

Multiscale Digital Survey and HBIM-GIS Integration for the Conservation of the Kasbah of Mehdyia (Morocco)

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Abstract

This paper presents the development and validation of a multiscale digital workflow to document and support the conservation of the Kasbah of Mehdyia, a coastal fortified complex located at the mouth of the Sebou River (northern Morocco). Data acquisition integrates UAV survey (photogrammetry and aerial LiDAR) to capture site morphology and topography, SLAM-based mobile mapping for rapid point-cloud acquisition in GPS-denied or partially constrained areas, and high-resolution terrestrial imagery, including spherical panoramas, to enhance material and decay interpretation. The datasets are processed, filtered, and aligned to generate georeferenced orthophotos and dense point clouds that feed a scan-to-HBIM pipeline. HBIM models are structured as semantic repositories of construction phases (12th–17th centuries), traditional materials, and mapped decay patterns, and are exported through interoperable standards (e.g., IFC) to enable integration within a GIS geodatabase. The resulting HBIM–GIS environment supports multiscale spatial queries, correlation analyses between observed pathologies and key coastal environmental drivers (e.g., sea-salt aerosol exposure and vegetation colonisation), and the progressive validation and refinement of pre-existing territorial datasets through “as-built” survey data. Beyond format-level interoperability, the approach treats geo-referencing consistency and data reliability as prerequisites for a transferable heritage digital twin bridging architectural and territorial scales. Finally, it lays the groundwork for participatory dissemination through a WebGIS interface and immersive visualisation tools to support evidence-based, time-sensitive conservation strategies.

1. Introduction

1.1 Background and state of the art

The ongoing digital transformation of cultural heritage practices has positioned Building Information Modeling (BIM) as a central methodology for the documentation, analysis, and management of existing architectural assets.

Within the domain of heritage conservation, BIM has evolved into its specialized form—Historic or Heritage BIM (HBIM)—enabling the integration of geometric data with material, structural, and historical information. However, the application of HBIM to complex, stratified, or large-scale territorial contexts still presents significant challenges, mainly related to representation scale, data heterogeneity, and the absence of tools to manage broader spatial relationships.

To address these gaps, Geographic Information Systems (GIS) have emerged as complementary environments capable of expanding the scope of analysis, supporting risk assessment, and integrating environmental and territorial dynamics. The integration of HBIM and GIS thus facilitates the development of multiscale information models that can simultaneously manage architectural and landscape components, while supporting evidence-based and time-sensitive decision-making processes. Several studies have demonstrated the effectiveness of this integration. Matrone et al. (2019) and Pepe et al. (2021, 2024) highlight how HBIM models can be semantically enriched and queried within three-dimensional GIS environments, promoting new forms of spatial and historical analysis. Other contributions, such as those by Bruno et al. (2020) and Pozzoni et al. (2024), focus on temporal integration and the management of dispersed

heritage in marginal areas, developing WebGIS platforms and tools for public engagement.

In the field of structural assessment (Chiabrando et al., 2016, Sammartano et al., 2023) researches propose integrated HBIM–GIS workflows for seismic vulnerability and structural instability analysis, combining laser scanning surveys with semantically informed HBIM models. Other investigation (Sammartano et al., 2021), extends this approach to the urban scale, testing city-wide semantic digital twins. In archaeological contexts, (Limongiello et al., 2025) demonstrate the potential to reconstruct and simulate historical scenarios through parametric integration of HBIM and GIS.

Overall, the current state of the art reveals a clear shift toward integrated, intelligent, and interoperable information systems—capable of connecting building and landscape scales, improving long-term data management, and enabling participatory and evidence-based conservation and enhancement strategies.

1.2 Research gap

Most HBIM–GIS applications have focused on individual monuments (e.g., churches, palaces) or relatively homogeneous historic fabrics. Coastal fortifications remain under-represented, although they are exposed to aggressive environmental agents and are often affected by long periods of neglect. These contexts require workflows capable of managing multiscale geometries and semantics while addressing data reliability and discrepancies between pre-existing territorial sources and high-precision survey products.

