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Architecture in Southern Algeria: A Study on the Factors and Causes of its Collapse and the ways of its Preservation: *Ksar Melouka* "Melouka Palace" as a Model.

Mansouri M'hammed Nour Bachir University Center of El-Bayadh

(Algeria), m.mansouri@cu-elbayadh.dz

https://orcid.org/0009-0009-9994-6093

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Abstract:

Desert palaces are among the most important archaeological and civilization landmarks found in the Algerian desert. They serve as significant evidence of architectural presence and human connection to this region, given the harsh living conditions imposed by its natural environment. Despite the challenges, the desert dwellers managed to tame and overcome them, building palaces and buildings that resisted various forms of decay and collapse. Therefore, it is imperative to maintain, preserve, and restore these structures to serve as a link between ancestors and future generations, as well as to utilize them in the development of desert tourism. The importance of the study lies in: Giving value to the historical and archaeological heritage to preserve the memory of the region's inhabitants, by providing the necessary protection for the palaces, which is manifested in regular and continuous monitoring.

To achieve the objectives of the study, we relied on observation and field work.

Keywords: Architecture; Ksar Melouka; Touat; Rehabilitation; Preservation; Restoration.

Mansouri M'hammed

Introduction:

The southern region of Algeria, especially the area of Touat, is rich in numerous desert-style palaces constructed from pure local materials such as clay, bricks, palm wood, and mortar. This is attributed to the nature of the region, characterized by extreme heat in summer and freezing cold in winter. These interrelated factors have affected the chemical and physical properties of the materials used in construction, making them prone to collapse and decay. Through this intervention, we aim to explore the concept of desert architecture, understand the nature of *Ksar Melouka*, its construction materials, factors contributing to its decay, and the ways for its maintenance and preservation.

Through this title, we pose the following problem: **To what extent can desert architecture be preserved?**

To answer this question, we pose the following questions:

What does desert architecture stand for? What are its influencing factors? And how can it be rehabilitated and preserved?

1. Concept of Desert Architecture:

Desert architecture is characterized by a harmonious construction style that reflects the natural environment of the region it exists in. This architecture carries cultural characteristics dictated by the geographical features of the area, including high temperatures, scarce rainfall, winds, and vast expanses of land. These conditions collectively impose a specific reality on the inhabitants, compelling them to build dwellings suitable for adaptation to harsh environmental conditions using locally available building materials[1].

2. Location and History of *Ksar Melouka*:

Ksar Melouka is one of the palaces in the Touat region, currently known as the Wilaya of Adrar. It is situated about 5 km to the west of the provincial headquarters along the same axis leading to the municipality of Bouda. The palace is bordered on the eastern and southern sides by palm oasis and some sand dunes, while on the western and northern sides, it is bordered by the palaces of Bouda, from the south Bouzane, and Koussem palaces. To the east, it is bordered by the Palace of Barbaa and the city of Adrar, administratively falling under the jurisdiction of the municipality of Timmi.

Various narratives exist regarding the specific history of Melouka Palace, due to the absence of historical sources. The year 1010 AH was considered the beginning of inhabiting the region by a group of *Murabitun* from Tafilalt settled in the area and initially resided in various locations until they finally settled in the peripheries of Timmi; they named the place *Melouka*, a derivative of "*milkyia" which means* ownership, after they purchased the area.

Another account suggests that a group of *Murabitun* migrated from Morocco and settled in *Tabalbalah*, near Tindouf. They later moved to Touat, staying initially at the Palace of Adgha, then to Timmi. This narrative indicates that *Melouka* was a property of Hdya and was possessed by the five brothers in 1010 AH, founded by Hadj Belkasem and his brothers on Rajab, 29th, 1089 AH[2].

