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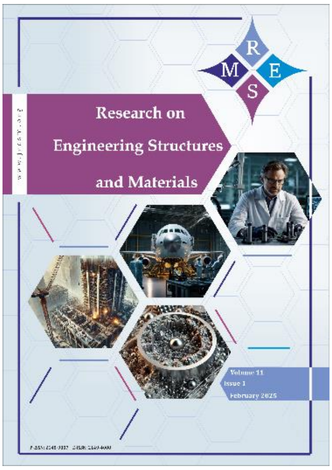

Using digital modelling for the partial reconstruction of Sheikh Al-Arab Hammam citadel, situated in Farshout, Qena, Egypt

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Research Article

Using digital modelling for the partial reconstruction of Sheikh Al-Arab Hammam citadel, situated in Farshout, Qena, Egypt

Essam H. Mohamed

Archaeological conservation Dept., Faculty of Archaeology, South Valley University, Qena, Egypt

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Abstract

This article proposes the virtual partially reconstruction of the missed architectural units of the citadel of Sheikh al-Arab Hammam that is located in the western mountainside, north of al-Arki village in Farshout, Qena, Egypt. In order to achieve this, the following methodology was followed: Evaluation of the current state of the citadel by two methods: firstly, evaluation of building materials by several scientific techniques, and secondly, evaluation of the structural condition of the building by numerical analysis based on finite elements method (F.E.M.). This research presents the virtual reconstruction of the citadel by Building Information Modeling, "BIM". A 3D virtual reconstruction of the citadel has been based on the archived documents in National Books and Documents House. AutoCAD (2022), Extended 3D Analysis of Building System (ETABS-2023), and Autodesk 3D Max (2022) were used to get plans, elevations, and details of the citadel with real dimensions and the appropriate drawing scale, which aim to revive the citadel and provide a way to document it. By evaluating the current status of the citadel, it was found that there are weaknesses in the properties of building materials such as High porosity and water absorption and low resistance to compressive stresses, as well as the exposure of most of the citadel walls to tensile stresses higher than the permissible limit, in addition to the missing architectural units. The study concluded that it is necessary to improve the properties of building materials and carry out restoration work for the various symptoms of damage.

1. Introduction

Although adobe architectural hasn't gotten as much scholarly attention as stone architecture, mud-brick architecture was actually more prevalent in all time periods throughout Egyptian history. Unfired brick made from mud, river, or desert clay was used as the main building material for the various buildings such as citadels, mosques, monasteries, and houses [1].

Adobe architecture provided a more comfortable and versatile living and working environment compared to stone buildings. It was also more affordable and technically straightforward to construct walls and vaults [2]. Mud bricks are a part of masonry structures. Since it is an essential component of a wall mass, it must be understood both structurally and chemically. The type of raw materials used, the construction methods used, the location, the microclimatic conditions, and the mechanical and microstructural characteristics of the brick itself all affect how susceptible a mud brick is to deterioration agents [3]. Adobe buildings' durability depends on factors like soil type, construction techniques and regional climate [4, 5]. Clay sediments, commonly found in deltas and near construction sites, are the primary component of mud bricks [6]. Despite their widespread historical use, mud bricks are vulnerable to mechanical damage due to environmental factors,

*Corresponding author: essam.mohamed@arch.svu.edu.eg
[a]orcid.org/ 0000-0003-0695-6997
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temperature changes carried on by sunlight or water influence, such as rainfall or seepage water carried on by variations in groundwater levels [7]. Because of atmospheric conditions that deterioration of clay bricks, buildings made of these materials are destroyed, necessitating ongoing restoration [8]. This study examines a military citadel, a significant historical building witnessing events between Prince Hammam and Ali Bey al-Kabir during the Mamluk army's invasion of Farshut, Egypt [9,10]. The citadel suffered intentional destruction, resulting in architectural units' loss and physical deterioration, in addition to its poor physical condition as a result of neglect and exposure to many different damage factors. Since the late 20th century, "virtual archaeology" leverages digital technologies to simulate and reconstruct the past [11]. Advances in video game industry technology enable improved quality and accessibility [12, 13, 14]. Virtualizing heritage involves conserving, reproducing, representing and digitally reprocessing cultural evidence using advanced virtual reality imaging [15, 16]. We live in an era of significant technical innovation. Mechatronic systems optimize computing, enhancing efficiency and effectiveness [17]. Interdisciplinary knowledge structures hierarchies for cultural heritage protection [18,19,20]. Recent studies highlight 3D GIS and BIM significance in conservation [21,22,23]. Digital models, accurate and detailed virtual reproductions, result from survey phases preceding cultural heritage digitization [24,25]. Reverse engineering produces scaled models, coherent in metric terms, enhanced with material aesthetic appearance and reflectance qualities [26, 27,28]. Digital models, accurate and detailed virtual reproductions, result from survey phases preceding cultural heritage digitization [29, 30]. Reverse engineering produces scaled models, coherent in metric terms, enhanced with material aesthetic appearance and reflectance qualities [31].

The underlying assumptions of Historical Building Information Modeling (H-BIM) differ from those of BIM applications for new structures since architectural heritage objects must have historical, cultural, and social parameters included when taking into account the building's identity. The three key issues that the architectural BIM model must address are "what," "why," and "how" each component that has to be replaced was constructed. It is not always necessary to create a 3D model of the complete structure, but often only a part of it is sufficient [32, 33].

The present study aims to:

- Monitoring various symptoms of damage.
- Evaluation of the building's current state informs material properties and structural behavior [34].
- The evaluation process identifies and categorizes citadel deterioration symptoms, focusing on material degradation and architectural integrity.
- Precise structural assessment may help to have better restoration methodologies.
- Conservation strategies require comprehensive risk assessments and material evaluations.
- The current status report may provide the basis for targeted interventions and restoration strategies.
- This study presents a virtual module approach for reconstructing missing architectural units of historical citadels, facilitating accurate restoration and preservation.

2. Sheikh Al Arab Hammam Citadel

2.1. Historical Background of The Citadel

In The eponymous Sheikh al-Arab Hammam Citadel commemorates Prince Sharaf al-Dawla Hammam ibn Yusuf bin Ahmad ibn Muhammad bin Hammam (1709-1769/1121-1183 AH), an influential leader in Upper Egypt's Farshût region. Sheikh al-Arab Hammam Citadel (18th century) was built by Prince Hammam bin Youssef to protect Farshout. It witnessed the war between Ali Bey al-Kabir and Prince Hammam, enduring destruction by the Mamluk army. The Sheikh Al Arab Hammam Citadel's walls stand testament to traditional construction techniques. Composed of mud bricks forged from Nile-sourced straw, sand and silt, the structure's 22x7x7 cm bricks showcase precise alternating headers and stretches. Excavations revealed foundations built upon a single layer of mud bricks, merely 15 cm high [35,36].

2.2. Architectural Design Of The Citadel

The Prince Hammam citadel's main building covers around (2,156) m^2. It has four facades, the eastern façade is the major façade, and it looks out over the main road that leads to the village. This facade is (47.5) meters long and 6 meters high, extending from north to south. The citadel's southern tower, which is square in design and measures (5.25) meters on each side and (7) meters in height, is situated at the southern end of this facade. It extends (4.4) meters from the southern facade and (2) meters from the eastern facade. At a distance of five meters north of this tower (Fi. 1). The western façade is stretching (40) meters from north to south. The citadel's western tower rises in the southern half of the wall, dividing it into two sections: the (1.1) m long section facing south, followed by the (5)m long tower block, and the (23.5) m long section facing north. This facade is comparable to its structure, and its aesthetics are consistent with the other citadel facade, and it features viewing openings.

