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FULL LENGTH ARTICLE

Adopting the HBIM System as a Basis for Preserving the Architectural Heritage in the City of Aleppo (Al-Matbakh al-Ajami Building as a Case Study)

Samah Zeitouni[1,*] **Hala Asslan[2]**

[1] Master student in Building Information Modeling and Management, Syrian Virtual University, Syria
[2] Cultural heritage rehabilitation expert, Lecturer at Syrian Virtual University, ICOMOS Expert (International Council of Monuments and Sites), Syria

Emails: Samah_209307@svuonline.org · t_hasslan@svuonline.org

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ABSTRACT

This study examines the role of Historic Building Information Modelling (HBIM) in preserving the architectural heritage of the Old City of Aleppo, focusing on a case study of the Al-Matbakh al-Ajami building. The study aims to provide an integrated framework for using HBIM for documenting and managing historical buildings. This is done through multiple stages and working according to the levels of detail by developing the 3D model from LOD200 to LOD500, which contributes to improving restoration and maintenance processes.

Keywords: Building Information Modeling (BIM) ▪ Architectural cultural heritage ▪ Documentation ▪ Heritage Building Information Modeling (HBIM) ▪ Level of Details (LOD) ▪ The old city of Aleppo ▪ Al-Matbakh al-'Ajami

1. INTRODUCTION

The interest in protecting urban heritage in global forums after the adoption of the Convention on the Protection of the World Cultural Heritage in Venice in 1964 contributed to the continuous development of the foundations of urban development and the sustainability of cultural heritage in accordance with international methodologies, which established many guidelines for managing urban heritage in countries in accordance with maintenance, protection, rehabilitation, and revival, in harmony with the surrounding historic urban environment.

This article relies on Aleppo, Syria's largest city. The ancient city of Aleppo was inscribed on the World Heritage List of UNESCO in 1986. It suffered severe damage and destruction between July 2012 and December 2016 during the Syrian crisis. As a result, in 2013 it was inscribed on the List of World Heritage in Danger as an endangered site [1]. December 2016 witnessed the end of fighting in the city. Aleppo then became partially able to receive people coming from outside it, which allowed UNESCO to send an assessment mission in January 2017 [2].

Organizations continued to work on various projects to restore and rehabilitate historical buildings. Traditional methods failed to deal with those requirements and resulted in myriad issues, so there is an urgent need for new methods [3]. Developed countries use BIM to solve those issues, reaping the benefits of its implementation to achieve project-participant requirements and client satisfaction [4]. Due to the significant influence of BIM on the architecture, engineering, and construction (AEC) industry, it has resulted in considerable enhancements in project-delivery performance and efficiency [5, 6, 4].

The global adoption of Building Information Modeling (BIM) is accelerating, emerging as an effective method for enhancing efficiency within the AEC sector and addressing its critical challenges [7].

BIM models are created for new-build projects using construction drawings and are updated as the project progresses. Heritage or Historic BIM (HBIM) is an evolution of BIM, first suggested by Murphy et al. [8], regarding assets of historical significance, herein referred to as Cultural Heritage (CH) [9]. This model effectively supports the restoration process and the operation and maintenance (O&M) phase. Assessing the true condition of heritage assets through digital documentation provides valuable insights for stakeholders, facilitating informed decision-making throughout the project's lifecycle [10]. Various contextual factors affect the implementation of BIM and its associated levels of detail (LOD). Accordingly, a case study was chosen in the Old City of Aleppo: the Al-Matbakh al-'Ajami building, which is considered one of the city's most important historical monuments and serves as a model for preserving cultural heritage using HBIM.

2. LITERATURE REVIEW

Documentation of heritage buildings is one of the most important procedures that ensure their preservation, protection, and sustainability. To preserve a building, one must know its data, history, and all other information about it. Thus, the preservation process is based on a comprehensive study and understanding of the building's conditions, resulting in a plan and method for dealing with it without harming its value. The process of documenting urban heritage is one of the important initial steps in the system of preserving and sustaining this heritage if it is subjected to damage, collapse, or extinction.

The damage to the Old City of Aleppo was documented based on a comparison of satellite images taken at different times, in addition to the associated 3D documents, given the difficult security situation in Aleppo and the difficulty of accessing the city at that time [2]. The structure of the urban fabric was also analyzed historically in the Suwayqa Ali neighborhood, which was severely affected by the armed conflict in Aleppo between 2012 and 2016, in three time periods (1932, 2001, and 2019). Historical information was reviewed and analyzed, including functional changes and architectural characteristics of 38 buildings, to assess the total damage to the area. The analysis was based on historical references, available previous studies, the database of the Syrian Heritage Archive Project at the Museum of Islamic Art in Berlin, and field survey work [11].

Heritage Building Information Modelling (HBIM) is a novel prototype library of parametric objects based on historic architectural data and a system of cross-platform programs for mapping parametric objects onto point-cloud and image-survey data [12]. Murphy et al. emphasized the use of HBIM to document European classical architecture using laser scanning and photographic techniques. The study provided advanced tools for creating accurate models and developing a library of classical architectural elements. However, it was limited to European classical architecture and did not address Islamic or Oriental architecture or the challenges of applying HBIM in post-conflict or disaster areas [12].

HBIM models can be linked to geodatabases to facilitate architectural heritage management. An open-source platform has been created to exchange data and link geographic information to HBIM models [13]. However, the study did not adequately address the challenges of applying these technologies in developing countries or their use in post-crisis reconstruction operations.

Guidelines and procedures for applying HBIM to architectural heritage in Ireland were developed, establishing uniform standards for documenting heritage using HBIM and ensuring the quality of models and data [14]. The study focused on the Irish context without considering cultural and technical differences in other regions and did not address the challenges of implementing HBIM in severely damaged buildings.

A comprehensive review of HBIM applications in cultural heritage analyzed current trends and discussed future challenges and opportunities [9]. However, it did not provide practical solutions to the challenges mentioned and did not focus sufficiently on applications of HBIM in post-conflict reconstruction.

The use of BIM requires identifying the Level of Development or Detail (LOD) for the information in the model at various stages of the facility's life cycle [15]. LODs range from LOD100 to LOD500, with LOD100 being less developed and LOD500 being more developed. The LOD framework enables project participants to grasp the evolution of a model element from an initial conceptual idea to a detailed and precise definition. The LOD associated with a specific model element communicates the anticipated development level of the information and the degree of reliability that can be placed on it at a specific stage. Identifying the LOD for each model element, along with its development trajectory, helps prevent participants from using the model element in unintended ways or assuming precision beyond the author's intent [16].

