HBIM's Role in the Conservation and Restoration of Archaeological Buildings: Case Study: Omar Al-Khyam Hotel in Damascus

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Abstract

Historic Building Information Modelling (HBIM) has emerged as a critical methodology for preserving cultural heritage by documenting the condition of building materials, assessing the extent and causes of damage, and managing restoration and maintenance activities. By integrating advanced technologies such as thematic mapping and 3D modeling, HBIM offers a comprehensive approach to analyzing and conserving historic structures. This research highlights the significance of HBIM in preserving the integrity and sustainability of heritage buildings, emphasizing its role in maintaining their historical and cultural value. The study focuses on the Omar al-Khiam Hotel in Damascus, an iconic historic building requiring urgent restoration. A detailed photographic survey was conducted using a mobile camera, with images processed through AGISOFT METASHAPE and enhanced using Photoshop. These data were used to create a precise 3D model in EDIFICIUS HBIM software, incorporating detailed assessments of material conditions, including corrosion, damage, leakage, and environmental pollution. Based on this analysis, a restoration and maintenance schedule was developed to guide the rehabilitation process and ensure effective project management. The findings demonstrate the effectiveness of HBIM in providing a dynamic and collaborative platform for heritage conservation. The study underscores the need for integrating diverse data sources and engaging stakeholders in restoration efforts. While HBIM offers significant advantages, challenges such as data precision and software complexity were identified. Future research should focus on enhancing HBIM's predictive capabilities for long-term material degradation and exploring its application across diverse heritage sites to refine conservation strategies further.

Keywords: Historic Building Information Modelling (HBIM); Cultural Heritage Preservation; Material Condition Assessment; 3D Modeling and Thematic Mapping; Restoration and Maintenance Planning; Omar al-Khiam Hotel Case Study

1. Introduction

Preserving historic buildings and their original materials is essential for safeguarding cultural heritage and maintaining the historical identity of communities. These structures serve as tangible evidence of history, carrying exceptional cultural and architectural value that must be preserved for future generations. However, the restoration and maintenance of historic buildings pose numerous challenges, including documenting the condition of construction materials, diagnosing the causes of damage, and managing restoration and maintenance processes to ensure the long-term sustainability of these structures [1, 2].

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In this context, Historical Building Information Modelling (HBIM) emerges as an effective solution. HBIM offers a robust methodology for documenting material conditions, analyzing the degree and causes of damage, and managing the costs associated with restoration and periodic maintenance. Through thematic mapping and 3D modeling technologies, HBIM provides a comprehensive and dynamic approach to preserving historic buildings [3].

This research aims to develop a methodology for documenting building materials, assessing their condition, and integrating this information into a 3D BIM environment [4, 5]. Additionally, it seeks to create schedules for restoration and maintenance activities, along with cost management strategies. The study focuses on the case of the Omar al-Khiam Hotel in Damascus, leveraging photographic surveys and HBIM tools to assess and document the building's current condition. By integrating advanced tools and methods, this research highlights the potential of HBIM in supporting restoration efforts and ensuring the sustainability of cultural heritage sites [6].

2. Literature Review

2.1 Previous Studies and Applications of HBIM in Cultural Heritage Preservation

Historical Building Information Modelling (HBIM) has gained significant attention in recent years as a powerful tool for the preservation and restoration of cultural heritage [7]. Numerous studies have explored its application in documenting, managing, and analyzing historical buildings. For example, Murphy et al. (2009) pioneered the integration of parametric modeling with HBIM for detailed documentation of heritage sites, demonstrating its potential in preserving intricate architectural details. HBIM has since evolved to include advanced features such as photogrammetry, laser scanning, and semantic enrichment, enabling accurate and comprehensive representations of historical structures [8].

One notable study applied HBIM to document the architectural heritage of the Palace of Diocletian in Split, Croatia [9]. Researchers successfully combined terrestrial laser scanning and archival records to create an accurate 3D model, facilitating restoration and conservation planning. The integration of historical data into the HBIM environment not only preserved the authenticity of the palace but also allowed for the analysis of its structural integrity over time. Such case studies highlight the growing reliance on HBIM as a bridge between digital tools and traditional conservation practices [10].