3. Building Materials:

Upon examining the structure of the palace, it became apparent to us that the materials used in the construction process were locally sourced from the surrounding environment, readily available in abundance, and easily obtainable without much effort. These materials include:

1. Clay:

Clay has been used for thousands of years as a building material. It is a mixture of dry earth combined with water. This material has been widely favored by the inhabitants of the region and used for bonding and cohesion of stones and bricks. Clay contains various minerals[3] that give it specific colors such as black, white, yellow, or red[4]. This material is known for its insulation properties and malleability, as it absorbs a high percentage of water ranging from 60% to 70% of its weight. There are two types of clay: fat clay and lean clay. To be suitable for use, the clay should have the following composition, as illustrated in the following table[5]:

Material	alchemical symbol	Percentage
Silica oxide	SO2	35% to 85%
Aluminum	AL2O3	9% to 25%
Lime	Cao	0% to 25%
Magnesium	Mgo	0% to 25%

Iron oxide	Fe2O3	3% to 9%
Carbon dioxide	CO2	0% to 13%
Water	H2O	5% to 11%
Alkaline oxide	K2+Na2O	1% to 5%
Sulfur trioxide	SO3	0% to 3%

Schedule (1): The table Shows the percentages of clay components, Source Ali Hamlawi, *Ibid*, *p. 188.*

2. Bricks:

Sun-dried local bricks were used in building the palace. Bricks are considered one of the main components of construction. The process of forming them is as follows: raw clay is mixed with water and sand if it is of the weak type, and then straw or palm fronds are added to reduce its density and enhance its cohesion. The mixture is thoroughly mixed with feet and turned with a mallet until it becomes a soft and cohesive dough. Then, the clay is poured in quantities into rectangular wooden molds without a base, smoothed by hands, and removed from the mold from one side and then the other by hand, forming a pile of clay dough. It is then shaped by hand and palm fingers, giving it a circular shape. This process continues until all the dough is shaped. After completing this process, the formed bricks are left in the sun for a few days to dry and harden.

In some cases, after the upper surface dries, the manufacturer flips the brick to allow the lower surface to dry. Sun-dried bricks are environmentally clean and soundproof. They retain heat throughout the day and release it at night due to their low thermal conductivity of 0.22 calories per square centimeter per minute[6].

It is preferable to manufacture bricks in spring and summer to avoid rain and ensure thorough drying. Although bricks are susceptible to natural elements, they can last for a long time due to the low humidity of the desert environment and their resistance to vibrations[7].

3. Clay Mortar:

Clay mortar is the primary material used for plastering between the components of walls. It comes in different colors depending on its composition. It is primarily composed of dry clay and sand, with some containing lime and sand, known as "*tashmnet*," which is a locally used

mortar in Touat's palaces, characterized by a pink color. It is obtained from damp gypsum from the swamps. It takes the form of piles or horizontal layers reaching a depth of 1 meter[8]. The manufacturing process of clay mortar does not differ much from bricks in terms of shaping or the proportions of its constituent materials. Clay mortar is used to bond and stabilize the walls.

As for the mortar used for plastering walls, it is prepared by mixing water, clay, and locally known soil called "bali". The mixture is thoroughly combined until it becomes a viscous mortar, which is also used for plastering walls and in roofing processes as well. It's worth noting that the thicker this material becomes, the better its thermal insulation properties[9]. Mortar plays a significant role in binding and cohesion of building materials due to its numerous advantages, including:

- Good adhesion with building materials,
- Quick hardening process,
- Resistance to pressure and climatic effects,
- Non-porous, thus protecting the building from humidity,
- Plays an important role in smoothing irregular surfaces during construction.

Ibn Khaldun describes mortar as: ".... some of them (walls) are built with interlocking stones or bricks, with lime binding them together, so that they adhere as if they were one body ..."[10]

4. Wood:

Wood is among the fundamental materials used in the buildings and palaces of Touat in the wilaya of Adrar since early times. It was used to make doors, supports, roofs, and in connecting walls and other components. Ibn Khaldun points out the importance of wood in human life, saying: "It is used as pegs and columns for the tents of nomadic Bedouins." Palm wood is the most commonly used type of wood due to the richness of the region in palm trees. After cutting, the large palm tree is divided longitudinally into two or four sections, depending on the building's nature, and left under the sun for a few days to dry and become suitable for use. It is used in roofing buildings and as a means of support in stairs and door manufacturing.

