.3.2 Detailed Analysis and Restoration Planning:

HBIM serves as a dynamic repository that not only houses geometric data but also integrates historical, material, and contextual information. By leveraging the capabilities of HBIM, practitioners can conduct detailed analyses of structural conditions, identify areas of deterioration, and simulate restoration scenarios. The enriched digital model facilitates a more informed decision-making process regarding conservation strategies, allowing for precise restoration planning that respects the original fabric of the heritage asset.

3.4 Spatial Contextualization

The final phase of the integrated model focuses on embedding the heritage data within its broader environmental and urban context using Geographic Information Systems (GIS).

3.4.1 Incorporating GIS Layers:

GIS provides a platform for integrating various spatial datasets—including cadastral maps, satellite imagery, topographical data, and environmental monitoring layers—with the detailed HBIM models. This integration enables researchers to visualize heritage sites not as isolated entities, but as components of a larger geographic and socio-cultural landscape.

3.4.2 Environmental and Urban Analysis:

By overlaying GIS data, it becomes possible to analyse the surrounding environmental conditions and urban dynamics that may affect the heritage site. For example, GIS can be used to monitor urban encroachment, assess risks from natural hazards, and evaluate the impact of environmental degradation. This spatial contextualization supports the development of comprehensive preservation strategies that consider both the physical integrity of the heritage asset and its external influences.

The integrated model for documentation and preservation advances heritage conservation by unifying precise data acquisition, detailed 3D modelling via HBIM, and rich spatial analysis through GIS. This multi-faceted approach not only enhances the accuracy and depth of heritage records but also supports proactive conservation planning, ensuring that cultural heritage is preserved within its environmental and urban contexts for future generations.

4. Case Studies

4.1 Case study: Ibn Shukban Castle

Ibn Shukban Castle, a significant historical landmark, reflects the architectural ingenuity and cultural richness of its era. Its unique construction techniques and strategic design underscore the importance of adopting modern documentation methods to preserve such heritage. In this case study, we employed high-resolution terrestrial laser scanning (TLS) alongside UAV-based photogrammetry to capture both the intricate architectural details and the broader spatial context of the castle. These complementary technologies generated dense point clouds and high-quality orthophotos, forming the foundation of our digital reconstruction. The acquired data were then consolidated into a Heritage Building Information Modelling (HBIM) platform. This integration not only allowed for the precise representation of the castle's geometry but also enabled the embedding of historical and material information critical for restoration and conservation planning. The HBIM model facilitates detailed analysis, supports simulation of intervention scenarios, and provides a robust digital archive for ongoing research.

Figure 9. Bakrhosh Bin Alas Castle from scan to HBIM

By leveraging this integrated methodology, we achieve a balanced approach that maintains historical accuracy while embracing advanced documentation techniques. This innovative framework not only safeguards Ibn Shukban Castle's legacy but also offers a scalable model for preserving cultural heritage in the digital age.

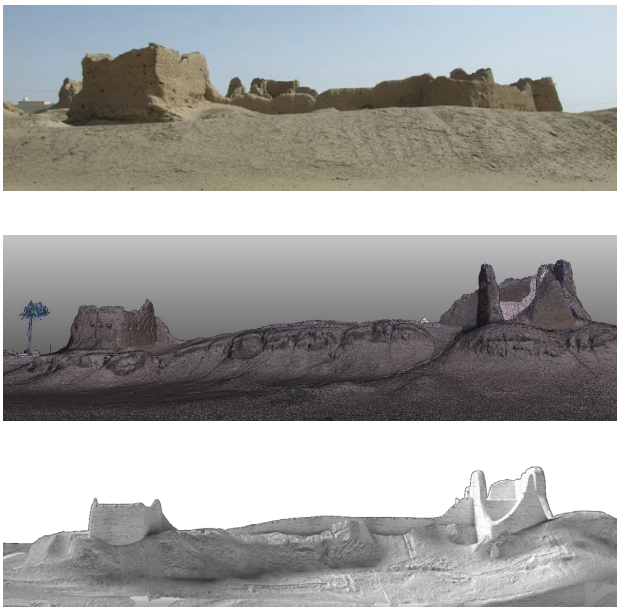

Figure 10. Ibn Shukban Castle from scan to HBIN model

4.2 Case study: Bakrhosh Bin Alas Castle

Bakrhosh Bin Alas Al-Zahrani Castle stands as a testament to the rich history and architectural heritage of the Al-Baha region in Saudi Arabia. Its distinctive design and strategic importance underscore its value as a cultural asset, meriting both detailed study and proactive preservation efforts. In this case study, we employed high-resolution terrestrial laser scanning (TLS) and UAV-based photogrammetry to meticulously document the castle's architectural intricacies and its broader spatial context. The TLS approach enabled the generation of dense point clouds, capturing fine structural details such as stone textures, intricate carvings, and construction techniques that are vital for understanding the castle's historical construction methods. Complementary UAV photogrammetry provided extensive aerial imagery, which was instrumental in mapping the overall layout and contextualizing the castle within its surrounding landscape. Following data acquisition, the resulting datasets were integrated into a Heritage Building Information Modelling (HBIM) platform. This integration allowed for the consolidation of geometric data with critical historical and material information, facilitating detailed analysis and simulation of restoration scenarios. The HBIM model serves as a dynamic digital archive that supports both conservation planning and long-term preservation efforts. By applying this integrated methodology, we achieve a balanced approach that upholds historical accuracy while leveraging advanced digital documentation tools. This innovative framework not only honours the cultural and historical significance of Bakrhosh Bin Alas Castle but also ensures its legacy is meticulously preserved for future generations.