The citadel's southern façade, which is its secondary façade, looks out over the remains of the military barracks. Its design is similar to that of the main façade, and it is (47.5) meters long and 6 meters high, extending from east to west. Its easternmost point is the castle's eastern tower, while the secondary entrance is (15) meters away. The structure attached to the citadel is visible from the 48-meter-long northern façade, which runs from east to west. It is composed of two parts: the eastern part is (21) meters long and extends (3.5) meters from the western part, and the second component is 21 meters long and extends westward, with a length of (27) m. The southeast corner of the castle is home to the southeast corner tower. It is square in shape, with a side length of (5.25) m and a height of (7) m. It consists of two floors. The first floor is covered with a shallow dome supported by spherical triangles, and the second floor is exposed. The Western Tower is located on the western façade, (11.5m from its southern end. It is square in shape, with a side length of (5) m. It consists of two floors. The first floor is roofed with a hemispherical dome supported by spherical triangles, and the second floor is exposed. After entering through the main entrance of the citadel, which is located on the eastern wall, we see a huge courtyard whose sides, from east to west, are (9.25) m long and from north to south, (8.25) m. This courtyard opens onto a corridor that is (29.5) m long and (3.25) m wide as we head north. With a length of (19.5) m and a width of (2.6) m, it moves north until breaking to the west. A door leading south across the courtyard in front of the main entrance leads to an open architectural block that has two square rooms on the east side. This architectural block had a second level that led to the southeast tower.

Fig. 1. General site of Sheikh al Arab Hammam citadel (Google map: https://www.google.com/maps/@26.011198,32.1626764,1624m/data=!3m1!1e3!5m2!1e1!1e4?entry=ttu&g_ep=EgoyMDI1MDExNC4wIKXMDSoASAFQAw%3D%3D)

3. Present Condition of The Citadel

The Sheikh Al Arab Hammam citadel's building materials were deteriorated due to multiple factors, including intentional destruction, resulting in architectural units loss and physical deterioration, in addition to its poor physical condition as a result of neglect and exposure to many different damage factors such as, man-made deterioration, human activity and neglectance, lack of Maintenance: Inadequate preservation accelerates decay, also climatic conditions: temperature, humidity, wind, and rainfall accelerate deterioration, biological degradation, vandalism, temperature and humidity fluctuations, structural damage, elevated groundwater levels and contaminated soil saturation. All the aforementioned causes of deterioration have led to the emergence of several symptoms, including the following: The citadel shows significant loss of its architectural elements, either partially or entirely, and detachment and losing of considerable areas of plaster layers. In addition to Human actions have led to the deterioration and loss of wall sections, the adobe materials exhibit significant thermal-induced deterioration, characterized by: Temperature stresses causing tiny cracks/fractures, plaster degradation and disintegration. Facade's damage: Detachment and losing of considerable areas of plaster, fissures, cracks, missing parts of walls, and partial collapses and losses of bricks and mortar in walls (Fig. 2). The mud-brick structures were susceptible to deterioration due to rainfall and solar exposure, exacerbated by human activity. Climate change and human intervention are primary factors in the degradation of earthen fortifications. Removal of the protective silt layer exacerbated degradation processes, affecting the citadel's mud-brick structure. The exposure duration and neglect of buildings significantly impact mud-brick deterioration, both qualitatively and quantitatively.

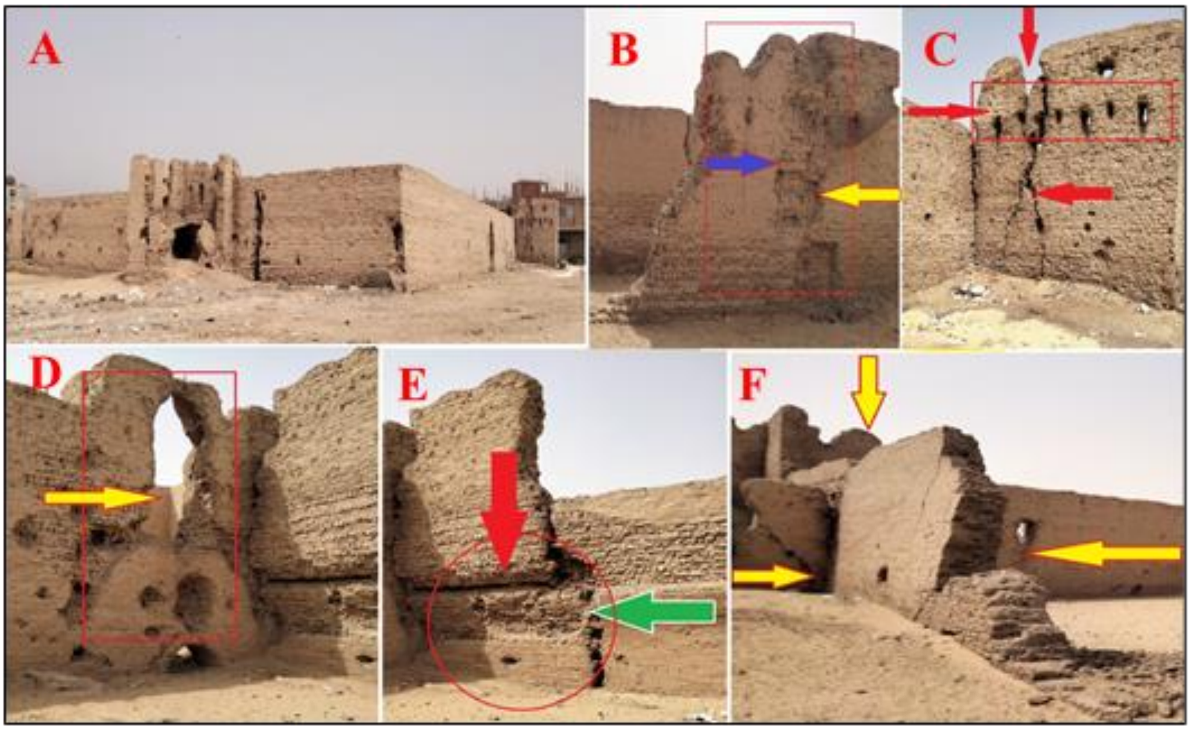


Fig. 2. A. Shows the western façade of the citadel. B. loose parts of the wall. C. fissures in along the wall (western tower). D. loose parts of the wall due man-made deterioration. E. Partial collapse and separation in the wall. F. loose parts and slanting in the wall.

4. Materials and Methods

4.1. Materials

Mud brick samples were collected from the detached and fallen parts of the citadel's walls, the studied samples were cut into cubes 4 × 4 × 4 cm in order to conduct physical and mechanical properties tests.

4.2. Methods

4.2.1. Examination and Mineralogical Composition

Mineralogical composition analysis of mud brick samples carried out using X-ray diffraction (XRD) on a Philips PW 1840 diffract meter (Cu-Kα radiation, 40 kV/40 mA, 2θ: 5-50°). XRD analysis characterized mud brick mineralogy between 5° and 50° 2θ.

