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Implementation of Management Facilitators in Historic Buildings: Integration of BIM and GIS for Pathology Monitoring

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The efficient management of historic buildings requires innovative preservation and pathological monitoring methods. This study proposes the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) to optimize the conservation of ruined structures, using the former prison of Ilha Anchieta State Park (PEIA) as a case study. The methodology included (1) historical and structural data collection, (2) BIM modeling in Revit, (3) geospatial mapping of anomalies in QGIS, and (4) the definition of maintenance priorities. The results demonstrate that combining these technologies enables the precise tracking of cracks, fissures, and displacements and facilitates preventive interventions. The study outlines a five-step guideline, from data collection to action planning, providing a replicable method for other historic buildings. It is concluded that the proposed approach improves the efficiency of heritage management, reduces costs, and contributes to the preservation of structural originality, with the potential for expansion through automation and artificial intelligence.

I. INTRODUCTION

Efficient management of buildings, especially those with historical value, has become an increasingly significant challenge due to the need to preserve their original characteristics and the complexity of their structures. Advances in Information and Communication Technologies (ICTs) have led to the growing use of digital tools such as Building Information Modeling (BIM) and Geographic Information Systems (GIS) to optimize inspection, maintenance, and documentation processes.

However, a substantial portion of the documentation related to historic buildings is still stored in physical formats or in non-specialized software, which hinders both access to and organization of this information. Furthermore, the absence of a standardized system for tracking structural pathologies compromises the effectiveness of conservation efforts.

This study, employing a case study methodology, proposes the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) with terrestrial laser scanning data to monitor pathological manifestations in historic buildings. The ruins of the former prison located in the Ilha Anchieta State Park (PEIA), Brazil, served as the case study. The proposed methodology offers guidelines for implementing a management system based on digital technologies, thereby contributing to the preservation and conservation of built heritage.

II . STATE OF THE ART

The application of Building Information Modeling (BIM) in the management of existing buildings has proven to be particularly effective in centralizing and systematizing information, enabling quick and reliable access to data on materials, historical interventions, and the structural condition of built heritage [1].

This capacity to consolidate information within a single environment positions BIM as a strategic tool for the documentation and monitoring of architectural assets, particularly in contexts that require rigorous traceability of historical transformations.

In parallel, Geographic Information Systems (GIS) complement this approach by introducing a geospatial dimension, thus supporting multiscale analyses and facilitating the detection of structural and environmental anomalies [2; 3].

Recent literature increasingly highlights the importance of interoperability between BIM and GIS platforms, emphasizing its role in overcoming informational fragmentation and advancing integrated models for managing the built environment [4]. Initiatives such as hybrid Maintenance Management Systems exemplify these developments by combining detailed geometric representations with georeferenced databases, thereby expanding the possibilities for preventive monitoring and intervention planning [4].

However, despite these advances, significant challenges remain. These include the standardization of data exchange formats, the alignment of ontologies, and the broader dissemination of interoperable practices. These issues continue to hinder the large-scale adoption of these integrated technologies [3, 5].

Reflecting this integrated approach, [2] applied a methodology using GIS and BIM for the documentation, management, and structural monitoring of heritage within an ICT framework. Their approach consolidates multidisciplinary data—including architectural, geometric, historical, and material information—with structural assessments and records of interventions. The combined use of GIS and BIM enables spatio-semantic management and anomaly monitoring, facilitating efficient and updatable lifecycle management of the structure.

III. STUDY CONTRIBUTIONS

This research makes the following key contributions:
(1) A novel integrated BIM-GIS management framework, complete with implementation guidelines, specifically designed for pathology monitoring in historic buildings. The supported structured workflow integrates the collection of historical and structural data, BIM-based modeling of ruins, GIS-based anomaly mapping (QGIS), and a strategy for prioritizing maintenance.
(2) Practical validation in a real-world setting, demonstrated by applying the proposed methodology to the case study of Ilha Anchieta State Park (PEIA), which confirms its feasibility and effectiveness for conservation management.

IV. RESULTS AND ANALYSIS

IV.I Survey and BIM Modeling

The exterior façades of the buildings surrounding the square of the former Presídio were scanned using a FARO Focus Laser Scanner. For the building that currently houses the administration, 12 scan positions were established. The processing of these scans generated a point cloud comprising 204 million points with a registration error of 8.1 mm.