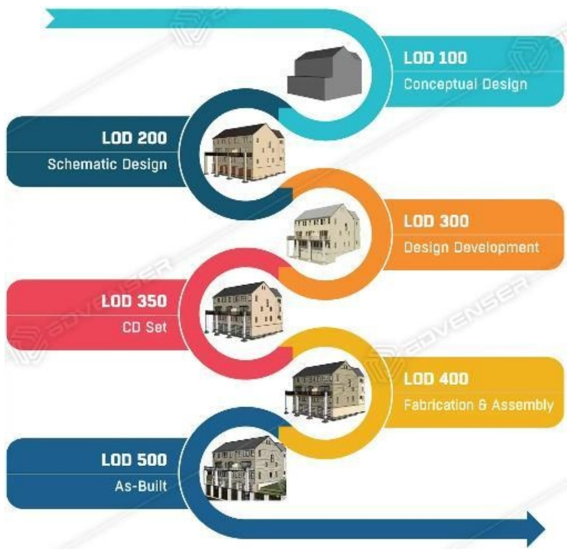


Figure 1. Levels of Development (LOD) for BIM as defined by the AIA.

The LODs associated with design are not applicable to built heritage. Given the complexities associated with existing structures, a minimum LOD of 300 is deemed necessary for HBIM. For refurbishment projects, achieving LOD500 is essential because the model must accurately reflect the as-built condition [17, 18].

Stakeholder priorities are integrated into complementary

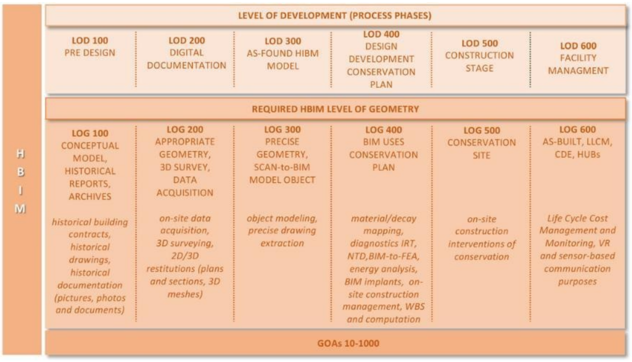


Figure 2. HBIM LOD proposal for the built heritage (Brumana, Stanga, and Banfi, 2020).

LOD guidelines for HBIM implementation, and a framework is presented for improving HBIM implementation by considering the needs of different stakeholders [15]. However, the study did not adequately address how to apply these guidelines to severely damaged historic buildings or post-conflict areas.

The emphasis was placed on defining specifications (GOA–LOG) for creating and reusing HBIM object libraries in a common data environment [18]. However, the study did not adequately address how to apply these specifications to severely damaged historic buildings. An overview of the current state of HBIM is provided in [19]; however, it did not provide sufficient details on how to apply different LOD levels to architectural heritage conservation projects.

3. RESEARCH METHODOLOGY

Thorough investigation and documentation of historic buildings lay the foundation for their conservation and the effective sharing of information [20]. To reach this goal, the research methodology is divided into five stages, as adopted from the design-science research methodology proposed by Peffers, Tuunanen, and Chatterjee [21]. In the first stage, the problem, or gap in knowledge, is identified through a literature review and analysis of published HBIM case studies. Identifying this gap assists in defining the research objectives. Data collection includes studying the current condition of the building, construction documents, and archival records.

The proposed solution's development includes identifying the priorities of stakeholders involved in built heritage, particularly in relation to standard HBIM applications, and establishing intervention strategies. This analysis informs the creation of a supplementary LOD framework tailored for HBIM. Ultimately, the supplement is validated through a case study that showcases its application in the development of specific building elements. An internal evaluation of the results provides insights into areas for improvement in future research.

3.1 Identify the Gap in Knowledge (Problem)

Previous studies focused on the use of HBIM in documenting European classical architecture using laser scanning and photographic techniques to create accurate HBIM models and develop a library of classical architectural elements. They were limited to European classical architecture, without significantly addressing Islamic or Eastern architecture, and did not address the challenges of applying HBIM in post-conflict or disaster areas. There is also a low level of detail achieved.

There are many problems and errors resulting from the use of traditional methods in documenting buildings in general and historical buildings in particular, as well as the absence of guidelines for reconstructing and restoring these important buildings under the current circumstances in these regions. This led to the need to understand the importance and effective impact of adopting building information modelling to preserve architectural heritage and its mechanisms and tools affecting architectural form as design, guidance, modelling, and calculation instruments; to mitigate human error as much as possible; and to create a model capable of supporting cooperation among different parties.

3.2 Define the Objectives

The most important objectives are to promote a strategy that facilitates the management of heritage-building restoration projects using historical building information modelling and to create a building information model with an advanced level of detail. The model will be used to:

- Coordinate between different specialties and identify conflicts.
- Extract all necessary drawings that the design company will be required to provide.
- Develop the LOD of these drawings based on the Industry Foundation Classes (IFC) level so that they can support building implementation.
- Ensure compatibility with software for detecting conflicts between disciplines and availability throughout the project life cycle (design, implementation, operation, and maintenance), allowing all or part of the model to be exported and imported.

3.3 Data Collection

Data collection includes:

- Researching and studying references related to historical buildings, their historical periods, and development over time.
- Collecting and documenting historical, cultural, and architectural information related to these buildings.
- Conducting a quick and comprehensive assessment of building conditions and identifying existing problems and damage.
- Documenting the current condition and studying it using photography, photogrammetric architectural surveys, architectural drawings, and other documents.

3.4 Development of the Proposed Solution

At this stage, the current state of the building is modelled using historical building information modelling software, the damage is shown on the model, and intervention methods are determined through which historical buildings can be restored and maintained.

3.5 Evaluation of the Results

The Al-Matbakh al-'Ajami case study demonstrates how archaeological buildings can be documented using HBIM by representing the building as an integrated database of physical and functional characteristics at an advanced LOD.