The Kasbah of Mehdyia is a particularly relevant case: a stratified fortified complex whose transformation spans multiple phases,

including Almoravid and Saadian periods, a Spanish occupation between 1614 and 1681, and a subsequent reorganisation under the 'Alawite dynasty. Today the site is largely abandoned and exhibits widespread decay and structural vulnerabilities, including local collapses, wall settlements, invasive vegetation growth, and accelerated material deterioration associated with marine aerosol exposure.

1.3 Objectives

The project "Study, Conservation and Valorization of the Kasbahs in Morocco", launched in 2024 with the support of the Italian Ministry of Foreign Affairs and International Cooperation (MAECI), the International University of Rabat, and the Ministry of Youth, Culture and Communication of the Kingdom of Morocco, aims to establish a replicable operational model for documenting, managing, and enhancing the fortified heritage of Moroccan kasbahs.

The initiative develops a multiscale digital acquisition workflow integrating UAV photogrammetry, Insta360 spherical imaging, and SLAM-based mobile mapping to capture high-resolution geometric and chromatic data, providing the basis for high-fidelity digital twins of selected kasbahs. The collected datasets are then processed through a scan-to-HBIM pipeline to structure construction phases, traditional materials, building pathologies, and past restoration interventions. HBIM outputs are subsequently integrated into a GIS geodatabase, enabling territorial-scale analyses—from structural vulnerability to environmental risk exposure—and supporting long-term conservation planning.

To enhance dissemination and stakeholder engagement, the project also explores WebGIS platforms, immersive tours, and virtual/augmented reality tools targeting researchers, policymakers, and the wider public, with the goal of ensuring open-access availability of the collected information and scalable guidelines for similar fortified heritage sites across Morocco.

Accordingly, this study aims to: (i) develop and validate a multiscale acquisition workflow integrating UAV survey, SLAM-based mobile mapping, and high-resolution terrestrial imaging; (ii) implement a scan-to-HBIM process to structure construction phases, materials, and pathologies; (iii) integrate HBIM outputs into a GIS geodatabase for spatial analysis and long-term management; and (iv) test a progressive densification strategy for a heritage digital twin by validating and refining pre-existing territorial datasets through "as-built" survey data.

2. Study area

The Kasbah of Mehdyia is located on a promontory at the mouth of the Sebou River along the Atlantic coast of northern Morocco, approximately 30 km north of Rabat. Its position historically enabled the control of both the Atlantic shoreline and the river corridor connecting the Gharb plain with inland regions.

Ancient sources associate the area with the Phoenician port of Thymiaterion, although localisation remains debated. In the Roman period, the site is linked to Subur (Raoui, 2010). Historical reconstructions indicate reoccupation around the Ifranid period (c. 900 AD); the association with the toponym al-Ma'mūra/Marsā al-Ma'mūra is reported in modern syntheses but requires caution when early sources are not explicit (Ajaraam et al., 2024; Lakhdar, 2026). In the 12th century, the Almohad caliph 'Abd al-Mu'min reportedly established a naval arsenal supporting fleets operating in al-Andalus.

The current bastioned layout is primarily associated with the Spanish occupation (1614–1681), when the fortress of San Miguel de Ultramar was built, adopting a "tenaille" configuration with a floodable moat (Bueno Soto, 2010). In 1681, the site was

reconquered by the 'Alawite sultan Moulay Ismā'il and reconfigured with new architectural and defensive elements, including Bab Jadīd, the governor's palace (Dar al-Maghzen), a mosque, and a hammam (Saladin, 1913).

Over time, channel silting and the establishment of the port of Kénitra reduced the site's strategic role; it was later reused during the French colonial period and involved in events of World War II (Raoui, 2010; Coindreau, 1946). After independence, the



Figure 1. Plan of the Kasbah de Mehdyia (La Mamora), dated January 18, 1633. Signed by Cristóbal Lechuga, the plan documents the Spanish defense system during the occupation (1614–1681). Source: Bueno Soto, F.J., 2010: *Larache y La Mamora: dos fortificaciones españolas en tiempos de Felipe III*, Aldaba (34), 87.