4.3 Case study: Za'abal Castle

Za'abal Castle, located in Sakaka, stands as a historic fortress that embodies the rich cultural and architectural heritage of northern Saudi Arabia. Renowned for its strategic location and distinctive construction, the castle symbolizes the region's historical resilience and ingenuity. To ensure its preservation and a detailed understanding of its features, modern techniques such as high-resolution laser scanning and UAV photogrammetry were employed. The laser scanning process captured intricate architectural details and precise spatial dimensions, generating dense point clouds that reflect the castle’s complex geometry. Complementary UAV photogrammetry provided high-quality aerial imagery, which enriched the dataset by mapping the castle’s overall layout and contextual relationship with its surroundings. These datasets were then integrated into a Heritage Building Information Modeling (HBIM) platform. The HBIM model consolidates the geometric data with historical and material information, facilitating detailed analysis, restoration planning, and ongoing academic research. This integrated digital model not only supports proactive conservation strategies but also bridges the gap between traditional heritage and modern technology, ensuring Za'abal Castle’s legacy is preserved for future generations.

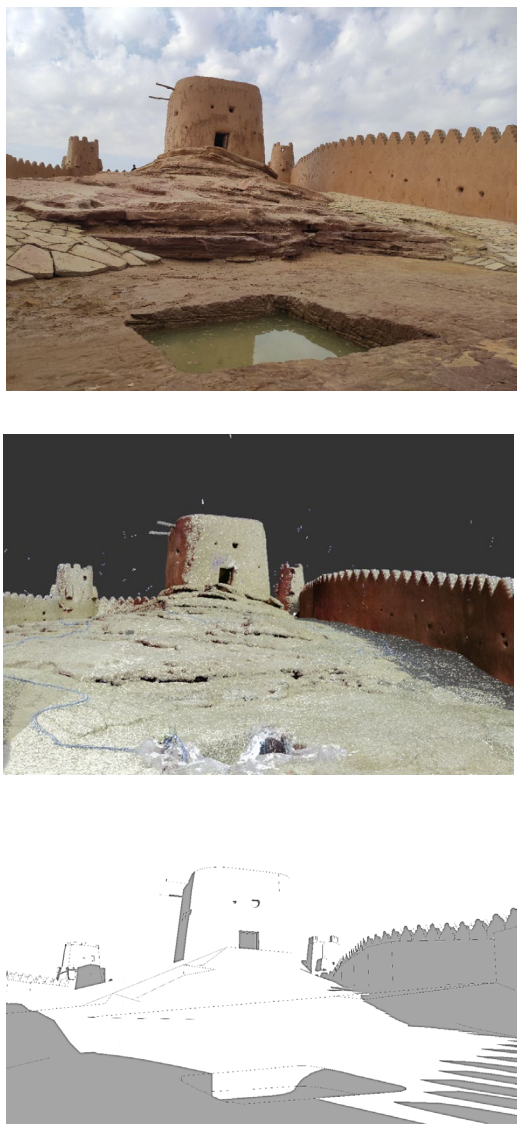

Figure 11. Za'abal Castle from scan to HBIM

5. Discussion

The integrated digital documentation approach, which combines terrestrial laser scanning, UAV photogrammetry, and HBIM, has proven effective in capturing both intricate architectural details and the broader spatial context of heritage sites such as Ibn Shukban, Bakrhosh Bin Alas, and Za'abal Castles. This methodology results in comprehensive digital models that consolidate geometric, historical, and material data, thereby facilitating detailed analysis, restoration planning, and long-term preservation while also informing proactive conservation strategies and enhancing public engagement with cultural heritage. Despite challenges related to environmental variability during data acquisition, the need for standardized integration protocols, and significant resource and expertise demands, ongoing refinements and broader application of this approach promise to advance the preservation of Saudi Arabia's cultural legacy for future generations.

6. Conclusion

The integrated digital documentation approach—merging terrestrial laser scanning, UAV photogrammetry, HBIM, and GIS—has demonstrated significant potential for the comprehensive recording and preservation of Saudi Arabia's architectural heritage, as evidenced by the case studies of Ibn Shukban, Bakrhosh Bin Alas, and Za'abal Castles. This methodology has enabled the creation of detailed digital models that not only capture intricate structural and decorative elements but also contextualize these heritage sites within their broader environmental and urban landscapes. By consolidating geometric, historical, and material data, the approach supports meticulous analysis, informed restoration planning, and proactive conservation strategies while enhancing public engagement and academic research. Despite challenges related to environmental variability, data standardization, and resource demands, continued refinement and broader application of this integrated model promise to safeguard cultural heritage for future generations and provide a robust framework for heritage documentation worldwide.

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