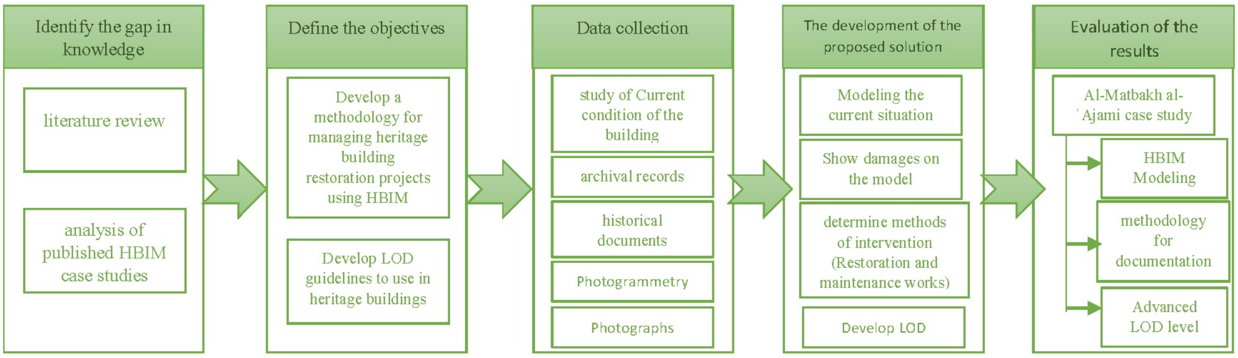


Figure 3. Research methodology diagram.

4. CASE STUDY—AL-MATBAKH AL-AJAMI—OLD CITY OF ALEPPO

4.1 Al-Matbakh al-Ajami Location

The building is located within the walls of the Old City of Aleppo, on the street opened between the Umayyad Mosque and Aleppo Citadel at the beginning of the 1950s. It is surrounded by tourist cafes and the famous old inns surrounding the citadel.

Figure 4. Al-Matbakh al-'Ajami location in the Old City of Aleppo (Syrian Heritage Archive Project using Google Earth, July 7, 2018).

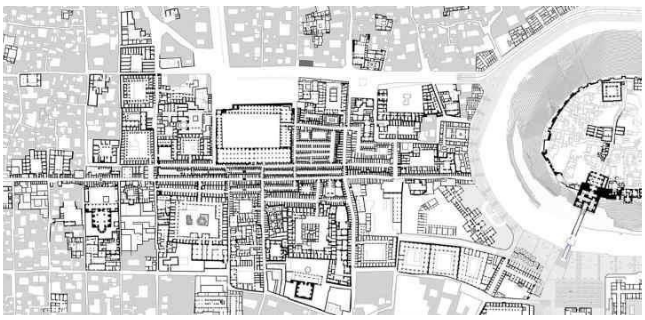


Figure 5. Al-Matbakh al-'Ajami location in the Old City of Aleppo (Syrian Heritage Archive Project after BTU Cottbus, 2016).

4.2 Historical Description of the Building

The building is the remains of a Zengi palace that was modified several times and was the residence of several prominent figures. It was built in the middle of the twelfth century AD, in approximately 1150 AD, as local historical documents indicate.

It was the House of Justice during the reign of Nur al-Din Mahmoud; then it was the residence of Ahmed bin Yaqoub al-Sahib during the Mamluk era; and afterward it was inhabited by Khayir Bey, the last Mamluk ruler. It was used as a workshop for a long period during the Ottoman era and as a museum of popular traditions from 1967 to 1975.

In 1999, it was revived with a traditional heritage function serving luxurious traditional cuisine related to the ancient traditions of Aleppo. The ground and first floors were occupied with luxury restaurant furnishings, while the middle floor was limited to a purely administrative function. In 2005, the General Directorate of Antiquities and Museums began internal restoration work aimed at turning it into a tourist investment. The building was destroyed to varying degrees because of the war, as discussed below.

4.3 Architectural Description of the Plan

The building is entered from the east through a long, winding, domed vestibule. It contains a large hall oriented along a north–south axis, covering approximately 500 m^2, and made up of an approximately square central void measuring about 9.30×9.80 m. A water pool lies in the middle, above which is a large dome (008.A). The heavenly space is surrounded by three corridors separated from it by wonderfully decorated columns dating to the Mamluk period.

To the south is a huge iwan (013.C), and to the north is a smaller one (005.A). On the east and west are two domed halls that open into the central courtyard. The side halls are entered through a large door, on either side of which are two small openings surmounted by smaller arches (002.A and 007.A).

From the southern iwan, one can enter two rooms. The eastern room is rectangular, with shallow iwan-like supports on three sides (014.C). The western room is covered by a semi-circular dome with a twelve-sided neck and windows. It is elongated westward through a hall covered by a carved-stone arch (015.C). The two rooms were completely demolished when the adjacent street was opened in 1950, and their features were removed during recent restoration.

At both ends of the small northern iwan are corridors and an entry vestibule that communicate with the other courtyards in a well-known classical style. The northeastern entrance (004.A) currently converges with the main entrance corridor, while the northwestern entrance (006.A) allows entry to a small open courtyard containing a stairway to the roof (012.B).

To the north is a large hall with different architecture, oriented along an east–west axis (008.B). Together with the entrance corridors, it covers an area of less than 100 m^2. It consists of a central square courtyard with a side length of 5 m, covered by a twelve-sided dome without a neck and surmounted by an octagonal upper opening. The dome is centered on a very short elevation above triangular overhangs common in buildings from the twelfth and thirteenth centuries through the Ottoman period, but later replaced by spherical double pendentives.

To the west, a large iwan opens with a low convex arch. To the east is a hall entered through a pivoting door surmounted by a low arch on a wooden lintel. Researchers consider this hall one of the rare examples of Mamluk-period residential halls found in Aleppo. To its north is a small hall covering approximately 30 m^2, organized around a central courtyard covered by a dome. This hall may have been part of a private bathroom (010.B).

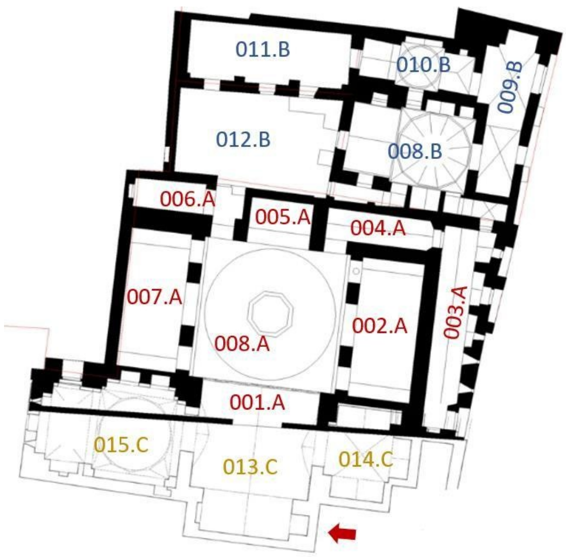


Figure 6. Plan of the Al-Matbakh al-'Ajami building.