5. Stones:

Stones were used in building the palace, especially in the exterior walls, which are clearly visible. These stones were collected from the palace's outer surroundings and used by the builders as they were found, without polishing or altering their natural shape. They are considered ready-made materials used by humans in building their houses[11], as evidenced by the remaining artifacts. Their function was to strengthen and support the walls, especially the stones used in the foundations.

4. Construction Techniques:

Construction techniques are traditional and primarily depend on locally available raw materials, followed by climatic conditions and other influencing factors. Engineers and construction enthusiasts in the Touat region have focused on buildings and devoted themselves to their construction techniques to ensure the safety and stability of the structures. They aimed to find all means to ensure the building's safety on one hand and the stability of its parts, considering the natural aspects such as sandstorms and tremors, on the other hand. Among these techniques are:

1. Foundations:

Builders search for the primary foundation that can support the initial structure of the wall, distributing its weight evenly and harmoniously with the building's components. The depth of the foundation depends on the firmness of the ground. The foundation is the base of the building or the supporting columns in the ground, secured to bear the weight. Hence, the lower part of the building's floor, especially in the south, is thicker and denser than the upper part.[12]

2. Walls:

Walls are built with composite bricks, sometimes in an orderly manner and sometimes irregularly. Their thickness varies from one wall to another, decreasing as their height increases. At the base, the thickness reaches 1 meter and gradually decreases to 15 centimeters as the walls rise. When the walls reach the surface level, they serve only as enclosures. The bonding material is mortar, which varies according to the wall type. To plaster the walls with mud mortar, builders use a flat wooden piece, and sometimes even their hands, leaving visible traces on the walls, as shown in the following image.

figure 01: The image illustrates the use of hands in plastering the walls.

Source: The researcher.

Builders used a thread to achieve straight walls.

3. Roofing:

Palm trunks were used in the roofing technique of the palace due to their abundance. The roof takes the shape of the covered area, with a series of prepared wooden pieces placed vertically on the walls, spaced equally apart. Then, the leaf bases (*Kurnaf*) are placed on top of them, as shown in the following image.

figure 02: The image illustrates the technique of roofing with palm wood.

Source: The researcher.

Afterward, it is covered with palms fibers or worn-out clothes, then the whole structure is covered with clay. Afterward, it is polished to create a smooth layer. In building this type of roof, it is important to ensure its slope towards the roof gutters "*mizeb*" to prevent water accumulation. In this technique, the length of the room does not exceed three meters based on the length of the palm wood. The thermal insulation increases with the

thickness of the clay material used above the palm wood, but it should not exceed 40 cm to maintain its compatibility with the load-bearing capacity of the wood for this thickness[13].

4. Stairs:

The stairs were built using palm trunks, with palm trees husks "*dibsh*" also contributing to its composition, and clay serving as a binding material[14]. A set of palm trunks, not exceeding three trunks, is placed in a sloping manner to match the desired shape. They are supported at the bottom by a group of stones while the other end leans against the wall. After placing the stones, they are covered with clay as a bonding material. Then, refined rectangular pieces are placed to form the steps of the stairs. Finally, they are plastered with "*tashment*" mortar due to its resistance to weather fluctuations[15].

5. Factors of Damage and Causes of Collapse:

The factors and causes of collapse are numerous and varied, categorized into three main causes, in addition to causes related to the original material, as follows:

1. Natural Factors:

This factor is limited to three basic elements:

5.1.1. Moisture:

All buildings need complete insulation from moisture, rain, groundwater, and surface water. The impact of moisture and seepage water on buildings helps in the deterioration of structural and construction materials, leading to a shortened lifespan of the building. Additionally, moisture aids in the proliferation of insects, rodents, algae, and fungi[16]. Moisture also plays a significant role in most chemical processes of deterioration. Its effect on the stability of dimensions and physical properties of some materials is of great importance. For example, wood may bend and crack in cases of fluctuating moisture levels, causing the applied layer to not adjust to the wood's expansion and contraction, leading to likely delamination. These effects are particularly noticeable in hot and dry climates, where wood not only contracts noticeably but also becomes brittle[17]. There are many and varied causes of moisture, which can be summarized as follows:

a. Rainwater:

Due to the fact that palaces "*Ksour*" are located in a desert environment where rainfall is rare, it is seldom discussed; however, this does not prevent us from addressing this factor. The building materials used in these monuments are highly affected by rainwater, which works to disintegrate the building materials and can directly penetrate the roofs of the buildings and their various elements. This is especially true considering that rainfall in these areas can be sudden and sometimes heavy, lasting for periods of up to 48 hours. It often leads to the collapse of many buildings, and rainwater frequently manages to infiltrate buildings through the gaps between walls and windows, as well as through the porous nature of the building materials and the roof surface. The following image illustrates this:

figure 03: The image illustrates the effect of rainfall on *Kasr Melouka*.
Source: The researcher.

Water is considered the main and principal factor in deteriorating the buildings built with soft bricks, because the increase of water provokes the total separation of clay's minerals and moving them from their places. This case happens directly when the buildings are exposed to heavy rains, and happens indirectly when rain water is flowing on their walls[18].

b. Groundwater:

Groundwater may accumulate under the foundations of the monuments as a result of a burst drainage pipe or other factors. This could lead to subsidence of the buildings if not accounted for, such as by installing open drainage pipes or drainage ditches around the buildings, especially in a context witnessing cultural and architectural transformations in this region.

c. Rising Ground Moisture:

Moisture rises from the soil beneath the building to its foundations through capillary action, passing through the pores of the soil and the building materials used in construction. Particularly in desert environments containing considerable groundwater, the water level rises due to capillary action, posing a threat to the monument's future. Other causes include poor water drainage at the site, condensation, surface water, etc[19].

The effects of moisture on the monuments can be summarized as follows:

- It causes erosion of the walls, ceilings, and floors of the monuments.
- It leads to bending and deterioration of the wood used in the buildings.
- It damages all floor and wall coverings.
- It promotes the proliferation of fungi, bacteria, and wood-boring insects in the wood used in the buildings[20].

5.1.2. Temperature:

High temperatures significantly affect historical buildings and monuments due to their fluctuation, weakening the bonds between the basic components of the construction. High temperatures cause expansion in different degrees and directions, particularly in desert climates. Facade temperatures can rise during the day to 60-70 degrees Celsius and drop significantly at night. Moreover, variations in facade colors can cause differences in expansion rates. Heating raises the temperature of the outer layer, causing it to expand more than the layers beneath, leading to their disintegration, a phenomenon known as spalling. The greater the temperature differences, the greater their impact, especially as they work to disintegrate the original materials of the building components[21].

5.1.3. Winds:

Winds contribute to the burial of buildings and archaeological elements with soil and sand, exerting pressure on them. They also work on sculpting and disintegrating walls, often resulting in walls and rocks standing on sharp edges as a result of this phenomenon[22]. Additionally, they contribute to the deterioration of buildings made of soft bricks, which is an important factor directly affecting them, primarily through the phenomenon known as sandblasting[23], as illustrated in the following image:

figure 04: The image illustrates the impact of wind on the northern wall of *Kasr Melouka* ***Source:*** The researcher.

2. Human Factors:

The negative effects mentioned above are somewhat acceptable as they are beyond control. However, human encroachment in such cases is unacceptable. Unintentional human actions due to routine life activities might have excuses, but what cannot be excused are the harmful effects resulting from mismanagement, deliberate sabotage, human indifference, and neglect, especially through fires, demolitions, and improper renovations. This type of destruction stems from a lack of recognition of the historical and cultural value of the building on one hand and a desire for renewal and alignment with urban development trends on the other. Blaming such practices on ignorance, lack of respect, and negligence cannot be justified. If humans, who have reached the highest levels of intelligence, are unable to organize themselves and deal appropriately with their properties, this is unacceptable[24].

Such damages can be avoided through effective and regular monitoring, strict and continuous guarding, legal deterrence, public awareness, and familiarizing the public with their heritage, its importance, and its position in world cultural heritage[25].

3. Biological and Animal Factors:

Rodents are one of the creatures that play a significant role in the destruction of brick-built buildings, especially rats that dig burrows inside

the building and can thus undermine its foundations. Additionally, some insects like beetles and cockroaches contribute to the deterioration of buildings. Among the insects that have had a significant role in the destruction of buildings is the termite, known as white ants, representing a category of harmful insects, especially for buildings with wooden structures. Since many monuments had wooden roofs, it played a major role in their collapse.