Petrographic characterization employed ZEISS Axio Imager. A1m Polarized Light Microscopy (PLM) at 20× magnification. Deteriorated mud brick samples were examined using an Olympus BX40 optical stereo microscope with digital camera recording at 40-60× magnification. Microstructural and chemical analyses of deteriorated mud brick samples were performed using Scanning Electron Microscope (SEM) Model Quanta 250 (FEG) Field Emission Gun (Accelerating voltage 200V-30kV Operating Voltage 5-30kV, Magnification: 30X- 300kX) coupled with X-ray energy dispersive system (EDS) with accelerating voltage 30 K. V., Magnification (14X) up to (1,000,000) and resolution for Gun. In, K550X Sputter Coater, England.

4.2.2. Physical and Mechanical Properties of Mud Brick

The properties of building materials of the citadel carried out according to (ASTM C62-17). The bulk density was calculated by the following Eq (1):

$$\rho\, dry = \frac{M(solid)}{V(total)} \tag{1}$$

Where, ρ = density, m = mass, V = volume. The water content was calculated by the following Eq (2):

$$WC = \frac{W2 - W1}{W1} x100 \tag{2}$$

Where, W_1= sample weight after drying, W_2= sample weight before drying. Compressive strength carried out according to (ASTM C67/C67M-19). The compressive strength of mud brick was calculated by the following Eq (3):

$$Compressive\ strength, C = \frac{P}{A} \tag{3}$$

Where, P= maximum recorded load indicated in testing machine (N), A= Average of the gross of the upper and lower bearing surface of the specimens mm^2.

4.2. Structural Analysis of The Citadel

3D numerical model of the citadel carried out using the finite element (FE) software (ETABS). The aim was to understand the structural behavior under the different loading conditions that citadel had subjected to. These loading included the self-weight and earthquake. ETABS 2021 was used to simulate the structural response of Sheikh Al Arab Hammam Citadel to own weight and earthquake loads, using the finite element (FE) with shell elements for walls. Data of building materials properties have been entered into ETABS software. Earthquakes loads were calculated in two orthogonal directions (X-X) and (Y-Y), structural elements were represented with consideration that the walls as load-bearing walls [37].

When calculating stresses due to loading on a building, it's essential to consider the following factors:

- Building design and construction details
- Type of materials used
- Site conditions and climate
- Architectural and engineering standards and specifications

4.2.1. Self-Weight Stress

The self-weight stress (σ) can be calculated using the following Eq (4):

$$Self - weight\ stress\ (\sigma) = (W \times g\ /\ A)$$
$$\text{Self} - \text{weight stress } (\sigma) = \left(\frac{14290 \times \text{g}}{559.03}\right) = 250.60 \text{ kPa} \quad (4)$$

Where, σ= self-weight stress, W= self-weight of the building = 14290 ton, g: acceleration due to gravity= 9.8 g , A= cross-sectional area of the building = 559.03 m^2 . The resulting value from the equation (250.60 kPa) is the maximum allowable stress of the building under its own self-weight. The self-weight induced stress values derived from the finite element method of the building are calculated to be 2000 KPa. Which appears as shown in (Fig. 3) deformation that appear in dark orange and dark green in the corners of the building. The deformations are shown in dark green and dark orange at the corners represent the maximum stress the building is exposed to, which is equal to 2 MPa.

4.2.2. Earthquake Stress

The earthquake stress (σ) can be calculated using the following Eq (5a):

$$Earthquake\ stress\ (\sigma) = (S \times W)/(A) \quad (5a)$$

$$Earthquake\ stress\ (\sigma) = \frac{1 \times 14290}{559.03} = 250.60\ KPa \quad (5b)$$

where: σ: earthquake stress, S: seismic coefficient (dependent on building location) = 1,W: self-weight of the building =14290 ton, A: cross-sectional area of the building = 559.03 m^2 ,Eq (5b). The resulting value from the equation (250.60 KPa) is the maximum allowable stress of the building under earthquake stress. The resulting value from the equation is the average shear stress of the building under earthquake loading. The earthquake induced stress values derived from the finite element method of the building are calculated to reach 5000 KPa due to stress concentrations in two orthogonal directions (X-X) and (Y-Y) as shown in (Fig. 4 - 5)

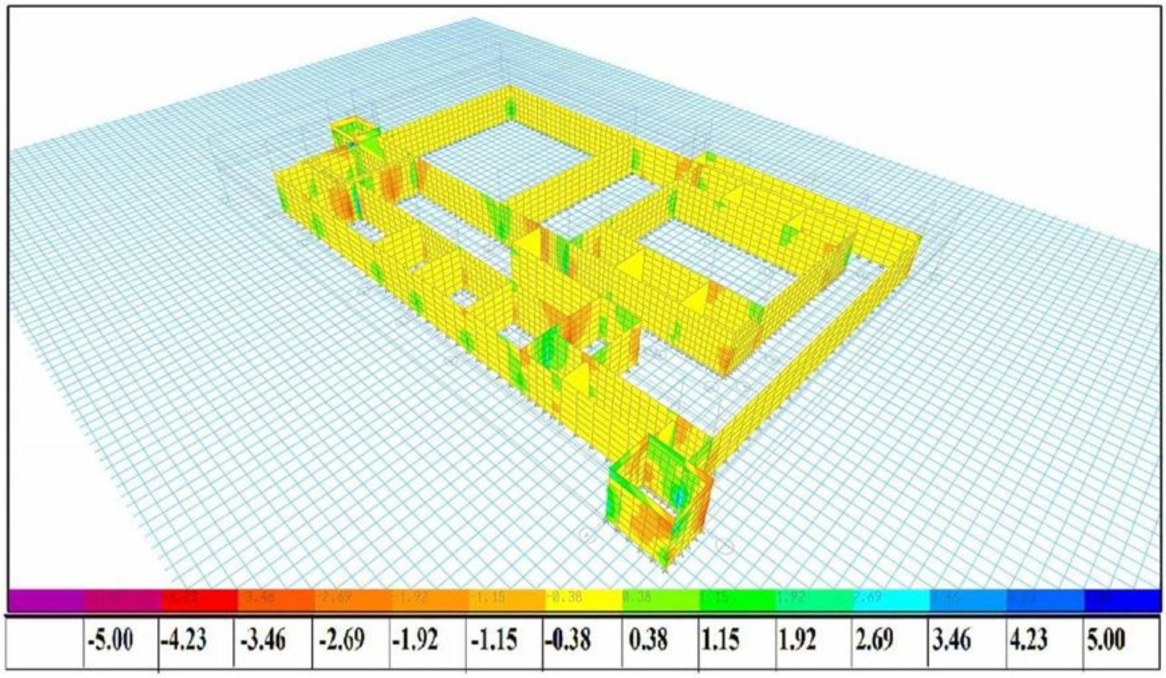


Fig. 3. Variation of the stresses (self-weight stress) in considered building (MPa)of the citadel walls.