For the scanning of the eight pavilions, the service building, and the isolated cells that complete the square, 18 scanner positions were planned to ensure comprehensive coverage of all façades. The registration of these individual scans into a unified point cloud resulted in a model of 300 million points with an overlap error of 6.2 mm.

BIM modeling was conducted using Autodesk Revit software (version 2020). Automated component recognition techniques were not employed, primarily because the vast majority of the buildings no longer contain elements such as windows, doors, or grates, leaving only the walls.

The point cloud was imported into Revit, and all architectural components were manually modeled by overlaying them onto this reference base. For modeling specific families (e.g., doors, windows, railings), a point cloud file in DXF format was imported into the family editor environment. This was necessary because Revit does not support other point cloud formats in this specific workspace. This DXF file was generated using the open-source software CloudCompare (v2.9.1) from the laser scan data, which was first converted to LAS format using Faro Scene software, as illustrated in Fig. 1.

Fig. 1. Image of the point cloud generated by the Scene program

Because the site consists of ruins, the reconstruction of the buildings required consultation of historical materials, such as images, original plans, and publications.

Internal scans were performed for each pavilion and the other buildings, except for the Administration building. The scanner positions were determined based on the number of rooms in each area. Pavillion 6, for example, required two internal scan positions and one external scan position. Fig. 2 shows the point cloud generated by registering the individual scans.

Fig. 2. Record of the three laser shots with a view of the facade and back wall

The models shown in Fig. 3 depict the buildings that make up the pavilion area, completed in 1907. They accurately represent Ramos de Azevedo's original design.

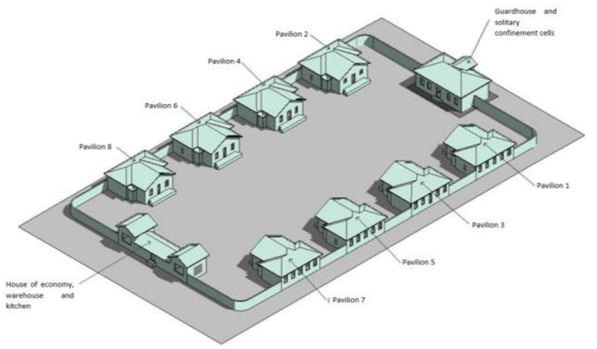

Fig. 3. 3D modeling of the original 1907 'Cuadrado' configuration

The modeling in Fig. 4 represents the area of the pavilions in 1928, the year in which the front and rear buildings were expanded.

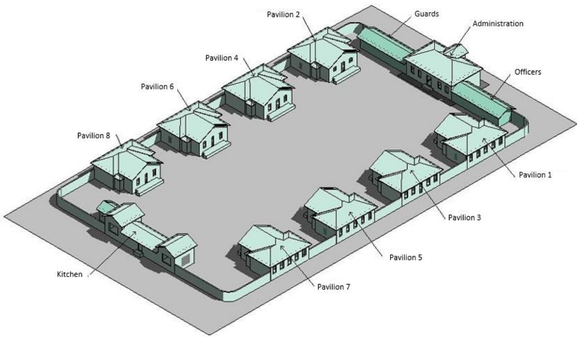

Fig. 4. Modeling of the "square" of the year 1928

Figure 5 shows a model of the pavilions area with the extensions completed in the 1940s, the last alteration undergone by the building.

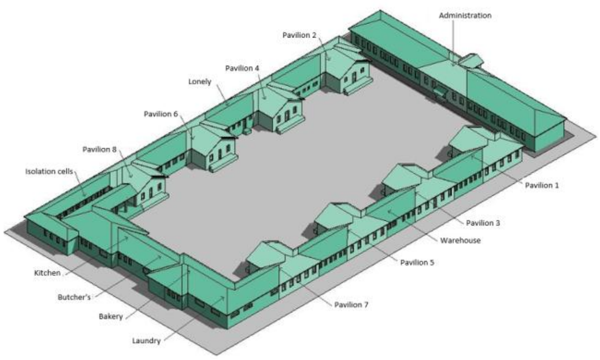

Fig. 5. Modeling of the "square" of the year 1940

In ruined structures, it is critical to identify and isolate areas at imminent risk of collapse to prevent accidents involving workers and visitors. This risk assessment can be performed in Revit by assigning color-coded classifications (e.g., minimum, medium, or high risk), as shown in Fig. 6. The resulting model can be shared with site administrators to communicate safety protocols and necessary emergency measures.