4.4 Stages of Work

4.4.1 Study the Current Condition and Assess the Damage

Damage resulting from the war was determined based on a study conducted in 2017 by the Directorate of Antiquities and Museums in Aleppo to identify damaged elements, together with a German study conducted in 2020 as a rapid damage assessment within the Syrian cultural heritage documentation project by A. Haddad, I. Ballouz, R. Alafandi, and Y. Rieffel. Field visits and the researcher's 2024 study also documented the increasing damage caused by the devastating 2023 earthquake.

4.4.2 Determine the Purpose of Using HBIM

The purpose is to restore and rehabilitate the Al-Matbakh al-'Ajami building using the latest technologies, obtain quick and accurate outputs, and apply this methodology to subsequent similar projects.

4.4.3 Required Level of Detail (LOD)

The LOD expresses the amount, quantity, accuracy, and reliability of information present in each building element that can be included in the digital model of the Al-Matbakh al-'Ajami building, and the extent of its development at each stage of the building life cycle. Development begins at LOD200 and continues until LOD500. Five main groups of elements are distinguished:

- Partially hidden structural and architectural elements—walls, floors, ceilings, and domes for the rest of the building—at LOD200.
- Structural and architectural elements in the southern facade and main hall—wooden lintels, walls, domes, openings, and doors—at LOD300.
- Architectural elements in the southern facade and main hall—windows, doors, and niches—and representation of building damage at LOD350.
- Architectural elements in the southern facade and main hall, including damage and decorations, at LOD400.
- Architectural elements and decorations in the southern facade and main hall at LOD500.

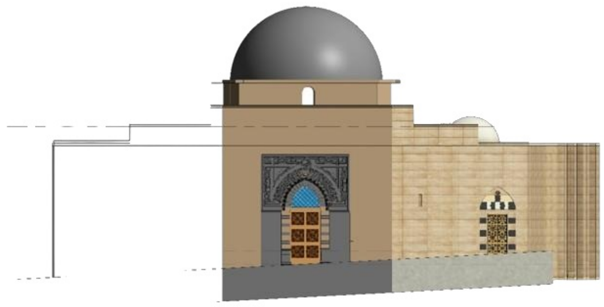


Figure 17. Work progress at different LOD levels from LOD100 to LOD500.

4.4.4 HBIM Modeling

An initial, non-detailed HBIM model was built using Revit, and preliminary information and specifications for the Al-Matbakh al-'Ajami building were entered. After collecting information, studying the current situation, and developing a clear vision of the building through photogrammetry and photography, the level of detail can be considered LOD100. The initial model then reaches LOD200 so that the building appears in general form and includes the main building elements, such as walls, floors, and domes, without additional information such as details and materials.

Accordingly, the AutoCAD file containing the project was exported to Revit to begin the modeling process, and the building heights were determined as they appear on the facade.

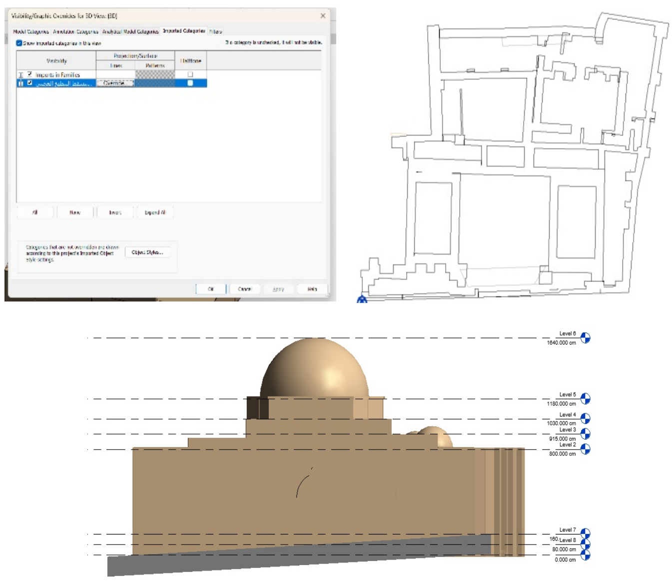
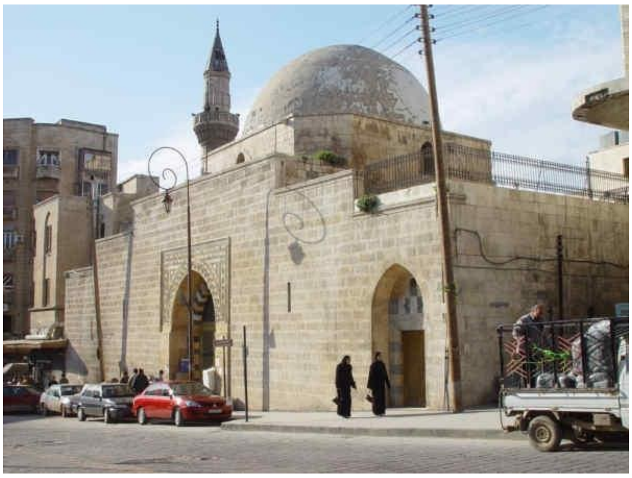


Figure 18. Initial HBIM workflow: importing AutoCAD data into Revit and defining the building heights.



(a) Before the armed conflict.

(b) After the armed conflict.

Figure 7. Al-Matbakh al-'Ajami before and after the armed conflict.

Figure 8. The dome of the large hall before the war.

Figure 10. Increased deterioration in the dome of the great hall after the earthquake.

Figure 9. Major collapse in the dome of the large hall after the war.

Figure 11. Corner squinches before the armed conflict.

Figure 12. Collapse of the southeast corner apse.