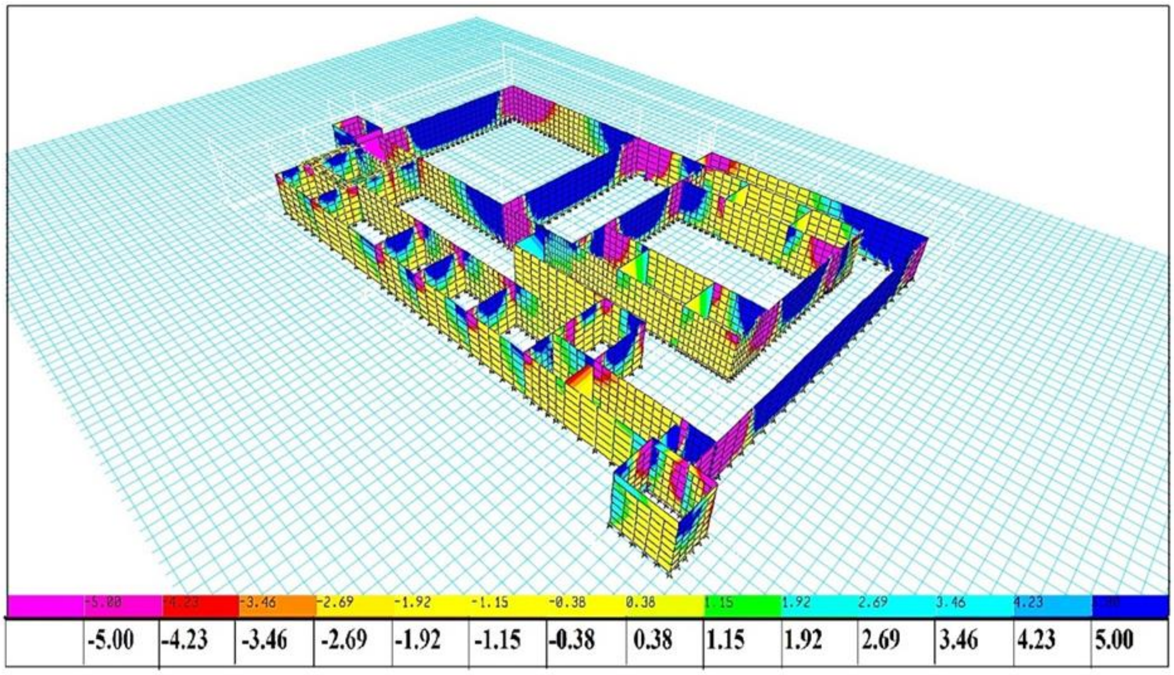


Fig. 4. Locations of the maximum principle stresses (earthquake stress) (MPa) in direction (X-X)of the citadel walls

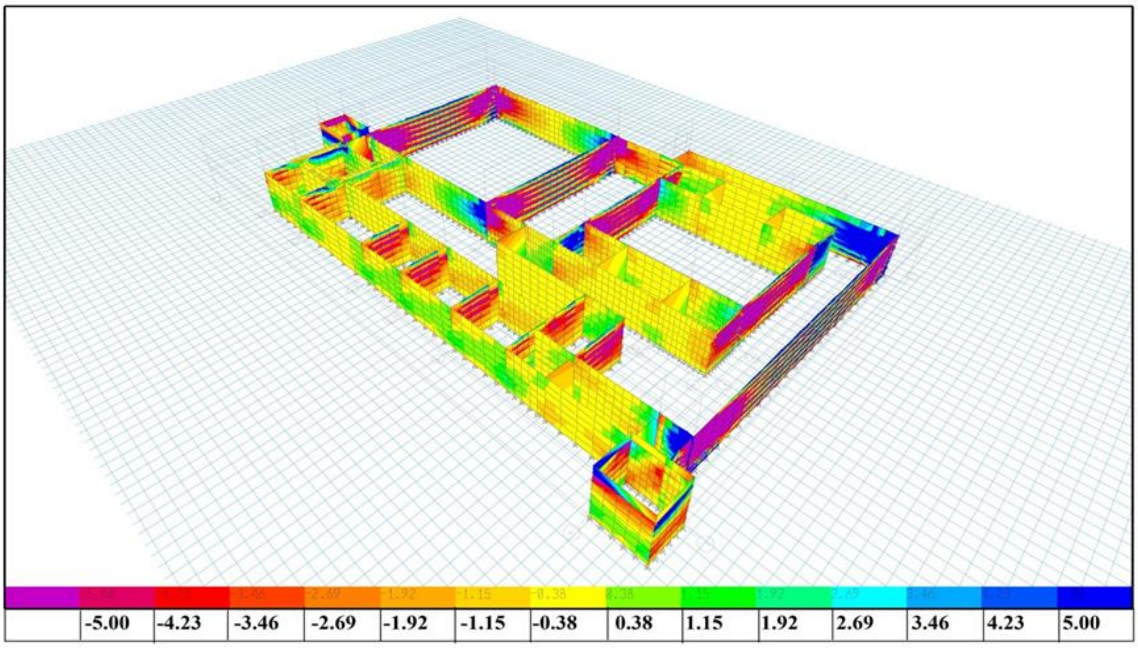


Fig. 5. Locations of the maximum principle stresses (earthquake stress) (MPa) in direction (Y-Y)of the citadel walls

5. Building Information Modelling for the Partial Reconstruction of The Citadel

5.1. Documentation of the Citadel

The study commenced with a comprehensive review of the building's historical, architectural, and construction significance, followed by material evaluation and structural analysis. A virtual model of the archaeological building was subsequently developed.

5.1.1. Archaeological Documentation

Sheikh Al-Arab Hammam Citadel (12th century AH/18th century AD) is a prominent Ottoman-era military fortification, officially registered as a monument under Prime Minister Resolution No. 2661 (2011) and Minister of Culture Resolution No. 661 (2011).

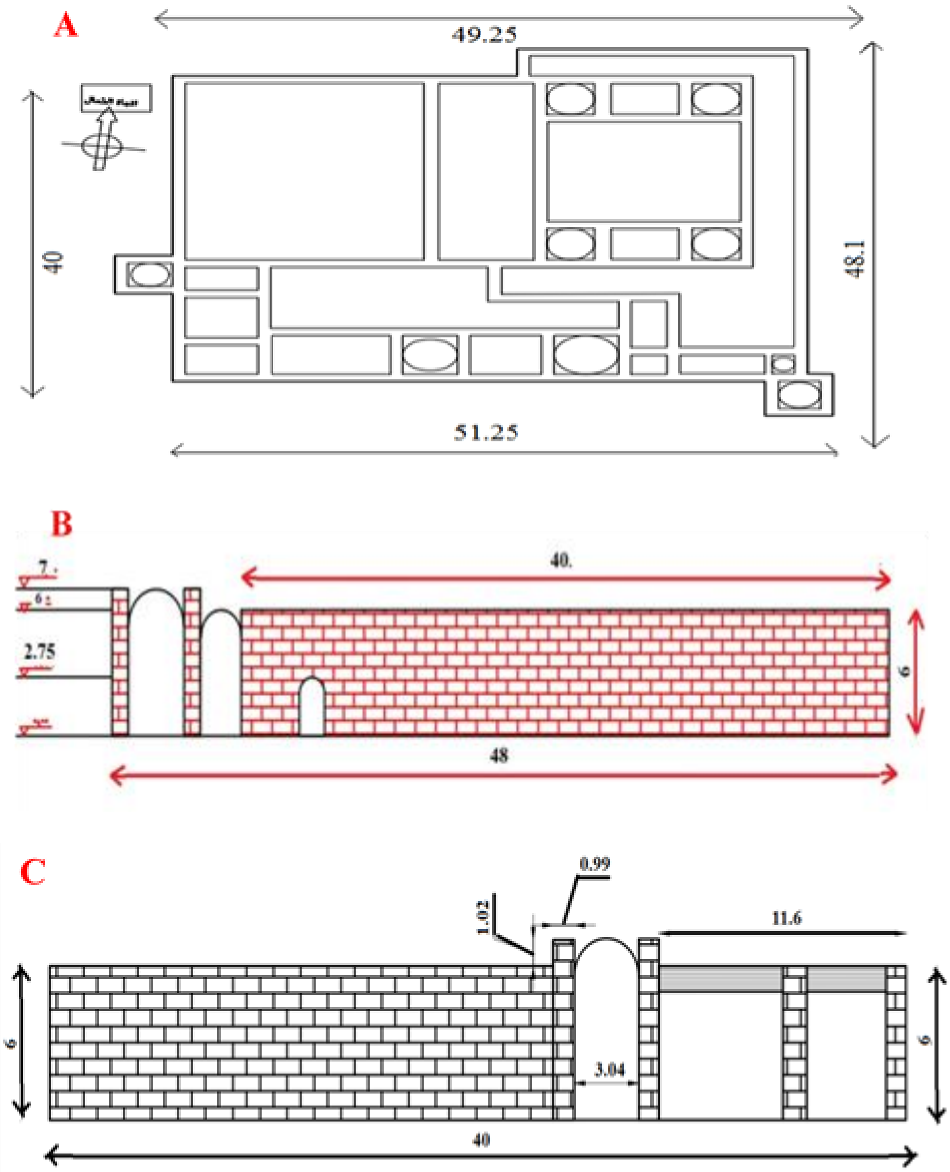
The citadel's construction is attributed to Prince Hammam bin Youssef, who, as leader of the Hawara tribes, sought to fortify Farshout, the center of his authority in Upper Egypt. Sheikh Al-Arab Hammam Citadel bears testament to the 1769 conflict between Ali Bey al-Kabir and Prince Hammam, suffering deliberate destruction by Muhammad Bey Abuo al-Dahab's Mamluk forces.