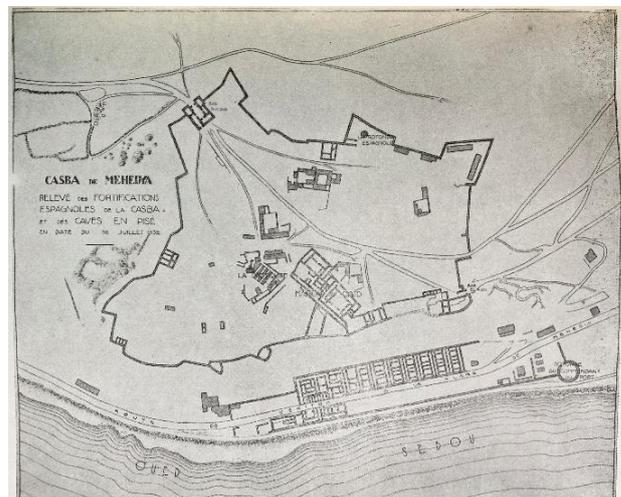


Figure 2. The Kasbah of Mehdyia in a 1932 drawing. Source: Guillermo Guastavino Gallent in Tirso de Molina, 1939.

complex underwent limited conservation actions; partial interventions occurred in 2010 under ALINSAP.

At present, the Kasbah is characterised by abandonment and high vulnerability: local collapses, wall displacements, vegetation colonisation, and accelerated decay consistent with coastal exposure.

3. Methodology

3.1 Multiscale and multimodal data acquisition

The site's logistical complexity and invasive vegetation required a survey strategy balancing extensive coverage and targeted detail. The idea from the very beginning was to integrate a comprehensive acquisition with more detailed spot surveys by studying the feasibility of a management platform for these two scales of information (Gigliarelli, Pontrandolfi, and Calcerano, 2020). Two field campaigns (2024–2025) were designed to (i) capture the overall morphology and main volumes, and (ii) document selected structures at architectural scale, prioritising areas of conservation concern. At site scale, UAV survey was used to provide a georeferenced framework and to capture topography and major architectural bodies.



Figure 3. External fortified walls of the citadel, with the view of Bab Jadīd, the main gate of the site. © Photo by the authors

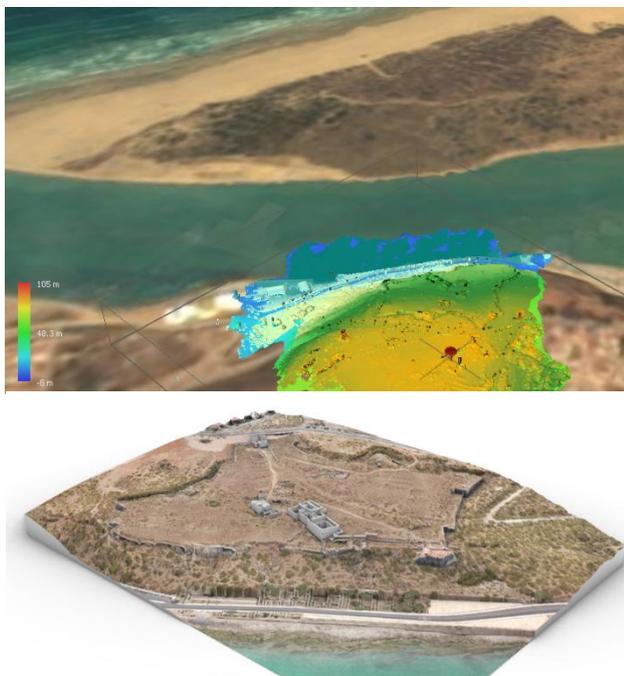


Figure 4. Results of the data processing and georeferencing workflow: (a) georeferenced point cloud accurately positioned within the terrestrial geographic reference system; (b) 3D model of the site, including photorealistic texture and integration of existing buildings.