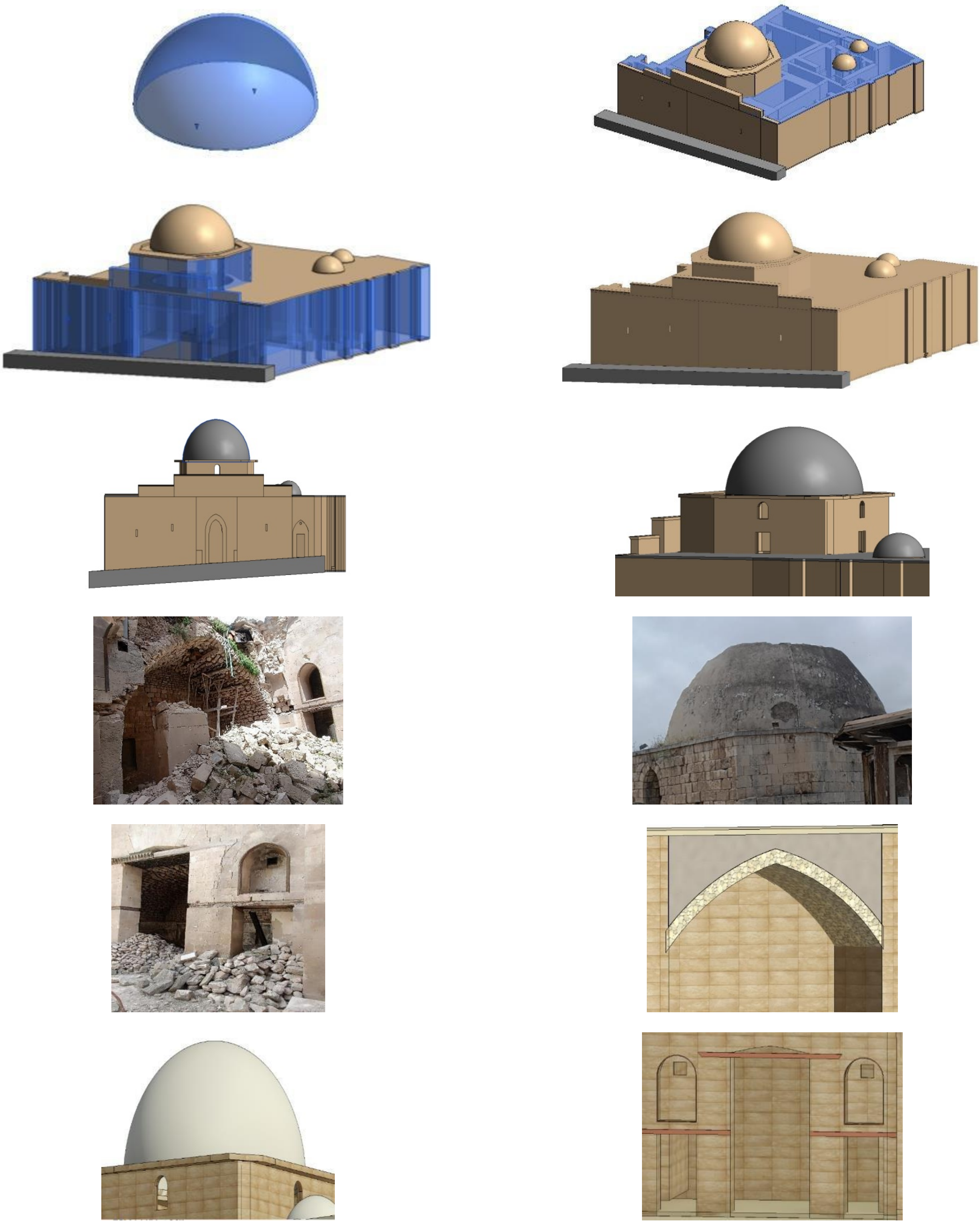
Figure 13. Collapse of the northwest corner apse.

Figure 14. The western wall in the main hall before the armed conflict.

Figure 15. Partial collapse of the western wall of the large hall.

Figure 16. Complete collapse of the western wall of the large hall.

Various structural and architectural elements were then built to produce a prototype at LOD200. During development from LOD300 to LOD350, information was added regarding the locations of window and door openings, the building's structural system, and the materials used in construction.



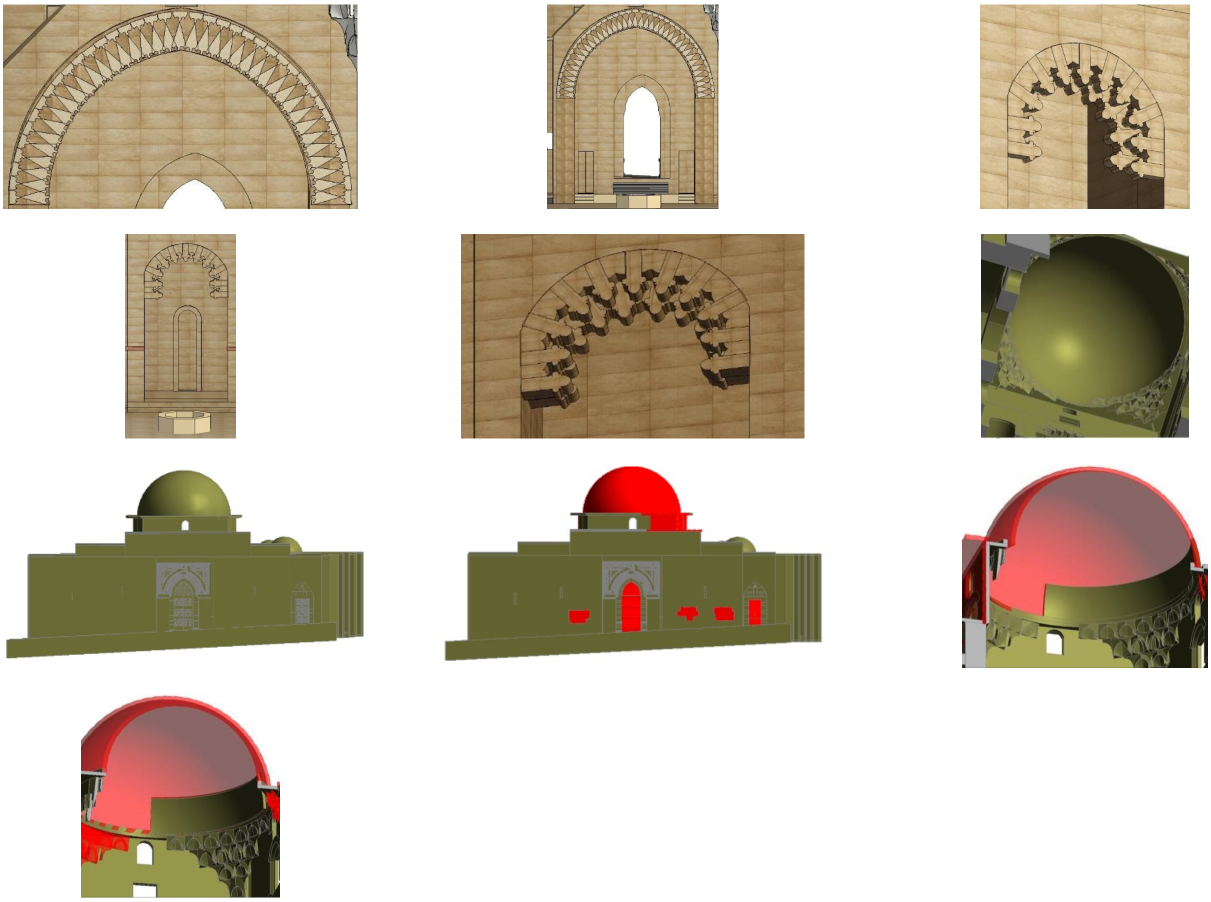
Development of structural and architectural elements from LOD200 to LOD350, including openings, construction materials, and corresponding site conditions.