5.1.2. Architectural Documentation

Through meticulous exterior and interior surveys, the citadel's architectural features were recorded. These dimensions facilitated the creation of detailed horizontal projections and architectural facades, revealing a main facade spanning 48.21m with a height of 6m. (Fig.6)

5.1.3. photographic Documentation

The citadel building was photographed from different angles to highlight on the architectural details. (Fig. 7 and Fig. 8).



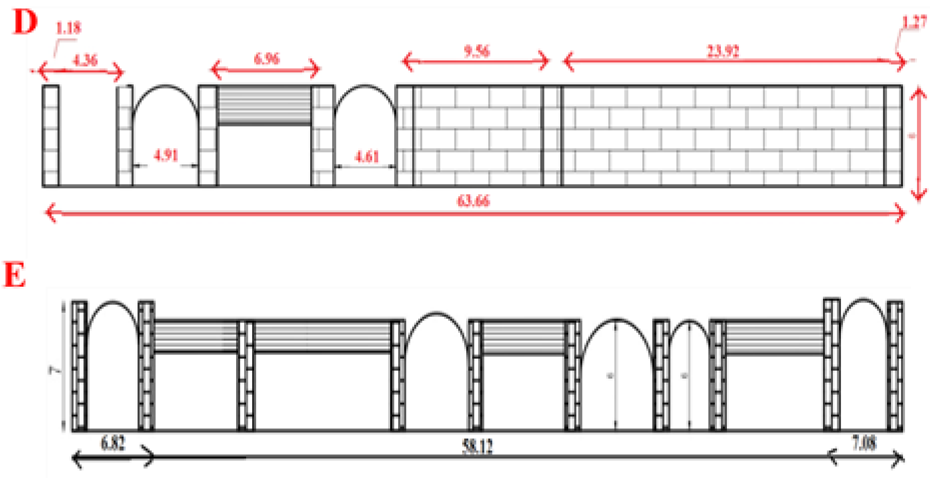


Fig. 6. A. Horizontal projection of the citadel. B. the eastern façade (the main facade). C. the western façade d. The northern facade. E. the southern façade

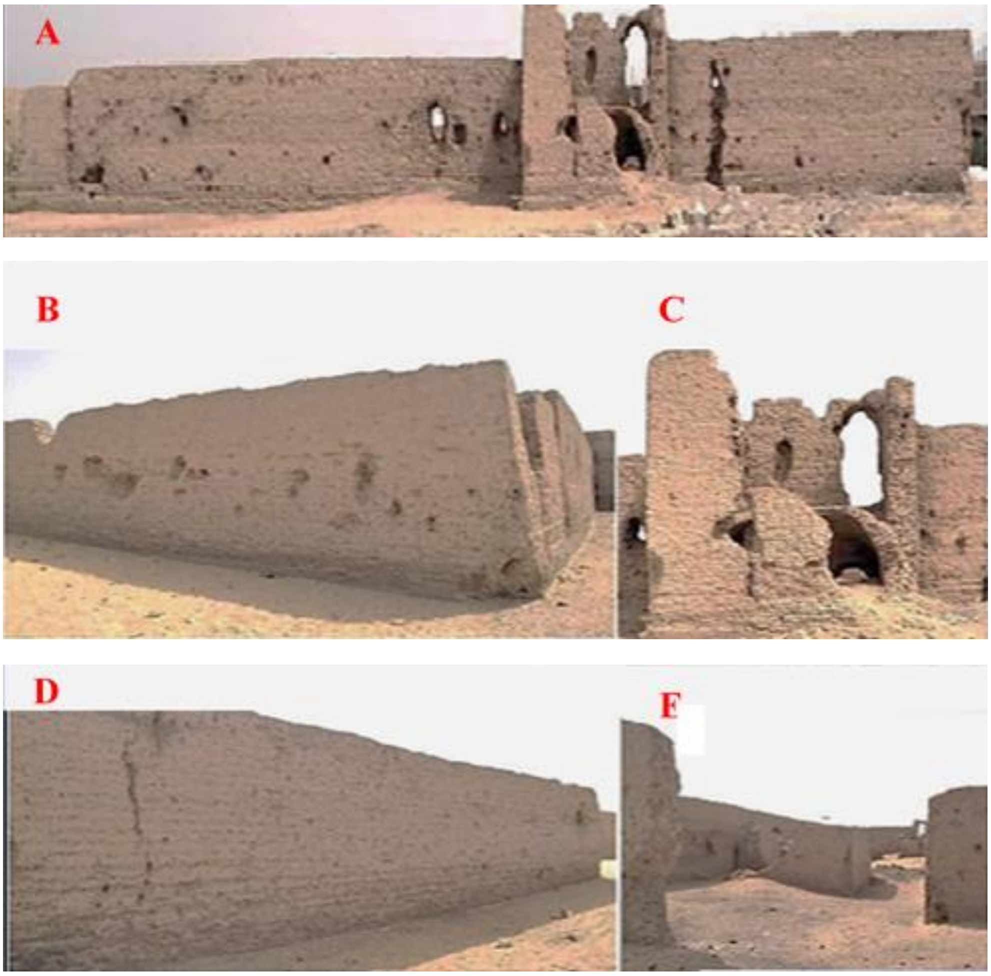


Fig. 7. A. The western façade of the citadel. B. the southern façade. C. The northern facade. D. the eastern façade (the main facade). E. The western tower F. the citadel from inside. G. the southern tower