In 2025 a complete UAV campaign included both photogrammetric acquisitions and aerial LiDAR to improve coverage and robustness in vegetated sectors. At building scale, SLAM-based mobile mapping was conducted using GeoSLAM

ZEB Horizon, suitable for rapid acquisition in partially constrained or GPS-denied conditions. Although the team had previously conducted large-scale SLAM surveys by connecting multiple routes into a single macro acquisition (Bernabei et al., 2023), the Kasbah site posed additional constraints, including discontinuous accessibility, lack of direct connections between buildings, uneven terrain, and limited possibilities for placing connection markers. Therefore, SLAM acquisitions were performed as targeted “spot” surveys. Due to discontinuous accessibility, irregular terrain, and limited opportunities for establishing continuous connections between buildings, SLAM acquisitions were performed as targeted “spot” surveys, later positioned within the UAV reference framework.

To support high-resolution surface documentation and masonry interpretation—often insufficient in RGB SLAM outputs—the dataset was complemented with terrestrial imagery: spherical panoramas acquired with Insta360 Pro2 and conventional high-resolution photographs captured with Canon EOS R5. Spherical imagery covered interior spaces (e.g., mosque, palace sectors) and selected interior/exterior transitions, while DSLR imagery focused on elevations and areas requiring detailed reading of materials and decay.

3.2 Data processing and georeferencing

UAV photogrammetry was processed in Agisoft Metashape Professional through image alignment (aerotriangulation) and dense point-cloud generation, producing georeferenced orthophotos and 3D products. To improve completeness at building scale and strengthen the overall dataset, mobile mapping data acquired via GeoSLAM were integrated within the same processing pipeline, enabling a coherent fusion between rapid, high-resolution local mapping and the extensive spatial coverage provided by aerial survey.

Georeferencing and co-registration were managed through a consistent spatial reference framework to ensure interoperability with regional GIS datasets and repeatability across campaigns. For metric operations and local processing steps, datasets were handled in a projected coordinate reference system; final deliverables and GIS publication layers were provided in WGS84 (World Geodetic System 1984), corresponding to EPSG:4326. Accuracy control was supported by Ground Control Points (GCPs) collected during fieldwork (where available) and/or stable control features identifiable across datasets, used to anchor orthophotos and point cloud from multiple sources were then filtered, aligned, and merged in CloudCompare to obtain a clean and consistent dataset supporting subsequent modelling and analysis (Diara et al., 2023). The unified cloud was segmented and classified to facilitate scan-to-HBIM operations, clouds to a global datum and minimise positioning errors (fig.4).

3.3 Structural inspection and damage mapping

A technical–structural inspection was conducted to identify crack patterns, deformation phenomena, and construction vulnerabilities, with particular focus on rammed earth (tapial) and rubble-stone masonry. Observed issues include settlement-related cracking, loss of cohesion in binders, plaster detachments, partially collapsed vaults, and out-of-plane mechanisms in vulnerable sectors. These observations were organised into a

preliminary damage map and translated into structured information layers for HBIM integration (fig.5).



Figure 5. General view of the Mosque and view of the western gate currently affected by structural settlements that compromise the stability of the arch and the adjacent masonry. The diagram illustrates the kinematic mechanisms. © Photo and elaboration by the authors

Pathology classification follows the Italian PCM Guidelines for seismic risk assessment of cultural heritage (PCM, 2011) and is cross-referenced with ICOMOS principles (ICOMOS, 2003) and CEN EN 16096:2012 (CEN, 2012), enabling consistent documentation and future comparative monitoring.

3.4 Scan-to-HBIM modelling pipeline



Figure 6. Example of dense clouds acquired by the GeoSLAM. A) Mosque B) Governor's Palace (Dar Al Makhzen), Medhyia, Kenitra (May 2025). © Elaborations by the authors

HBIM modelling was implemented to manage irregular geometries and ensure parametric control, starting from the filtered and aligned point cloud as a metric backbone. The GeoSLAM ZEB Horizon proved fundamental for the rapid, high-

resolution acquisition of point clouds in partially constrained or complex environments, providing a robust spatial dataset to support subsequent modelling phases. To build a coherent and reliable reference model, point clouds derived from different acquisition methods were filtered, aligned, and merged in CloudCompare, ensuring clean geometry and correct orientation prior to BIM generation (Diara et al., 2023).