More details were added until the model reached LOD350, including the small stone arches that transfer pressure above stone windows and doors and the mihrab in the inner wall of the small northern iwan. Modeling at LOD400 represented the building's current state, showed selected architectural details, and clarified damage on the model.

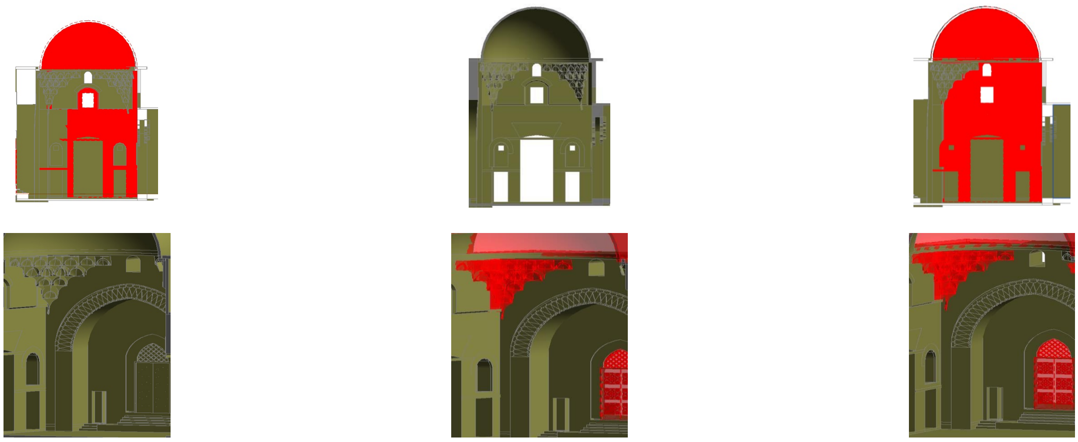
The ablaq stone used to decorate the main and subsidiary doors consists of rectangular stone courses in three colors—black, white, and yellow—overlaid with beautifully and harmoniously curved lines to create a unique decoration.

The architectural detailing stage included the decorations of the large arch on the inner southern facade of the main hall and the decorations of the northern iwan arch. Damage assessment was then represented directly on the model in pre-war, post-war, and post-earthquake states.

LOD350 and LOD400 modeling outputs: openings, mihrab, current-state geometry, and ablaq-stone details.



Architectural detailing and damage-assessment views for the large hall and northern iwan.



Damage-assessment states represented at LOD400 before selecting the restoration and maintenance interventions.

Intervention methods. The methods used for the restoration and rehabilitation of the Al-Matbakh al-'Ajami building can be classified as follows:

- **Architectural preservation and maintenance (conservation):** using additions and supporting materials that preserve the building's structure, ensure its continuity, minimize damage, and adapt it to rapid changes caused by war and earthquake.
- **Rehabilitation:** restoring, renovating, protecting, maintaining, and reusing parts of the building, while improving the roads leading to it and providing necessary infrastructure, facilities, and services by examining the water, sewage, electricity, and telephone networks.
- **Restoration and renovation:** returning the building to its original condition before the destruction suffered during the war and earthquake.
- **Adaptive reuse:** investing in and proposing new uses suited to current development.

The 3D building model was developed to reach the final model after reconstruction at LOD500.