Among the types of insects that harm dry wood are of the type Kalotermitidae[26].

Here, we are primarily concerned with the type that attacks wooden structures. Termites are classified into two groups:

1) Dry wood termites.
2) Subterranean termites.

Regarding animal hazards, birds are considered one of the most dangerous factors affecting archaeological buildings. They perch on them in groups, depositing their organic waste wherever they stand. This waste is not just harmless, as some may think, as it contains at least two types of dangerous disease-causing bacteria: Pseudomonas and Meningococcal meningitis bacteria. Additionally, these organic residues with acidic reactions, bird nests, and even their carcasses all pose a problem in dealing with and preserving archaeological buildings and monuments[27].

4. Factors Related to Original Material:

5.4.1. Defects of Used Wood (Palm Trunks):

The extensive use of wood in the composition of monuments has had a significant impact on their deterioration and collapse due to its inherent defects, which are divided into natural and structural defects.

- **Natural Defects:** The main natural defects can be summarized as follows: knots, deep cracks, ring cracks, warping, bending, and twisting.
- **Structural Defects:** Wood defects are few but dangerous and must be considered and treated. They include:
- **Decay:** Wood decay occurs due to wood-boring insects living in large groups. Wood decay is one of the most dangerous defects because, like cancer, it spreads rapidly and affects nearby wood, weakening its

structural integrity. Given that the roofs of monuments were mostly wooden, this factor played a significant role in their collapse.

- **Decomposition:** Occurs in wood due to bacteria or algae in the presence of moisture.
- **Flammability:** Most wood is flammable unless chemically treated.
- **Expansion and Contraction:** Wood is affected by moisture and heat, resulting in warping and twisting.

5.4.2. Unburnt Brick and its Damages:

- Unburnt brick walls cannot resist moisture and rainfall.
- Unburnt brick walls provide a suitable habitat for burrowing animals and insects to live and breed.
- Walls made of unburnt brick are prone to cracking due to various weather conditions, affecting the appearance of buildings.
- The lifespan of unburnt brick buildings is shorter compared to those made of red bricks[28].

6. Proposed Solutions for Maintenance and Restoration:

Maintaining and restoring buildings and historical monuments to prevent deterioration necessitates intervention in the buildings to mitigate and treat the serious effects, including reinforcement, repair, and renovation.

1. Reinforcement:

It involves adding adhesive or supportive materials to extend the life of the structure. Modern methods can be used, but traditional methods are preferable when the material is susceptible to rapid decay, such as wood and unburnt brick.

2. Repair and Renovation:

The need for repair and renovation is imperative and includes renewing damaged protective materials like fallen lime or broken parts of building materials, such as load-bearing elements like roofs, walls, arches, and columns, which may affect the structural integrity of the building. Replacement should be limited to what is absolutely necessary, as any modification or renovation to buildings and their elements will alter their features and diminish their value. This brings us to one of the most challenging concepts in modern restoration: authenticity.

In general, there must be a basic rule: the strength of the materials used in the restoration process should be equal to or weaker than the original materials, as theories have shown that if the materials used are stronger than the original ones (known as mechanical strength), they accelerate the deterioration of the old parts connected to the new ones, contradicting the techniques of preserving historical materials[29]. Regarding protection and maintenance, we specifically mention protection against natural factors like moisture, heat, and biological and animal factors.

3. Combatting Natural Factors:

Precise investigation of the source of moisture is essential to diagnose the condition accurately, as moisture is often a subsequent result of specific non-parallel physical forces in a structure. If present, architects and engineers must perform the necessary examinations to determine the nature of the problem. Among the proposed solutions to isolate moisture from monuments or buildings are:

6.3.1. Use of Moisture Barrier Layers:

The purpose of moisture barrier layers is to prevent the transfer of moisture or water from one area to another, as well as to prevent its passage between building materials and its spread inside the structure, whether it's vapor, rainwater, or seepage water through capillary action[30].