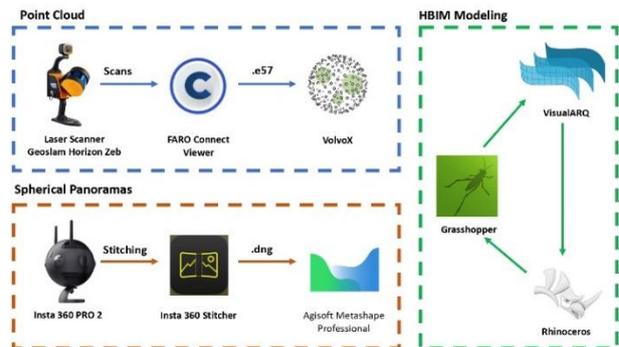


Figure 7. The workflow process divided into three sections: point cloud acquisition, spherical panoramas, and HBIM modeling. ©Elaborations by the authors

The workflow combined point-cloud segmentation and classification, extraction of reference sections and profiles, NURBS-based reconstruction of architectural surfaces, object-based HBIM modelling, and export to open standards to support interoperability (Fig. 7). The pipeline was first applied to the mosque and subsequently extended to the governor's palace (Dar al-Maghzen), establishing a scalable procedure for modelling additional structures. In this process, different approaches to 3D modelling were considered, including NURBS modelling based on mathematical curves and control points for surface reconstruction (Diara et al., 2020), mesh-based modelling for visually driven and texture-oriented representations, and BIM modelling based on intelligent objects enriched with structured information. High-resolution spherical panoramas (Insta360 Pro2) supported visual documentation and, where relevant, texture mapping, improving the readability of materials and



Figure 8. Example of two spherical panoramic images in equirectangular projection acquired by the Insta360 Pro2. A) Mosque B) Governor's Palace, Kenitra (May 2025). © Photo by the authors

decay patterns and strengthening the communication and dissemination potential (Paris et al., 2017).

3.5 Modeling and BIM integration

The HBIM modelling phase aimed to produce a semantically rich and geometrically accurate digital representation of the Kasbah, aligned with international standards for built-heritage documentation. Modelling was performed in Rhino 3D coupled

with Grasshopper, selected for advanced parametric control and extensibility through dedicated plugins. The pre-processed and georeferenced point cloud—previously filtered and aligned in CloudCompare—provided the geometric backbone of the workflow, enabling metric control during the generation of architectural components.

To extract orthogonal profiles for surface reconstruction, the VolvoX plugin for Grasshopper was used to slice the point cloud along defined X, Y, and Z axes and generate planar sections