Further applications of HBIM emphasize its role in fostering collaboration among stakeholders [11]. For instance, studies have demonstrated how HBIM serves as a centralized platform for architects, engineers, historians, and conservators to share data and coordinate efforts. This interdisciplinary approach ensures that preservation decisions are both informed and efficient. The implementation of HBIM in large-scale projects, such as UNESCO World Heritage Sites, underscores its importance in addressing complex challenges associated with cultural heritage conservation [12].

Despite its advantages, HBIM faces certain limitations, including the complexity of accurately modeling irregular geometries and the high cost of data acquisition technologies like laser scanning [13]. Nevertheless, advancements in software capabilities and data integration techniques continue to expand the scope of HBIM applications, making it a valuable tool for cultural heritage preservation worldwide [14].

2.2 Methodologies for Assessing and Documenting the Condition of Building Materials

Accurately assessing the condition of building materials is a critical aspect of preserving historic structures. Various methodologies have been developed to evaluate material degradation, ranging from visual inspections to advanced nondestructive testing (NDT) techniques [15]. Traditional methods such as manual surveys and photographic documentation have long been used to capture visible signs of damage like cracks, discoloration, and weathering. While these methods are cost-effective, they often lack the precision required for detailed analysis [16].

Recent advancements have introduced technologies like ground-penetrating radar (GPR), ultrasonic testing, and infrared thermography to assess subsurface conditions and detect hidden damages [17]. For example, studies have shown that GPR can effectively identify voids and moisture infiltration within masonry walls, providing critical insights into structural stability. Similarly, ultrasonic testing has been employed to measure the elasticity and strength of materials, making it a valuable tool for determining the feasibility of restoration techniques [18-19-20].

In the context of HBIM, these methodologies are increasingly integrated into digital models to enhance their functionality [21]. A noteworthy example is the use of laser scanning data to map surface irregularities and incorporate them into 3D models, enabling precise damage analysis. Additionally, researchers have developed frameworks for linking material condition data with metadata within the HBIM environment, ensuring that the models provide both visual and analytical insights [22-23-24].

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Another emerging trend is the use of machine learning algorithms to analyze material degradation patterns. By training algorithms on datasets of historic materials, researchers can predict the progression of damage and recommend preventive measures. This integration of computational tools with traditional assessment methods represents a significant step forward in the field of cultural heritage conservation [25-27].

2.3 Thematic Mapping and Its Role in Material Degradation Analysis

Thematic mapping is a powerful tool for visualizing the spatial distribution of material degradation in historic buildings. It involves the creation of maps that highlight specific attributes, such as areas of corrosion, moisture intrusion, or structural weakness. By overlaying these attributes onto architectural plans or 3D models, thematic mapping provides a clear and comprehensive view of a building's condition, facilitating informed decision-making in restoration projects [28, 29].

One of the earliest uses of thematic mapping in heritage conservation involved manually overlaying damage maps on architectural drawings. While effective for basic analysis, this approach lacked the precision and scalability offered by modern digital tools. Today, GIS software and HBIM platforms have revolutionized thematic mapping by enabling the integration of spatial data with real-time condition assessments. For example, researchers have used GIS-based thematic maps to identify high-risk zones in ancient masonry structures, prioritizing restoration efforts based on severity levels [30, 31].

In the HBIM environment, thematic mapping plays a crucial role in enhancing the functionality of 3D models. By associating material condition data with specific geometric elements, thematic maps transform static models into dynamic decision-support tools. For instance, damage maps created using infrared thermography can be integrated into HBIM to visualize heat loss patterns and identify thermal inefficiencies in historic buildings. These visualizations not only assist in diagnosing problems but also enable stakeholders to explore alternative restoration strategies [32, 33].

Additionally, thematic mapping contributes to long-term monitoring and maintenance. Periodic updates to thematic maps allow conservation experts to track changes in material conditions over time, providing valuable data for predictive maintenance. By identifying trends and correlations, these maps enable proactive interventions that minimize restoration costs and extend the lifespan of historic structures. As technology continues to advance, thematic mapping is expected to become an indispensable component of HBIM workflows [31].