6.3.2. Rainwater Disposal:

The issue of rainwater disposal must be thoroughly studied due to its dangers. It's possible to use suitable drainage systems to channel water from roofs or ceilings, as well as to use sloping techniques to direct water towards channels leading to an effective drainage system[31].

6.3.3. Complete Insulation Usage:

This involves constructing the roof of a brick building with a slope leading to side gutters to drain water from the surface. The formation of water ponds near walls should not be allowed. These buildings can live for long periods if continuously protected. The key vital points necessary for protecting these buildings are:

The roof system, the water drainage system, preserving wall foundations, quickly repairing building subsidence issues. The shear stresses resulting from building subsidence cause various cracks depending

on the tensile strength of building materials. Such cracks would be vulnerable if water is allowed to seep into them. Protecting the brick remnants involves repairing the roof above them and establishing a good water drainage system[32].

6.3.4. Protection from Sun Rays:

Protection from strong sun rays in hot regions is essential. Since ancient times, inhabitants of these areas have worked to protect themselves from them. Generally, protection of buildings from intense sunlight can be divided into two stages:

- Reducing direct reflected rays falling on buildings and facades.
- Protecting monuments from falling rays[2] by spraying or painting the external walls, ceilings, and facades facing direct sunlight white, as it reflects heat instead of absorbing it unlike other colors. This is done using lime emulsion to reduce the intensity of heat falling on the monuments, especially during extremely hot summers.

4. Control against Biological and Animal Factors:

6.4.1. Protection against Insects:

When a building is infested with termite attacks, all cell sites must be excavated and demolished, and treated, for example, with Zinc Oxide powder. If the cell is small, a small amount of this powder is injected into the hole made at the center of the cell. Tests conducted at the CSIRO Institute in Australia have shown that a quantity of 1.75 grams can eliminate a colony containing 1.5 million termites within two weeks.[33]

6.4.2. Protection against Birds:

Among the proposed solutions that have been tested and proven effective are the use of high-tension wires, chemical compounds that are harmful to birds' feet, toxic foods, fertility control, trap networks, adhesive compounds, annoying sounds, ultrasonic sounds, intermittent explosions, and predatory falcons[34].

5. For the maintenance and protection of wood from the dangers of insects and fungi that cause damage, wood has been generally protected against insects, fungi, and any other parasites as follows:

- By extermination using a brush or spray and saturating the wood with a special substance, namely "Wood treatment of syprinal type star."

- By injection using the same solution injected into every hole in the wood, whether from insect tunnels or natural holes. This dual preventive and therapeutic stage aims to eliminate all adult insects or larvae and keep the wood in good condition and, finally, preventive[35].

Among the materials used to preserve and protect wood is the use of wood preservatives such as Creosote and petroleum solutions, or by wax solutions such as paraffin wax solution. Wood preservatives can be applied to wood in several ways, such as brushing or soaking the wood in them[36].

6. **As for the role that humans should play towards buildings and monuments,** it consists of regular monitoring by placing them under supervision and conducting continuous inspections to ensure the condition of each building, to prevent sudden collapses or deterioration, and to observe the condition of restoration and the effectiveness of preventive measures. The aim of this process is to prevent any new damage and address any potential faults in the prevention system[37].

7. Conclusion:

In conclusion, through this study, we have been able to draw some conclusions, which we summarized in the following points:

- The necessity of rebuilding collapsed parts, restoring and renewing them, repairing what can be repaired, and reinforcing the foundations of the monuments.
- Ensuring the use of suitable and appropriate materials in the restoration and renewal process, so that the mechanical strength of the materials used equals or is less than that of the original materials to avoid affecting the buildings and facilitating their destruction.
- Ensuring the use of wood treated against termites and harmful insects to give the monument more strength and durability, especially the roof, to last as long as possible.
- Giving value to the historical and archaeological heritage to preserve the memory of the region's inhabitants, by providing the necessary protection for the palaces, which is manifested in regular and continuous monitoring.
- Finally, we appeal to the authorities responsible for this cultural heritage to take care of these remnants and monuments to remain a witness to our ancient heritage.

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