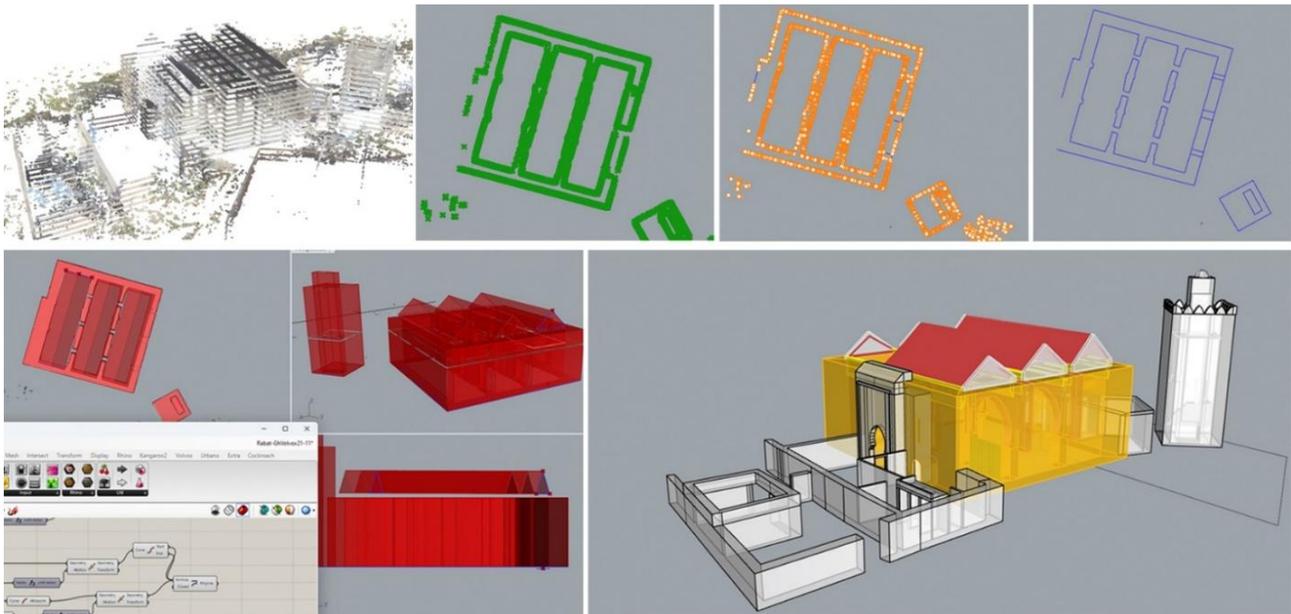


Figure 9 Stages of 3D modeling with VolvoX and Grasshopper: from point cloud to geometric reconstruction. © Elaborations by the authors

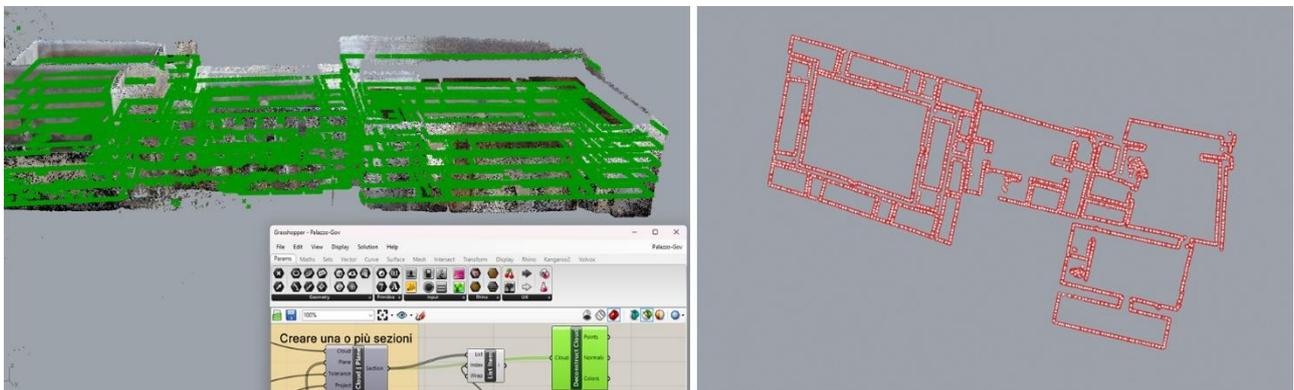


Figure 10. On the left, the extraction of profiles from the point cloud; on the right, one of the extracted curves used as reference for 3d modeling. © Elaborations by the authors

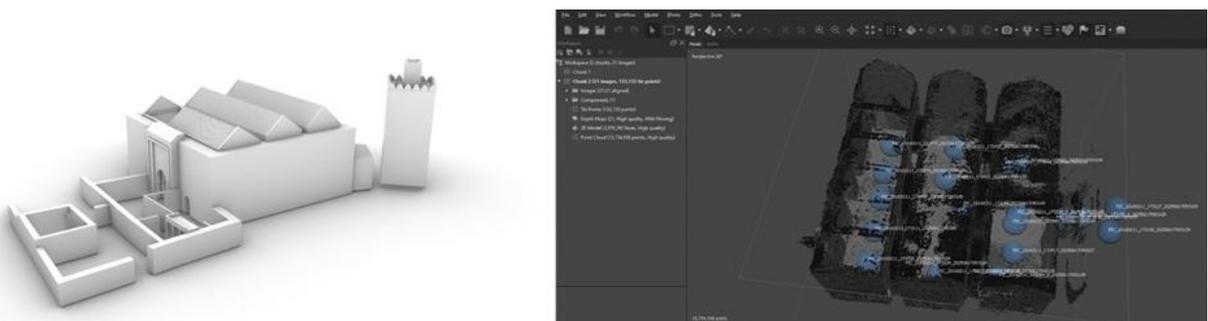


Figure 11. On the left, the final 3D model of the mosque; on the right, the spherical panoramas used for texture application and enhanced visual realism. © Elaborations by the authors