2.4 Challenges and Opportunities in Integrating HBIM with Material Analysis

While the integration of HBIM with material condition assessment and thematic mapping offers numerous benefits, it also presents challenges that must be addressed to maximize its potential [11]. One major challenge is the quality and reliability of input data. HBIM models rely on accurate data from various sources, including laser scanning, photogrammetry, and NDT methods. However, discrepancies between datasets can lead to errors in the final model, impacting its utility for restoration planning [34].

Another challenge is the steep learning curve associated with HBIM software and tools [35]. Conservation professionals often require extensive training to effectively use these technologies, which can delay project timelines. Furthermore, the high cost of acquiring and processing data poses a barrier to widespread adoption, particularly for smaller projects or organizations with limited budgets [36].

Despite these challenges, the opportunities presented by HBIM integration are significant. Advances in data processing algorithms, cloud computing, and open-source platforms are making HBIM more accessible and cost-effective [37]. Collaborative initiatives, such as the development of standardized workflows and interoperability protocols, are further enhancing the efficiency of HBIM projects. These developments not only address current limitations but also pave the way for more widespread adoption of HBIM in cultural heritage conservation [38].

By leveraging the capabilities of HBIM alongside thematic mapping and advanced material analysis methodologies, conservation experts can achieve a deeper understanding of historic buildings and implement more effective restoration strategies [39]. As research in this field continues to grow, the integration of these tools promises to transform the way cultural heritage sites are preserved and managed.

3. Methodology

3.1 Data Collection

The data collection process began with a comprehensive photographic survey using a high-resolution mobile camera to capture the current state of the Omar al-Khiam Hotel. The mobile camera was used to document all visible architectural features, material textures, and signs of damage, ensuring a complete visual record of the building's exterior and interior. Multiple angles and lighting conditions were utilized to minimize blind spots and

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produce a dataset suitable for 3D reconstruction. This approach provided a cost-effective yet reliable means of capturing data without the need for specialized equipment.

Once the photographic survey was complete, the images were imported into AGISOFT METASHAPE software for photogrammetric processing. This software was instrumental in generating a detailed 3D point cloud by aligning the images and identifying common points between overlapping photos. The resulting point cloud provided an accurate geometric representation of the building. The images were then processed in Photoshop to enhance clarity, correct lighting inconsistencies, and highlight areas of interest such as material damage or unique architectural details. This preprocessing step ensured that the data used for 3D modeling was both visually accurate and technically robust.

3.2 Model Creation

The next phase involved creating a 3D model of the Omar al-Khiam Hotel using EDIFICIUS HBIM software. This software was chosen for its specialized capabilities in historical building modeling and its ability to integrate detailed information about material conditions. The point cloud generated from AGISOFT METASHAPE served as the foundation for constructing the 3D model. Using EDIFICIUS, the building's architectural elements—such as walls, columns, and decorative features—were modeled with high precision, preserving their historical and cultural significance.

In addition to the geometric modeling, metadata was attached to specific elements within the HBIM model to document the condition of materials. This included information on the type of material, visible damage, and potential causes of deterioration. The ability to embed this data within the 3D environment allowed for an interactive and dynamic representation of the building's state. This feature enabled stakeholders to visualize not only the architectural layout but also the extent and nature of material degradation, facilitating informed decision-making for restoration efforts.

3.3 Assessment Criteria

The assessment of material conditions was based on four primary criteria: **corrosion**, **physical damage**, **leakage**, and **environmental pollution**. Corrosion was evaluated by analyzing visual signs of oxidation or material degradation, particularly in metal elements such as railings and window frames. Physical damage was assessed by identifying cracks, fractures, and surface wear on structural components. Leakage was documented by tracing water stains, damp areas, or evidence of seepage, which could indicate compromised waterproofing or plumbing systems. Lastly, the impact of environmental pollution was assessed by noting discoloration, surface deposits, or biological growth on materials exposed to the surrounding environment.

These criteria were systematically recorded and mapped within the HBIM model. Each instance of damage was linked to its corresponding architectural element, providing a clear spatial representation of the building's condition. The severity of the issues was categorized into levels—minor, moderate, or severe—enabling prioritization of restoration tasks. This systematic approach ensured that all aspects of material degradation were comprehensively addressed.