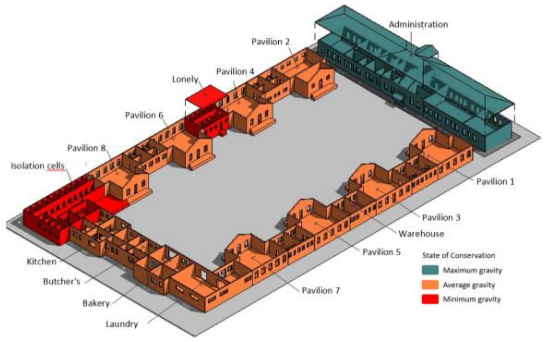

Fig. 6. Modeling with a risk degree classification

IV.II Mapping of Anomalies via GIS

This stage commenced with the georeferencing of the pavilion façade. Following an inspection of the site conditions, the team proceeded to the prison ruins to collect measurements. Five control points were established on the façade for the survey, which was conducted using two total stations, a prism, and a measuring tape.

After the field measurements were completed, calculations were performed to determine the coordinates of the points on the façades.

The proposed system for recording anomalies—which aggregates information on typology, dimensions, and location—can be implemented using the free, open-source software QGIS. This platform allows the data to be consulted, edited, and analyzed at any time. Furthermore, the installation of QGIS does not require a significant investment in high-performance computing hardware, enhancing its accessibility for building managers.

The point cloud was aligned using CloudCompare software and exported in a raster format. It was subsequently cropped to remove areas irrelevant to the study, which significantly reduced the data volume. To ensure georeferencing accuracy, the model was aligned with the field-collected coordinates. This alignment was performed by referencing the approximate locations of the in situ measurements within the point cloud. The process is illustrated in Fig. 7.

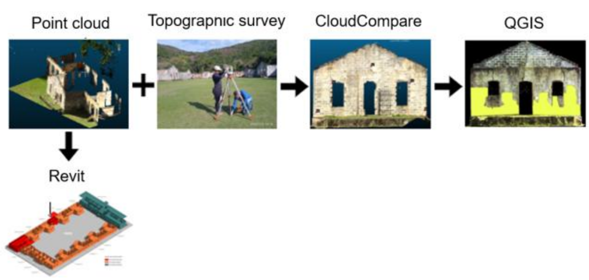

Fig. 7. Process for processing collected data

Figure 8 shows the pavilion image obtained from

CloudCompare, with the points aligned as indicated in the images and with the data already calculated from the topographic survey data.

Fig. 8. Point cloud in CloudCompare with aligned points – Clay brick facade

The authors defined the adoption of distinct core layers and other representation methods, as demonstrated in Figure 9. The appropriate approach is to use cores that contrast with each other and with the developed plan to facilitate their identification. However, anomalies should be delimited according to their openings and dimensions. For example, a breach and a position cannot be measured using a line, as it is important to identify the opening area in a breach, unlike a fissure, which has a relatively small opening, making it difficult to survey the area. In this sense, mapping is easier by representing a line.

After aligning the points in CloudCompare, the file was exported in raster format and imported into QGIS software to map the anomalies. Figure 9 shows polygons and lines in different cores to differentiate each typology.

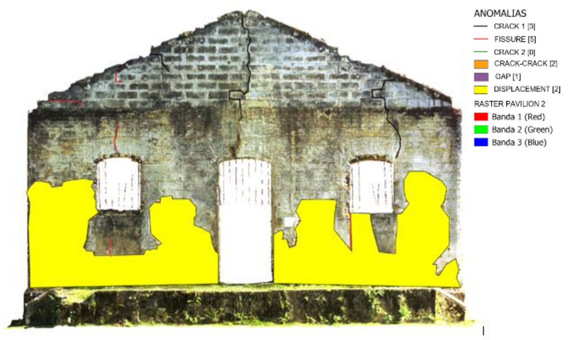

Fig. 9. Clay brick facade - mapping anomalies in QGIS

IV.III. Management Guidelines

A consolidated workflow that integrates HBIM and GIS specifically for the systematic classification and identification of pathologies is absent from the existing literature. To address this gap, the proposed framework is structured as a five-stage continuous process that links documentation, modeling, monitoring, spatial analysis, and decision-making within a unified information environment.