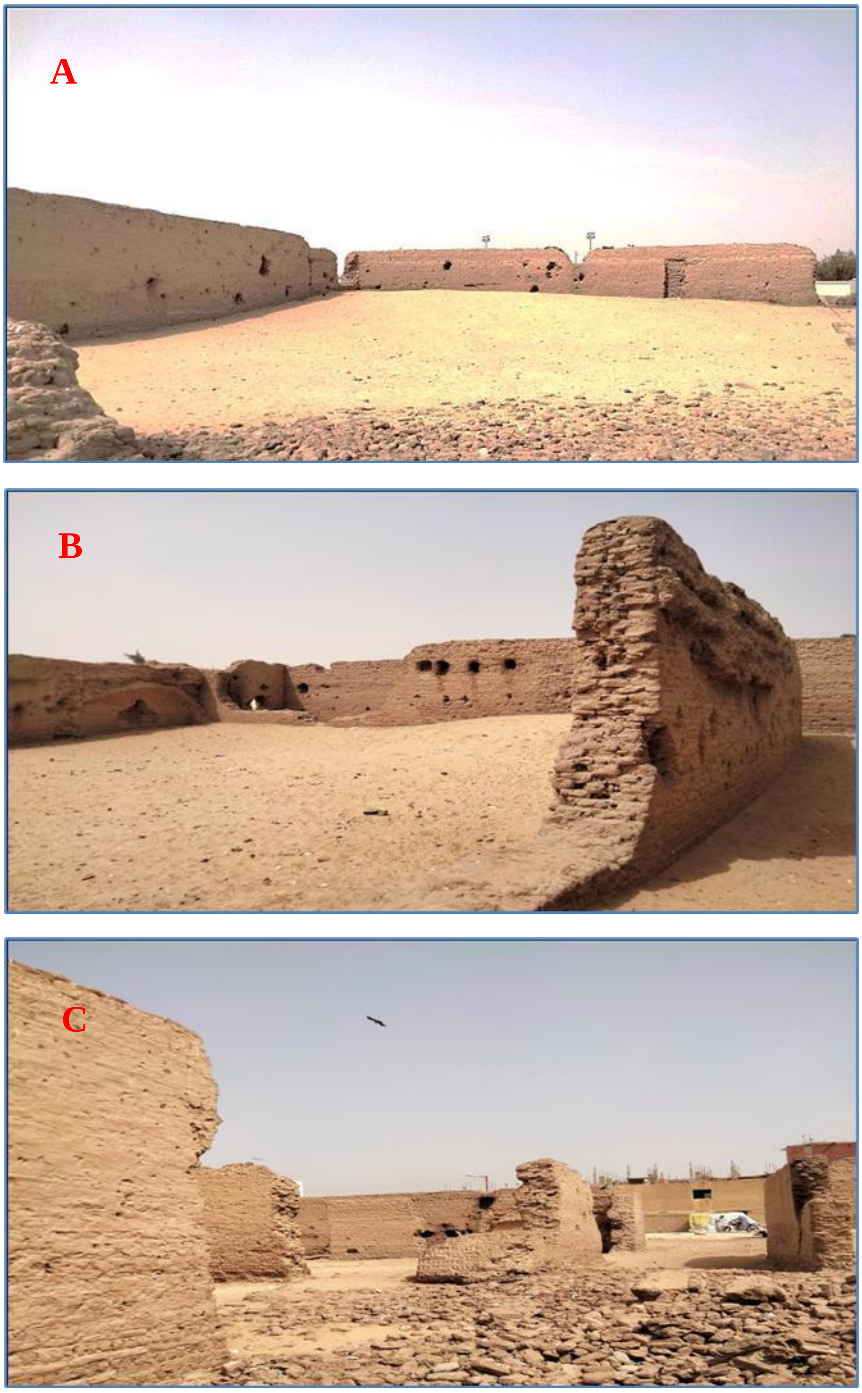


Fig. 8. A. and B. the courtyard of the citadel. C. the destroyed architectural units of the citadel

5.2. Design of the Virtual Models of The Citadel

The following software applications were utilized to create the virtual model of the citadel:

5.2.1. Data Collection and Correction

The data collection and validation phase encompass the systematic gathering, categorization, and verification of case study data, facilitating the development of virtual models.

5.2.2. The Data Input and Construction of The Database

This stage entailed digitizing collected case study data, converting paper-based records into computer-readable formats to facilitate analysis and modeling.

5.2.3. Data Storage and Retrieval Subsystem

Data Digitization Phase: Paper-based case study data was converted into digital format for computer processing and analysis.

5.2.4. Data Manipulation and Analysis Subsystem

Data Processing Phase: This stage includes data standardization, error correction, updates, and calculations (e.g., measurements, spatial analysis, and distance calculations).

5.2.5. Data Display and Modeling Subsystem

The data visualization stage employs multidisciplinary methods (modeling, graphical representations, multimedia) to communicate refined data insights, emphasizing spatial contexts and dimensional accuracy. This phase leverages visualization techniques (2D/3D modeling, graphs, images) to facilitate comprehension of complex data, focusing on spatial relationships, measurements and feature definitions.