3.4 Timetable Development

Developing a timetable for restoration and maintenance activities was a critical component of the methodology. The schedule was informed by the HBIM model, which provided a clear understanding of the building's condition and the extent of required interventions. Tasks were categorized based on urgency, with immediate repairs prioritized for elements showing severe damage or posing safety risks. Routine maintenance activities were planned for areas with minor or moderate damage to prevent further deterioration.

The timetable was structured using project management principles, outlining specific activities, estimated durations, and resource requirements. Dependencies between tasks were identified to ensure logical sequencing, such as completing structural repairs before addressing surface treatments. Additionally, cost estimates for each activity were incorporated into the schedule to assist in budget planning. This comprehensive timetable served as a roadmap for executing restoration efforts, ensuring efficient allocation of resources and adherence to project timelines.

4. Case Study: Omar al-Khiam Hotel

4.1 Historical and Cultural Significance

The Omar al-Khiam Hotel, located in the heart of Damascus, holds immense historical and cultural value as a symbol of the city's rich heritage. Constructed during the early 20th century, the hotel is a testament to a blend of traditional Syrian architecture and modern influences of the period. Its intricate façade, adorned with Arabesque

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motifs, and its historical prominence as a hub for cultural and political gatherings, make it a key landmark in Damascus.

Following are the photo-documentation of the building

Figure 1. Photo-documentation of the building

Over the decades, the hotel has withstood the challenges of time and environmental conditions, but it now requires significant attention to preserve its structural integrity and cultural legacy. Its restoration represents an effort not only to safeguard a physical structure but also to honor the intangible heritage it embodies, including its association with Damascus's vibrant social and historical narratives.