The process begins with the acquisition of historical and geometric data through archival research and structured field inspections. This is combined with laser scanning or photogrammetry to ensure accurate geometric capture, enabling longitudinal comparability for mapping construction phases and prior interventions [6].

Next, the datasets are processed to generate a semantically rich HBIM model. In this step, point clouds are translated into parametric objects endowed with attributes for materiality, conservation state, and chronology, following established practices for existing buildings and scan-to-BIM accuracy management [6].

The third step involves organizing anomaly tracking through defined typologies and severity scales. This combines periodic measurements (e.g., crack width, moisture levels, and deformation) with systematic visual inspections aligned with conservation guidelines. This structured approach supports risk-based assessment and ensures comparability over time.

Subsequently, the records are georeferenced and integrated into a GIS environment to analyze spatial patterns of deterioration and their relationships with environmental and territorial drivers. Recent work underscores that HBIM-GIS integration should be tailored to different contexts and use cases, including web-based, multi-scalar applications that broaden accessibility and enhance decision support [4].

Finally, the action planning stage operationalizes maintenance prioritization through a multicriteria evaluation that balances risk, heritage significance, and cost. This approach enables a shift from corrective to preventive conservation strategies while maintaining an auditable record of all decisions within the integrated HBIM-GIS environment.

Based on a review of the literature, we have developed a set of proposed guidelines for the restoration and preservation of building elements and their functionality. These guidelines, which are organized into a five-step process (see Fig. 10), encompass the entire workflow from initial data collection to ongoing maintenance, outlining the essential technical applications required for the effective management of built heritage.

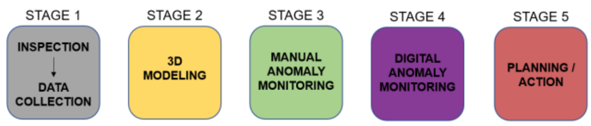

Fig. 10. Guideline steps

The proposed framework is structured in five stages. The first stage comprised an initial survey of documentary sources and geometric data, including an assessment of the structure's conservation status. In the second stage, the collected data were processed for BIM modeling using Autodesk Revit, which incorporated a classification system for building risk levels. The third stage involves monitoring pathological manifestations (anomalies) using low-cost instruments, enabling the prioritization of interventions based on their progression.

The fourth stage focuses on the registration and georeferencing of these anomalies within a GIS platform, utilizing a point cloud obtained through terrestrial laser scanning and processed in specialized software. Finally, the fifth stage establishes a maintenance plan based on the integrated information from previous stages, emphasizing the systematic documentation of all interventions and the implementation of preventive conservation actions.

Collectively, these guidelines facilitate efficient and sustainable heritage management, making it well-suited to address common technical and budgetary constraints.

V. CONCLUSIONS

The integration of BIM and GIS has demonstrated significant effectiveness in monitoring historic buildings. This approach enhances the accuracy of anomaly detection, reduces costs associated with corrective maintenance, and supports the preservation of architectural heritage.

The proposed five-stage guidelines encompass the entire process from initial data collection to the formulation of an intervention plan. They were developed based on the specific characteristics of the built heritage presented in this case study. While some stages can be directly applied to other buildings without modification, a preliminary analysis is necessary to verify the similarities between cases. Depending on the specific needs and conditions of a site, certain stages may be omitted or adapted.

By thoroughly understanding a building's condition, as outlined in Stage 1 of the guidelines, managers can effectively plan subsequent steps based on actual needs, ensuring a tailored and efficient conservation strategy.

Looking ahead, future research could focus on incorporating automated structural deterioration alert systems. This could be achieved through the use of IoT sensors integrated with BIM and GIS platforms, further enhancing predictive conservation strategies.

As demonstrated and justified in this study, the barriers to the effective preservation of built heritage can be mitigated by adopting periodic, standardized building inspections and implementing digital records managed by specialized software. This approach increases the precision of long-term anomaly monitoring, as all information is systematically recorded in reliable databases, thereby preventing data loss and ensuring information integrity.

Future Perspectives

- Expansion of the method to other buildings in a state of ruin.
- Integration with artificial intelligence to predict structural failure.

This study reinforces the importance of digitization in preserving historical heritage, offering a replicable and efficient approach for managers and conservators.

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