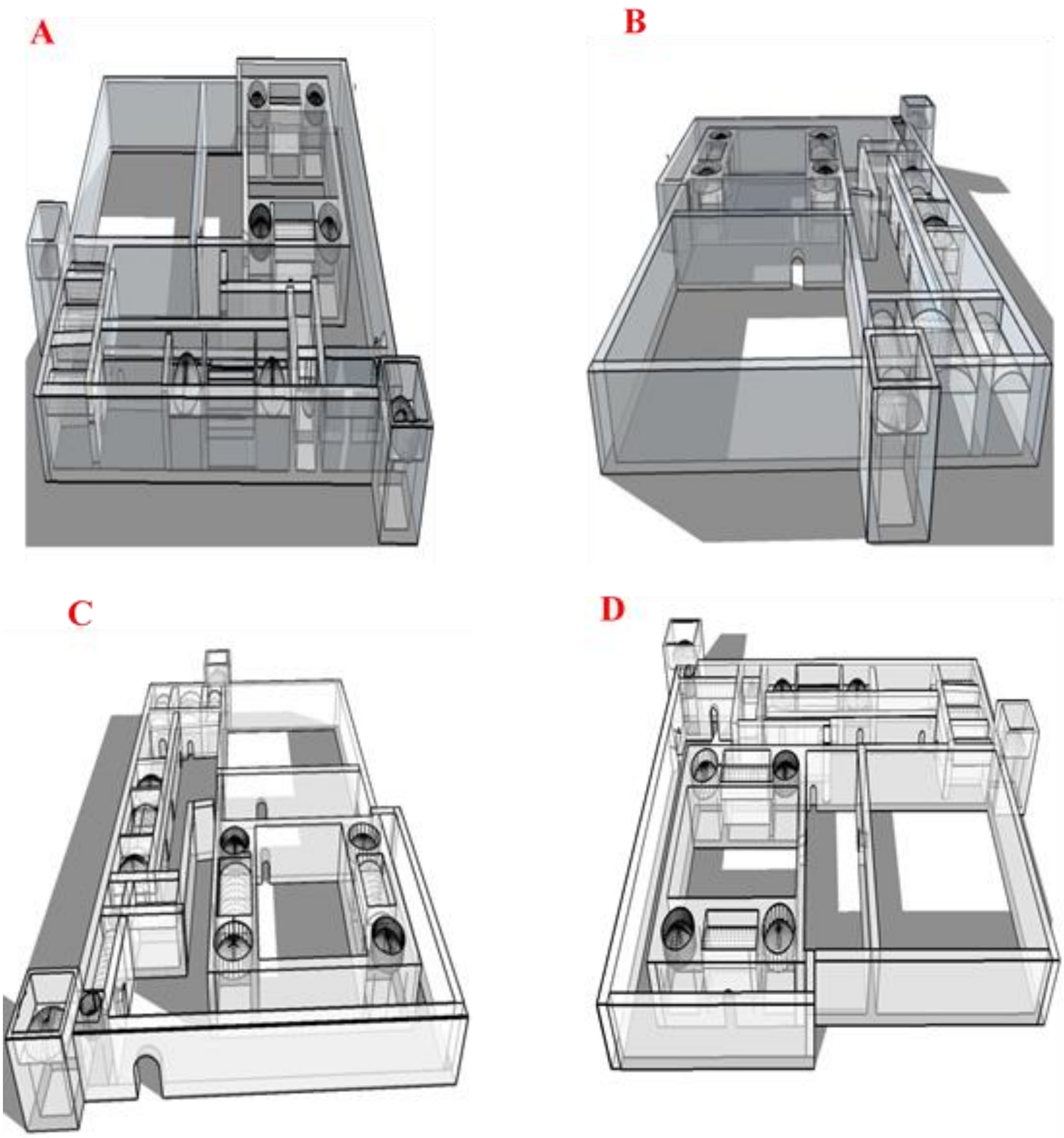


Fig. 9. The virtual models of the citadel a. the northern façade of the citadel. b. the southern façade

6. Results and Discussion

6.1. Results of Examination and Mineralogical Composition

Scientific analysis of the mud brick samples taken from Prince Hamam Castle revealed the following chemical and mineral components: X-ray diffraction patterns revealed that mud brick sample mainly consist of quartz (SiO_2) Kaolinite $AlSi_3O_8$ (K, Na) and Calcite ($CaCO_3$), Indalite $Mg_2Al_3(AlSi_5O_{18})$. The analysis results showed the presence of Indalite mineral, which is a transformed form of Cordierite mineral $(MgFe)_2Al_3(AlSi_5O_{18})$, resulting from the effect of high temperatures.

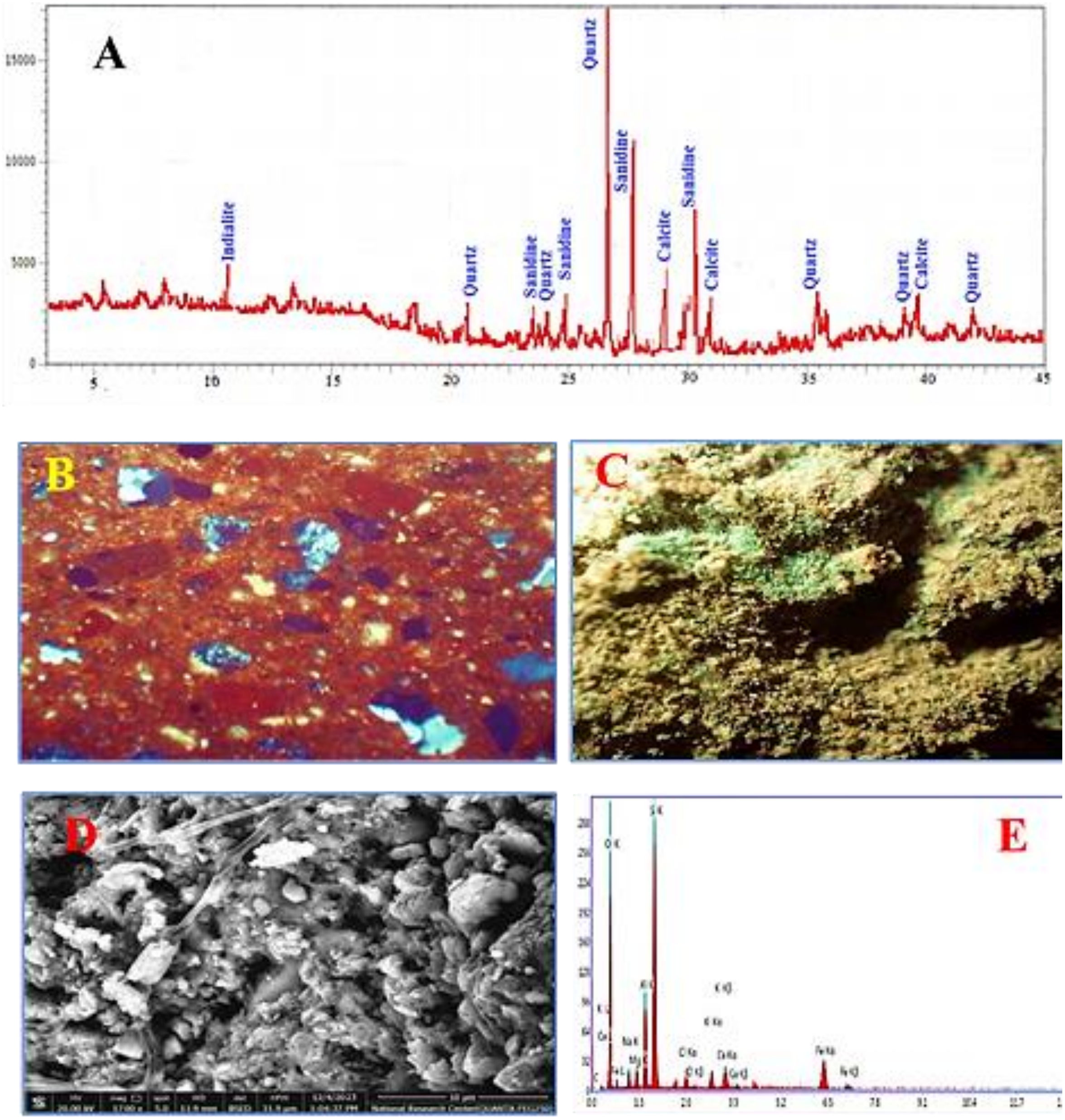


Fig. 10. A. X-ray diffraction analysis results of mud brick B. PLM investigation shows coarse texture of quartz grains. C. Stereo microscope shows granular disintegration and salt crystals. D. SEM photomicrograph shows disintegration and erosion of quartz crystals and salts . E. EDS analysis results of mud brick

Polarized Light Microscopy (PLM) analysis of mud brick thin sections revealed a coarse mosaic texture comprising quartz crystals and fragments, along with feldspar. Stereo microscopy revealed mud brick deterioration: surface roughening, relief, granular disintegration, and crystallized salt deposits. SEM analysis confirmed internal micro-cracks, quartz crystal disintegration, binding material loss, and quartz crystal erosion (Fig. 10). Scientific analysis of mud brick samples revealed compromised physical, chemical, and mechanical properties, primarily attributed to environmental factors. An assessment of the Sheikh al-Arab Hammam Citadel's mud brick materials demonstrated significant degradation, underscoring the interplay between material properties and environmental conditions.