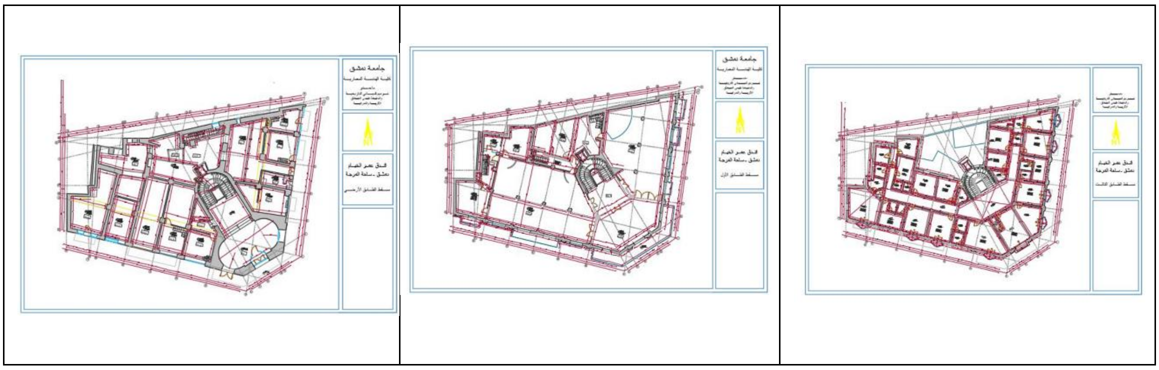

Figure 1. Plans of the building

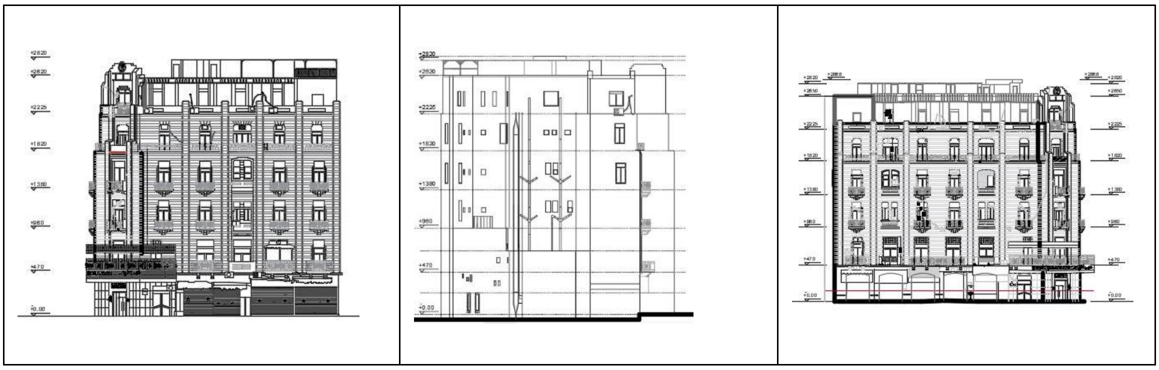

Figure 2. Elevations of the building

4.2 Results of the Photographic Survey and 3D Model Creation

The photographic survey of the Omar al-Khiam Hotel provided a detailed visual documentation of the building's current condition. Using a mobile camera, over 300 images were captured from multiple angles, covering the exterior façades, interior spaces, and intricate decorative elements. The images revealed visible signs of material degradation, including cracking plaster, corrosion of metal components, and biological growth on stone surfaces.

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Figure 3. Photographic Survey

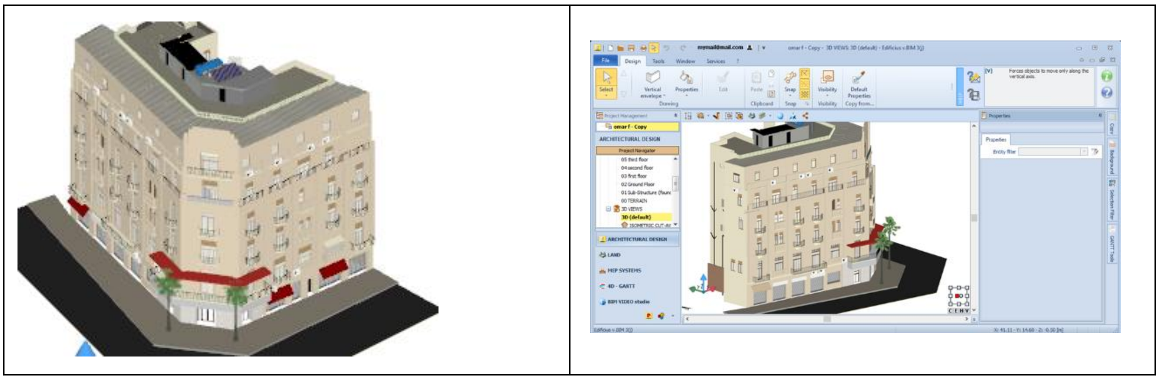

Figure 5. 3D Model creation

These photographs were processed using AGISOFT METASHAPE to generate a high-resolution 3D point cloud, forming the basis for the HBIM model. The processed data was imported into EDIFICIUS HBIM software, where a detailed 3D model of the hotel was created. This model included accurate geometries of architectural elements and integrated metadata about the condition of construction materials. The 3D representation allowed for an interactive exploration of the hotel, facilitating a comprehensive understanding of its current state and highlighting areas in need of immediate attention.

4.3 Analysis of Material Conditions, Damage, and Causes

The HBIM model enabled a thorough analysis of the material conditions of the Omar al-Khiam Hotel. Key findings included:

- **Corrosion:** Notable in the metal railings and window frames, primarily caused by prolonged exposure to moisture and lack of protective coatings.

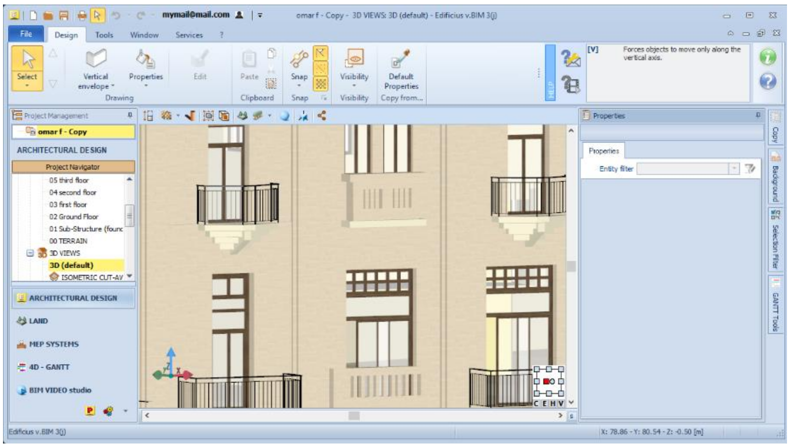

Figure 6. Corrosion Analysis

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- **Physical Damage:** Cracks and fractures were observed in walls and columns, likely resulting from aging materials and minor seismic activity.