exported as vector CAD files. These profiles supported NURBS-based modelling, allowing flexible adaptation to the irregular geometries and stratified fabric of the fortified complex (fig.9). The transition from surface modelling to BIM objectification was achieved through VisualARQ, a Rhino plugin for semantic enrichment and object classification. VisualARQ enables the transformation of geometric components into parametric architectural elements enriched with metadata. Support for the IFC (Industry Foundation Classes) standard ensured interoperability within OpenBIM environments (e.g., Revit, ArchiCAD), facilitating multidisciplinary collaboration across architectural, structural, and conservation domains (Bianchini et al., 2021).



Figure 12. Before-and-After Perspective of Geospatial from Autodesk Infraworks to Data Integration in the software.
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Following BIM integration, textures were applied using high-resolution spherical panoramas acquired with the Insta360 Pro2. The imagery was mapped onto 3D surfaces to increase visual fidelity and improve the readability of materials and decay patterns. The same sequence—point-cloud segmentation, NURBS reconstruction, BIM conversion, and texture mapping—was applied to the Governor’s Palace (Dar al-Maghzen), establishing a repeatable and scalable procedure for the documentation of additional structures within the Kasbah (fig10).

3.6 GIS integration and territorial baselines validation

To link architectural-scale information to the territorial context, HBIM outputs and survey-derived products (GeoTIFF orthophotos; LAS point clouds; IFC models) were integrated into GIS platforms (QGIS/ArcGIS Pro). The integration of multiscale data required a rigorous georeferencing and co-registration framework, ensuring that heterogeneous sources could be reliably combined within a single GIS environment.

Drone-acquired imagery was processed in Agisoft Metashape Professional via high-precision aerotriangulation and dense point-cloud generation. Mobile mapping data acquired via GeoSLAM were integrated within the same pipeline to strengthen completeness and robustness, ensuring coherent fusion between high-resolution local mapping and aerial

coverage. The spatial reference framework followed the approach described above: datasets were managed in a projected CRS for metric processing, while GIS-oriented layers and deliverables were provided in WGS84 (EPSG:4326) to ensure interoperability. The Kasbah of Mehdyia is located approximately at Latitude 34° 15' 50" N and Longitude 6° 39' 45" W. Accuracy control was supported by GCPs (where available) and/or stable control features, allowing orthophotos and point clouds to be anchored to a global datum and seamlessly overlaid with regional cartographic layers.

The transition from point clouds to the information system enabled the transformation of surveyed geometry into spatially referenced information. By exporting Metashape outputs to GIS platforms in standard geospatial formats (GeoTIFF for raster orthophotos and LAS for point clouds), each mapped element of the Kasbah was associated with unique coordinates. This facilitated multiscale spatial analysis of decay patterns and supported the management of conservation data within relational geodatabases, strengthening the linkage between HBIM-derived information and the territorial dimension addressed by GIS. In this integrated perspective, the HBIM–GIS environment supports long-term monitoring and evidence-based decision-making processes for site preservation.

A dedicated step addressed the reliability of pre-existing territorial datasets for urban modelling. A preliminary urban model was generated in Autodesk InfraWorks 2025 using “Model Builder” and ArcGIS baseline data. Architectural-scale evaluation revealed limitations typical of generalised datasets (e.g., incomplete geometries and unreliable heights), which are unsuitable for HBIM-informed decision processes. To mitigate these issues, a high-density SLAM dataset was processed in FARO Connect, converted to LAS in CloudCompare, transformed to RCP in Autodesk ReCap, and integrated into InfraWorks; manual co-registration supported discrepancy identification and correction. HBIM models were integrated into InfraWorks (FBX) to enable direct comparison between surveyed and baseline geometries and to support progressive densification of the heritage digital twin.