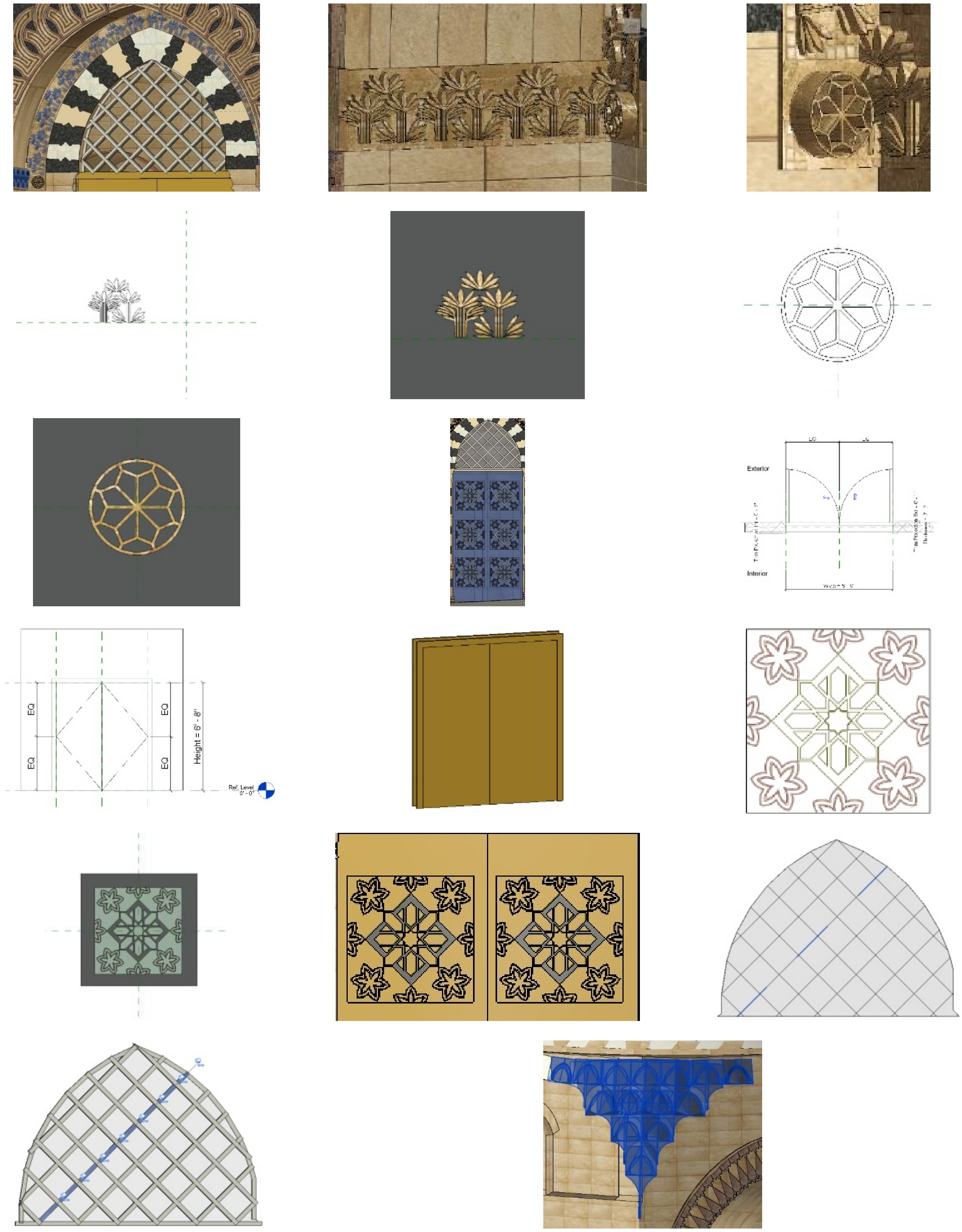
The architectural details in the Great Hall and the main southern facade were completed in three ways: (1) creating families in place for model-specific elements such as walls and arches; (2) creating external files that can be modified and reused for categories such as doors and windows; and (3) creating elements in auxiliary programs such as AutoCAD and exporting them to the HBIM model to obtain accurate geometric forms.

Main-door decorations. A high level of decorative detail was achieved by drawing each door component separately and later assembling the parts into the original model. The outer frame and terraces were created in an external file with the Sweep command, a Reference Plane, assigned parameters, a drawn section, and stone material. Interlocking stone decorations were developed partly in AutoCAD and completed in Revit with extrusions at several dimensions and separate materials. Floral decoration surrounding the pointed arch and circular pediment was created in an external file, transferred to the project, and repeated along the pointed-arch path.

Main-door ornament documentation and modeling sequence, including the frame, terraces, interlocking stonework, and floral decoration.

Ornate copper door. For the lower part, an external door family was imported, modified in dimensions and material, and exported to the original project file. Decorations were drawn in AutoCAD, exported to an external family, extruded, and transferred to the original model. The upper part was created as a curtain wall with diagonal axes at both ends and an aluminum construction.

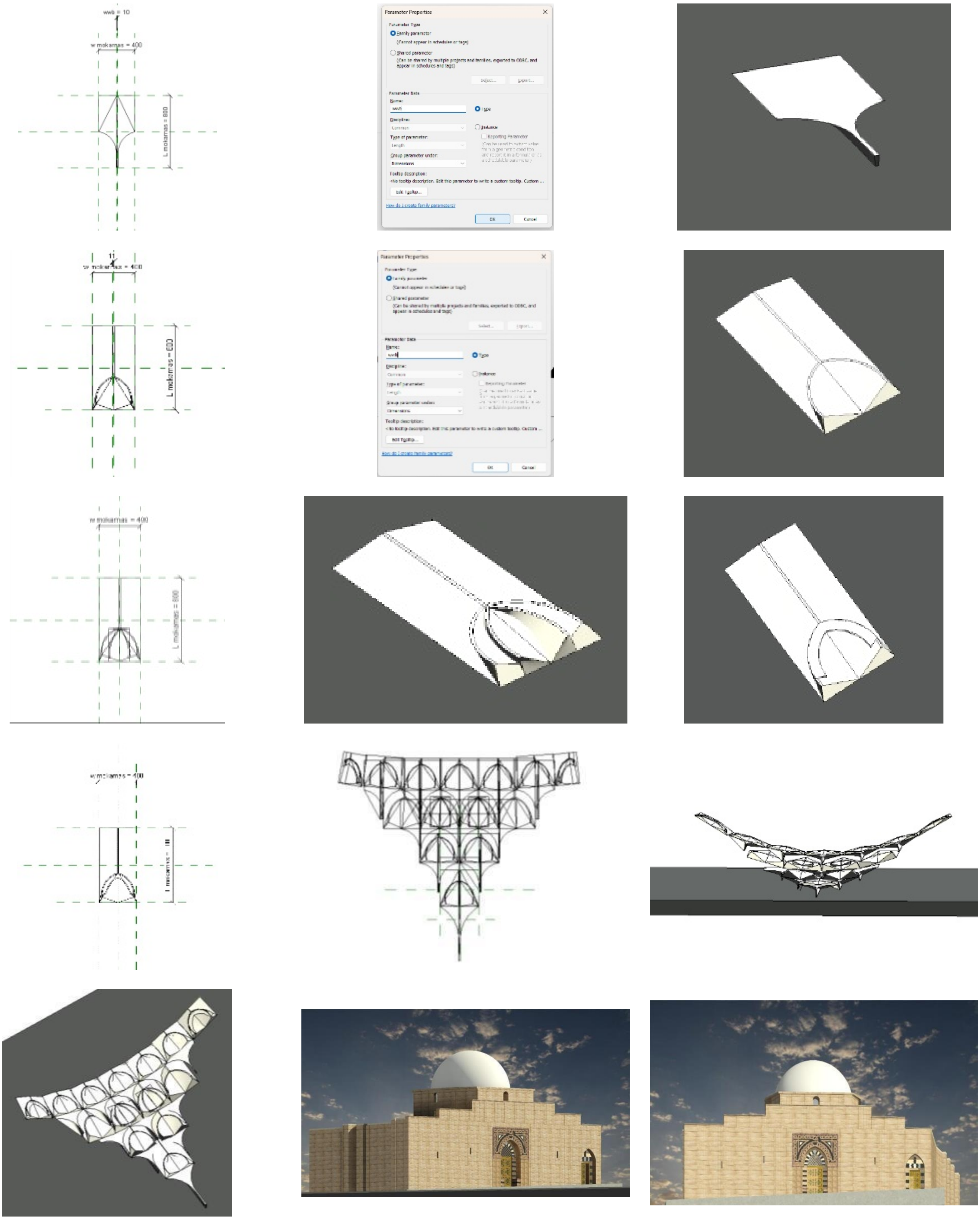
Corner squinches (muqarnas). This complex form was created using several external files and the Blend command, compiled into one file, and installed at several levels along a curved shape. The form results from fitting several component shapes together.