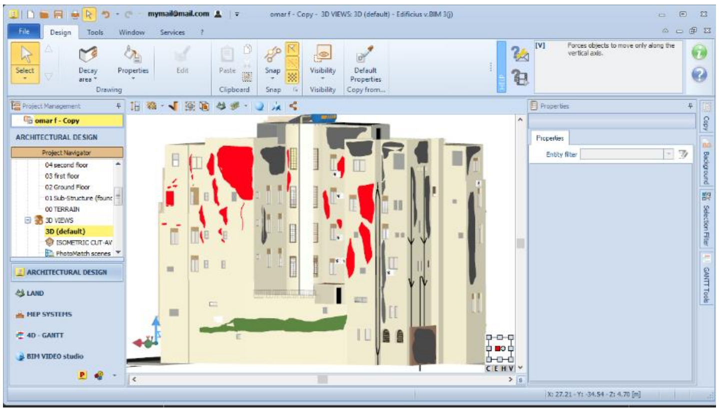

Figure 7. Physical Damage thematic analysis

- **Leakage:** Water stains and damp patches were identified, indicating deficiencies in the roofing and drainage systems.

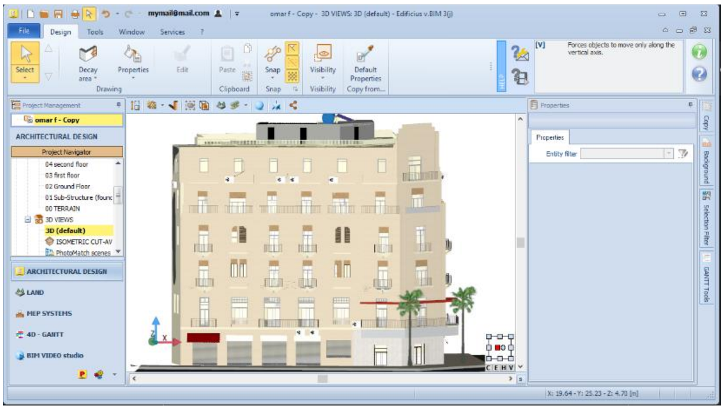

Figure 8. Leakage thematic analysis

- **Environmental Pollution:** Surface discoloration and biological growth, especially on stone surfaces, were linked to pollution from urban activities and nearby vegetation.

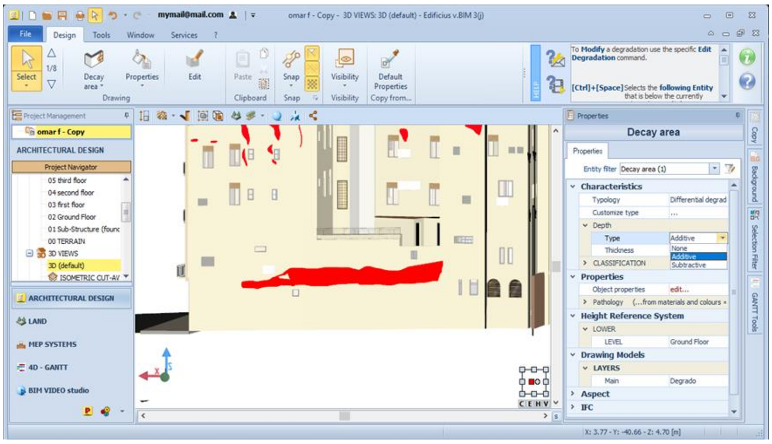

Figure 9. Environmental Pollution thematic analysis

The causes of these issues were attributed to a combination of environmental exposure, deferred maintenance, and inadequate protection measures. This detailed analysis provided the foundation for developing targeted restoration and preservation strategies.

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4.4 Restoration and Maintenance Schedule

A comprehensive timetable for restoration and maintenance activities was developed based on the findings of the analysis. The schedule-prioritized tasks according to the severity of damage and the risks posed to the building's structural and cultural integrity. Key activities included:

1. **Immediate Repairs:**

- Addressing severe corrosion in metal elements by applying anti-corrosion treatments.
- Sealing cracks and fractures in load-bearing walls and columns using injection techniques.