6.2. Results of Physical and Mechanical Properties of Mud Brick

The results obtained from the physical properties tests demonstrate that the mud brick specimens were taken from the case study exhibit the average density values are between 1.31 to 1.52 gm/cm^3, the means values of water content are between 1.89 % and 2.96 % (as shown Table. 1). The results obtained from the mechanical properties tests demonstrate that the mud brick specimens were taken from the case study exhibit the compressive strength values between 0.5 to 2 MPa. High variation is attributable to non-uniform degradation due to durability effects. The results indicate a reduction in the density of the mud brick, accompanied by an increase in moisture content and a decrease in compressive strength

Table 1. The means values Physical and mechanical properties of mud brick

	Average of physical properties of mud brick	
Test code	Density gm / cm3	water content %
ASTM C62-17	1.31 - 1.52	1.89 % - 2.96
	Average of Compressive strength of mud brick MPa	
Test code	Load (N)	Compressive strength (MPa)
ASTM C67/C67M-19	65.5- 75.6	0.5 – 2

6.3. Results of Digital Modelling

Finite element modeling simulations indicated that the maximum stress generated by the self-weight of the citadel (250.69kPa) is generally exceeded in wall corners. The maximum stressed sections generated by the earthquake loading of the citadel reaches values around 5 MPa which is highly above the average shear stress. Areas subjected to excessive stresses are observable on the southeast elevation of the castle, and is also apparent in the upper portions of the eastern and southwest towers.

6.4. Results of Design of The Virtual Models

Engineering programs were used to develop a virtual design for the partial reconstruction of the citadel as shown (Fig. 11).

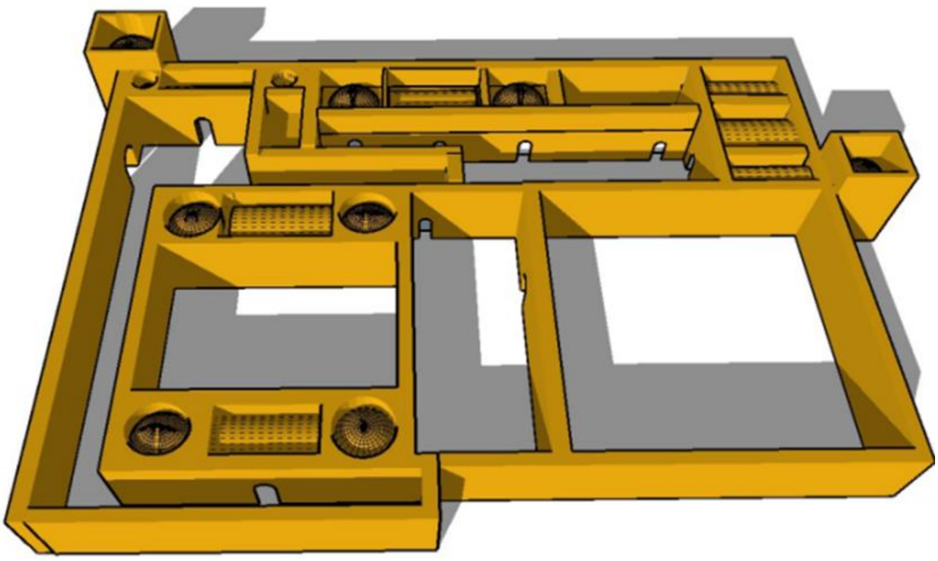


Fig. 11. The virtual model of Final appearance after a partial reconstruction the of citadel

7. Conclusions

This study explores the 18th-century citadel's partial ruin, attributed to Muhammad Bey Abuo al-Dahab's 1769 destruction and subsequent environmental degradation, informing conservation strategies. Seismic analysis of the 3-D numerical model revealed critical structural vulnerabilities. Recommendations include material treatment, completing missing sections, and wall reinforcement prior to partial reconstruction.

The comprehensive assessment of the castle's building materials, encompassing inspections, analyses, and testing, reveals a degradation of the mud brick structure and a corresponding decline in its physical and mechanical characteristics. To mitigate these effects, the application of strengthening treatments using consolidation treatments of mud brick such as Ethyl Silicate, Wacker OH 100, Nano Estel, and Nano Silica, which are deemed necessary to restore and enhance its physical and mechanical properties.

The results of the finite element modeling simulations reveal that the castle walls necessitate structural reinforcement measures, encompassing the repair of cracks, restoration of damaged elements, and reconstruction of degraded architectural components. This comprehensive approach will effectively mitigate structural weaknesses, restore the building's integrity, and revive the castle's original visual splendor.

Undoubtedly, the first steps in the architectural restoration of the castle begin with determining the soil's ability to withstand the pressures and loads imposed on it by the various buildings above it. From here, specialists in architectural restoration try, to the best of their abilities, to treat weak soil layers and inject them with suitable chemical materials to strengthen their weak components and restore cohesion to their separated layers.

We recommend following the subsequent steps for the restoration of the citadel walls:

- Treating structural cracks in the castle, especially those extending vertically from top to bottom or from bottom to top, resulting from the imbalance between the building and the soil beneath it. This treatment is one of the most important operations and is carried out in well-defined and studied stages, the most important of which are:
- Cleaning the cracks and voids in the building walls from dust, salts, and various damage residues, then moistening these cracks and voids with a spray of pure water without affecting the brick components. Subsequently, filling these cracks and voids with a scientific mortar mixed with sand, lime, and a small proportion of gypsum, and mixing these components with a solution of silicates and siliconates.
- Breaking the edges of the cracks from the back, thoroughly cleaning and moistening them with pure water, and filling them with the aforementioned mortar.
- Rebuilding missing parts of the walls or any architectural element in the archaeological building using new brick blocks that carry the specifications of the old brick, with improvements to their physical and chemical properties using suitable chemical materials.
- As for walls on the verge of collapse, they are dismantled using scientific and technical methods known in this field, separating the brick blocks from each other, thoroughly cleaning them from various damage residues, strengthening them with the aforementioned suitable chemical materials, and rebuilding them anew.
- External coating stage: A system was followed in the castle, which is coating its external walls with a layer of mortar with good properties. Therefore, we propose coating those walls with a layer of clay mortar composed of lime and sand or clay and straw, or covering these walls with a block of mud brick similar to the old brick in its composition, with some additions to improve its properties and increase its resistance to damage factors. This method has been adopted in earthen buildings found in Mexico, Peru, Ghana, and Nigeria.
- Reinforcement with wooden panels: Walls of the castle on the verge of collapse are reinforced and strengthened with wooden supports characterized by high rigidity. The roof of the building is covered with a wooden canopy resting on supports built from mud brick. This method has been used to protect earthen buildings from wind and rain, especially in Peru and Italy during the 19th century, and is still followed in some countries.

- Reinforcing foundations with mud brick blocks: As for the castle's foundations, many mud brick blocks that have been affected by various damage factors are reinforced and completed with new brick blocks similar to the old brick, with the addition of a proportion of clay, sand, lime, and red brick powder to their components. This is done to increase their mechanical strength and ability to resist damage factors.

The article highlights on the virtual partial reconstruction of the citadel of Sheikh al-Arab Hammam through of several key conclusions:

- Technological Advancement: The use of virtual reconstruction techniques demonstrates significant advancements in architectural preservation, allowing for a more detailed understanding of historical structures.
- Cultural Heritage Preservation: By reconstructing missing architectural units, the project contributes to preserving cultural heritage and offers insights into the historical significance of the citadel.
- Educational Value: The virtual model serves as an educational tool, enabling researchers, students, and the public to engage with the site's history and architecture in an interactive manner.
- Future Restoration Projects: This reconstruction can inform future physical restoration efforts, guiding decisions on materials and techniques that align with the original design.
- Interdisciplinary Collaboration: The project illustrates the importance of collaboration among historians, architects, and technology experts to achieve a comprehensive reconstruction.
- Overall, the article emphasizes the potential of virtual reconstructions to enhance our understanding of historical sites and support preservation efforts.

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