Floral-decoration and copper-door modeling details, followed by the initial muqarnas development.

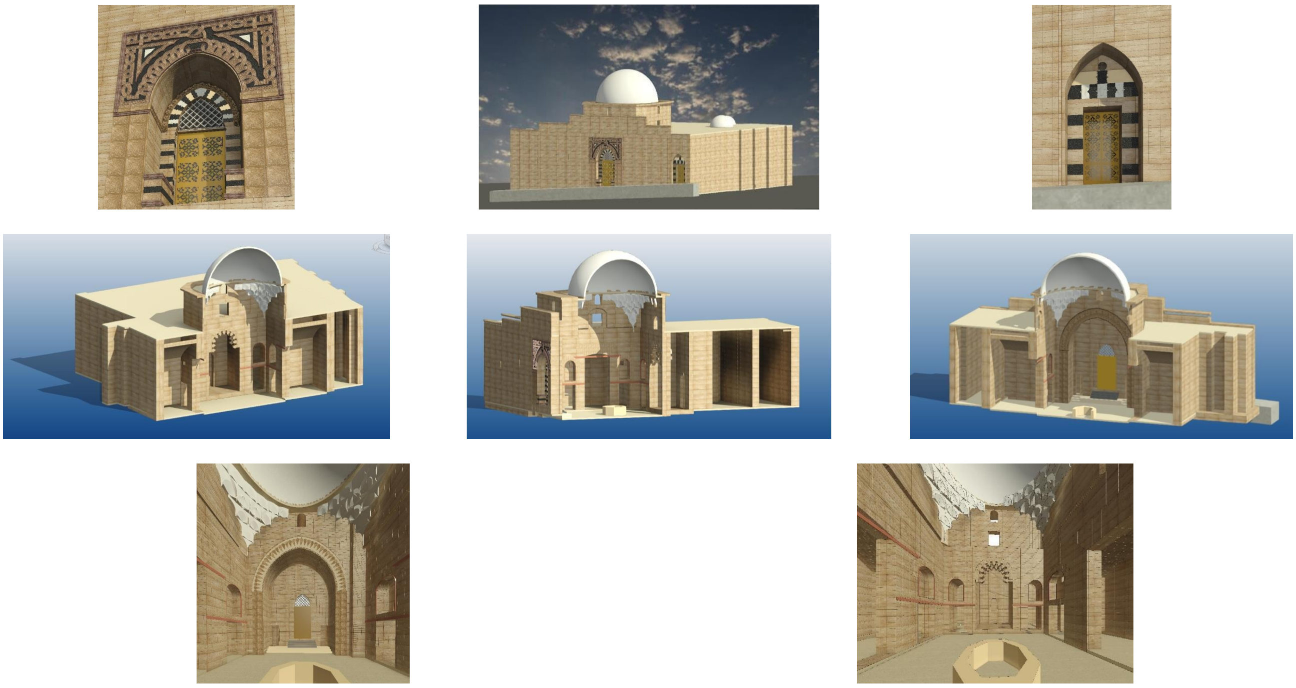
The muqarnas components were assembled in one file and installed at several levels according to a curved shape.

Final model after rehabilitation and reconstruction. After developing the work through the previous stages and multiple levels of detail from LOD100 to LOD500, the building was returned to its previous state and its general form improved without distortion. The final three-dimensional model of the studied part of the Al-Matbakh al-'Ajami building was thus completed with its architectural details.



Muqarnas component development and assembly, followed by exterior views of the rehabilitated building model.

Illustrative perspective sections show parts of the building and details in the main large hall, including interior views of the reconstructed space.



Final model perspectives and interior views of the main large hall.

5. CONCLUSION

The research is distinguished by its focus on the local context of the Old City of Aleppo, which represents a valuable addition compared with previous studies focused on other contexts. The approach takes into account the city's specific cultural, technical, and economic characteristics, ensuring the suitability and applicability of the proposed solutions.

The research directly addresses challenges resulting from conflicts and natural disasters. This is particularly important in crisis-affected areas, where heritage-preservation operations face unique challenges requiring practical and applicable solutions. By using digital technology, specifically Historical Building Information Modeling (HBIM), as a key tool for preserving Aleppo's architectural heritage, with a particular focus on LOD levels, the approach opens new horizons for digital technologies in heritage preservation and contributes to developing traditional practices and enhancing their efficiency and effectiveness.

The research also adopts a comprehensive and integrated approach, addressing the various stages of preserving architectural heritage using HBIM, from documentation and evaluation through design and restoration. This approach ensures the integration of efforts and maximizes the benefits of HBIM in heritage-preservation projects.

6. RECOMMENDATIONS

1. **Develop national guidelines for applying HBIM in architectural heritage conservation projects.**
    - Establish unified standards for documenting architectural heritage using HBIM while considering the specificity of each region.
    - Develop procedures to ensure the quality of models and data produced through HBIM.
    - Establish a national library of heritage architectural elements to facilitate modeling.
2. **Develop a methodology for applying HBIM in post-conflict and post-disaster areas.**
    - Develop a framework for using HBIM in reconstruction planning and managing heritage-conservation projects.
    - Develop a methodology for documenting severely damaged buildings using HBIM, focusing on assessing the current condition and identifying intervention priorities.
    - Establish a national database of HBIM models for damaged heritage buildings to facilitate restoration and rehabilitation.
3. **Promote sustainability and use HBIM in heritage-building life-cycle management.**
    - Use HBIM in life-cycle management, including regular maintenance and restoration.
    - Encourage research and development in HBIM applications for preserving architectural heritage in post-conflict and post-disaster areas.
4. **Spread awareness and use of HBIM in education and training.**
    - Raise awareness among practitioners of the importance of HBIM in architectural heritage preservation.
    - Incorporate HBIM into architectural and engineering education programs.
    - Organize training courses to qualify national cadres in the use of HBIM for heritage-preservation projects.

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