2. **Mid-Term Maintenance:**

- Replacing damaged roofing materials and improving drainage systems to mitigate leakage issues.
- Cleaning and treating biological growth on stone surfaces to prevent further deterioration.

3. **Long-Term Conservation:**

- Applying protective coatings to exposed surfaces to reduce the impact of environmental pollution.
- Implementing a regular inspection and maintenance program to monitor the building's condition over time.

The timetable also included cost estimates and resource allocations, ensuring an efficient and organized approach to the restoration process. The integration of the HBIM model into the planning phase allowed stakeholders to visualize and evaluate the schedule, ensuring alignment with conservation goals.

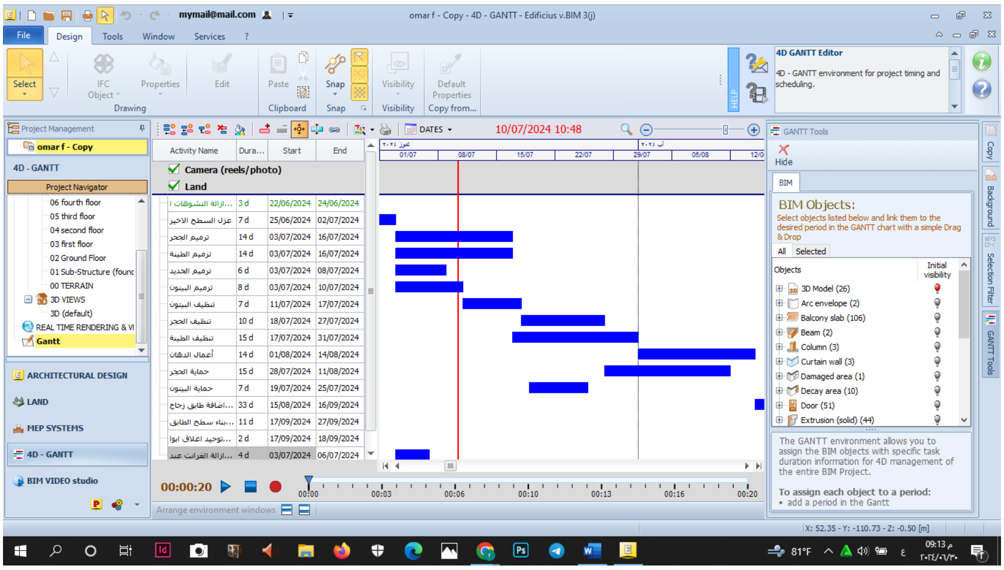

Figure 10. Restoration and Maintenance Schedule

This structured approach ensures the sustainable preservation of the Omar al-Khiam Hotel, maintaining its cultural and historical significance for future generations.

5. Discussion

5.1 Effectiveness of HBIM in Documenting and Managing the Restoration Process

HBIM proved to be an effective methodology for documenting and managing the restoration process of the Omar al-Khiam Hotel. The integration of high-resolution photographic data and 3D modeling allowed for a precise and detailed representation of the building's condition. The ability to embed metadata directly into the 3D model streamlined the assessment of material degradation, enabling stakeholders to identify and prioritize restoration tasks based on severity and urgency.

Furthermore, the dynamic nature of the HBIM model facilitated the visualization of structural conditions, damage locations, and proposed restoration interventions. This visual representation not only enhanced the understanding of the building's current state but also served as a tool for communicating complex technical information to non-expert stakeholders. By incorporating detailed data into a single digital environment, HBIM ensured a systematic and organized approach to the restoration process, reducing the likelihood of oversight and inefficiencies.

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5.2 Potential of HBIM to Integrate Data and Facilitate Collaboration among Stakeholders

One of the key strengths of HBIM lies in its ability to integrate data from various sources into a unified platform. In this research, photographic data, condition assessments, and restoration schedules were seamlessly combined within the HBIM model, creating a comprehensive repository of information. This centralized database allowed for real-time updates and ensured that all stakeholders—designs, engineers, conservators, and project managers—had access to accurate and consistent information throughout the restoration lifecycle.