4. Results and discussion

Preliminary results confirm the effectiveness of the proposed workflow in unifying survey acquisition, HBIM modelling, and GIS-based multiscale analysis within a single information environment. The integrated dataset enables consistent documentation of the Kasbah’s construction features and conservation conditions, supporting the identification and localisation of critical issues such as wall settlements, local structural instabilities, invasive vegetation colonisation, and salt-related material deterioration in the most exposed sectors.

By embedding element-level HBIM information within a territorial GIS framework, the HBIM–GIS integration supports multiscale spatial queries and correlation analyses between mapped pathologies and environmental drivers typical of coastal fortified contexts (e.g., sea-salt aerosol exposure, site morphology, and vegetation dynamics). A key outcome concerns the critical verification of pre-existing territorial baselines:

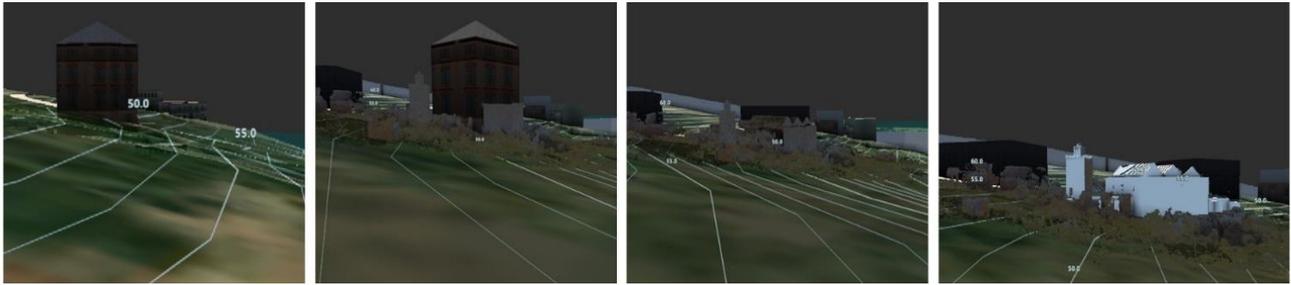


Figure 13. Workflow approach for the mosque of the Kasbah of Mehdyia: Through GIS, Scan and BIM integration. © Elaborations by the authors

comparison between generalised urban datasets and “as-built” survey-derived geometry highlights architectural-scale inaccuracies (e.g., incomplete volumes and unreliable height information), confirming the need for progressive densification of the heritage digital twin based on high-precision survey data and HBIM modelling.

Beyond file-format interoperability, the workflow reduces interpretive ambiguity by grounding geometric reconstruction and semantic attribution on survey evidence, and improves operational efficiency by combining UAV coverage, rapid SLAM mapping, and targeted high-resolution imagery. The resulting information framework establishes a scalable basis for conservation prioritisation and scenario definition, to be progressively refined through quantitative indicators and repeated monitoring campaigns. In this perspective, a WebGIS-based dissemination layer is envisaged to facilitate multi-actor consultation and collaborative updating of georeferenced contents over time.

5. Conclusions and prospects

The HBIM–GIS workflow developed for the Kasbah of Mehdyia provides a methodological contribution to the documentation and conservation of vulnerable coastal fortified heritage. By integrating multiscale survey datasets, semantically structured HBIM modelling, and GIS-based geospatial analysis within a single heritage digital-twin framework, the approach strengthens the connection between architectural knowledge (materials, techniques, decay patterns) and territorial context, supporting monitoring and evidence-based decision-making processes. The main contribution lies in a replicable and modular procedure based on interoperable standards and an open-data orientation, enabling transferability to other stratified fortified sites. Future developments will focus on: (i) extending HBIM coverage to additional structures of the complex; (ii) integrating complementary diagnostic datasets (materials, microclimate, and—where available—geotechnical and structural investigations); (iii) implementing a WebGIS interface for consultation and collaborative updating; and (iv) exploring predictive approaches (e.g., machine-learning-assisted trend analysis) to support monitoring of degradation across repeated campaigns. Further work will also address interoperability with territorial-scale BIM environments to strengthen integration with planning and management workflows.

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