HBIM also fostered collaboration by providing a common digital framework for communication and decision-making. The model's interactive features enabled stakeholders to visualize proposed interventions and their impacts, ensuring alignment on restoration strategies. Additionally, HBIM facilitated the integration of future data, allowing the model to evolve over time and serve as a valuable reference for ongoing maintenance and conservation efforts. This adaptability highlights HBIM's potential as a long-term tool for managing historic buildings.

5.3 Limitations Encountered During the Research

While the research demonstrated the significant advantages of HBIM, several limitations were encountered. The reliance on a mobile camera for the photographic survey, while cost-effective, posed challenges in capturing highly detailed or hard-to-reach areas of the building. This limitation affected the precision of the 3D point cloud in certain sections, particularly in areas with complex architectural details or significant deterioration.

Another challenge was the steep learning curve associated with specialized HBIM software such as EDIFICIUS. Developing a detailed 3D model and embedding metadata required significant time and expertise, which could be a barrier for teams with limited experience in HBIM technologies. Additionally, while the HBIM model facilitated documentation and planning, its predictive capabilities for material degradation over time were limited, requiring further research to enhance its functionality in this area.

Despite these challenges, the research highlighted the transformative potential of HBIM for preserving historic buildings. Addressing these limitations through improved data acquisition methods, enhanced software training, and integration of predictive analytics could further expand the applicability and effectiveness of HBIM in cultural heritage preservation.

6. Conclusion

6.1 Summary of Findings

This research demonstrated the effectiveness of HBIM as a comprehensive tool for documenting, analyzing, and managing the restoration of historic buildings, using the Omar al-Khiam Hotel as a case study. The integration of photographic surveys, advanced software such as AGISOFT METASHAPE and EDIFICIUS, and a robust methodology enabled the creation of a detailed 3D model that captured the building's architectural features and material conditions. The HBIM model allowed for precise identification of material degradation, facilitated restoration planning, and provided a centralized repository for collaborative decision-making.

The findings underscore the critical role of HBIM in preserving the structural integrity and cultural value of heritage buildings. By offering a dynamic digital representation of the building, HBIM not only supports immediate restoration needs but also lays the groundwork for ongoing maintenance and long-term conservation strategies.

6.2 Recommendations for Best Practices

Based on the research, the following best practices are recommended for implementing HBIM in similar projects:

1. **Comprehensive Data Collection:**
   - Employ advanced imaging techniques, such as drones or laser scanning, in addition to conventional photographic surveys, to capture complex architectural details and hard-to-reach areas.
2. **Integration of Diverse Data Sources:**
   - Use HBIM software to combine visual data, historical records, and environmental information, creating a holistic view of the building's condition and historical significance.
3. **Prioritization of Stakeholder Training:**
   - Invest in training programs for project teams to enhance proficiency in HBIM technologies and ensure efficient model creation and data management.
4. **Dynamic Restoration Planning:**
   - Use the HBIM model to simulate different restoration scenarios and evaluate their impacts on the building's integrity and aesthetics before implementation.

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5. Establishment of Maintenance Protocols:

- Develop a schedule for routine inspections and updates to the HBIM model to monitor changes in material conditions and prevent long-term deterioration.

6.3 Future Research Directions

To further enhance the utility of HBIM in cultural heritage preservation, the following research areas are suggested:

1. Monitoring Long-Term Degradation:

- Explore the use of HBIM in conjunction with predictive analytics to model material degradation over time and forecast future restoration needs.

2. Expanding HBIM Applications:

- Apply HBIM methodologies to a wider range of heritage sites, including those with varying architectural styles, materials, and levels of deterioration, to validate and refine best practices.

3. Integration with IoT and Sensors:

- Investigate the integration of Internet of Things (IoT) technologies, such as sensors for humidity, temperature, and vibration, to provide real-time data on environmental conditions affecting historic buildings.

4. Enhancing Public Engagement:

- Develop interactive HBIM models for use in educational and tourism applications, allowing the public to explore and appreciate the significance of cultural heritage sites.

By adopting these recommendations and exploring new research avenues, the potential of HBIM as a transformative tool for heritage preservation can be fully realized, ensuring that historic buildings remain a vital part of cultural identity for future generations.

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