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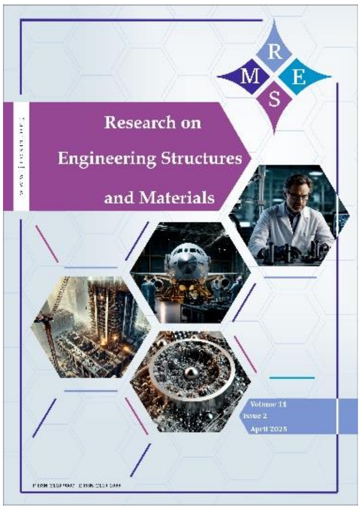

In-situ investigation of earthen building materials in the Ksour of the Ziban region, Algeria: A comparative study between Chetma and Lichana

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Research Article

In-situ investigation of earthen building materials in the Ksour of the Ziban region, Algeria: A comparative study between Chetma and Lichana

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Abstract

Earth is one of the primary building materials utilized in the Saharan region of Algeria. This study seeks to characterise, diagnose, and compare the earthen materials employed in constructing two (2) ksour in southern Algeria: the ksar of Chetma and the ksar of Lichana in the Ziban region. The research methodology combined in-situ observations, analysis of traditional construction techniques, and applying three (3) fundamental tests developed by CRAterre in 1979 and 1989: sedimentation in a bottle, the cigar test, and the pellet test. The investigation into the conservation state of the ksour of Lichana and Chetma revealed their highly precarious condition. Furthermore, the tests revealed that the earth used for construction at the two sites shows similarities, with the earth from Chetma containing slightly more clay than that from Lichana. This difference is more apparent in the composition of the mud bricks (40x20x10 cm), as those from Chetma incorporate a natural fibre, wheat straw. In contrast, the bricks from Lichana do not contain straw, resulting in distinct properties. In addition, the investigation into the conservation state of the ksour of Lichana and Chetma revealed their highly precarious condition. The article's findings contribute to the characterisation of the mud bricks, offering valuable insights for documentation purposes and informing future conservation and restoration efforts requiring compatible construction materials.

1. Introduction

Architecture has long been a profound expression of cultural and social values, often described as humanity's "great book" [1]. Indeed, earthen architecture is one of the most vital and original expressions of the human ability to shape the environment by making the most of local resources (Fig. 1). It encompasses various creations, from simple houses, granaries, palaces, and religious buildings to urban centers, cultural landscapes, and archaeological sites. Earthen architecture plays a crucial role in revealing local identities, and its construction techniques are enduring and often linked to genuine artistic expression. It is attracting growing interest because it can be used to make a significant contribution to social and cultural development while respecting the environment and promoting sustainable development [2–8].

The study of earthen architecture gained scholarly interest in the 20th century, beginning with Le Corbusier's *Les Constructions Murondins* [10], advocating for local materials like rammed earth amid post-WWII shortages. This marked a shift towards organic aesthetics in modern architecture. In 1945, Hassan Fathy's project in Gourna (Luxor), later published as *Gourna: A Tale of Two Villages* [11], became a seminal work in sustainable and community-oriented architecture. It revived

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Nubian mud-brick techniques to address housing needs through climate-responsive and low-cost solutions.

In the 1950s, CSTB published Le béton de terre in France, as reported by Guillaud H, et al [12], detailing the technical properties and applications of earthen concrete. In Senegal, Dreyfus released *Manuel de Construction en Terre Stabilisée en Afrique Occidentale Française* [13]. The United Nations, translated by SMUH in 1974, issued *Le béton de terre stabilisée*, which further advocated stabilised earth as a sustainable construction alternative.

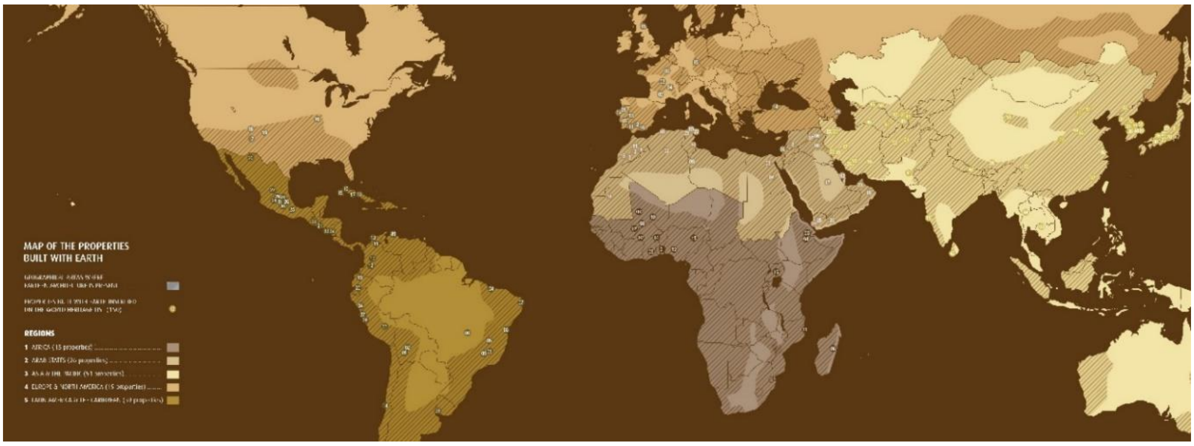


Fig. 1. Distribution of Earthen Architecture Around the World [9]

Notable publications followed: *Archi de terre* by Bardou & Arzoumanian [14], CRAterre's *Construction en terre* [15], and the *Traité de construction en terre* [16], all of which documented techniques like mud brick, cob, and rammed earth, promoting sustainability and heritage conservation. CRAterre, founded in 1979, has since led global education and research in earthen architecture, notably through its DSA postgraduate program launched in 1984.

In North Africa, French colonisation sparked early documentation of local techniques. Texier [17] researched Constantine and the Ziban region, while Cauvet [18] analyzed the symbolic and architectural importance of marabouts in Maghreb. The mapmaker Didier [19] also contributed to promoting earthen architecture through detailed drawings of Algerian sites, such as the ksar Tamacine in the Oued Righ region (Southeastern Algeria).

During the colonial period, major earthen projects like the Sahara Hotel in Biskra city and the Hospital of Adrar by Michel Luyckx were built [20]. However, post-independence Algeria witnessed a decline in the use of earth in construction, as modern materials and techniques gained prominence, often at the expense of local know-how and traditions.

Algeria, located in the north of Africa, has a long strip of land, naturally divided into three zones: The Tell, the high plateau, and the Sahara. The Sahara occupies 80-85% of Algeria's total surface area, occupying a large part of the country [21]. The Sahara's climate is marked by extreme heat, especially in summer, when temperatures often exceed 45°C and significant diurnal temperature variations occur. Rainfall is scarce, and evaporation rates are high due to intense solar radiation and low humidity. In addition, the Saharan regions of Algeria experience strong winds, leading to sandstorms, and despite the heat, winter nights can be very cold. These harsh conditions have shaped the sparse vegetation and traditional architecture, which is adapted to mitigate the effects of the intense climate.

In the Saharan regions of Algeria, urbanization manifests in the form of ksour (plural of ksar), which are the product of a continuous process reflecting the ingenuity of Saharan societies in planning, building, and sustaining themselves in an arid environment [21–27] These ksours are densely packed traditional dwellings with an inward-facing design. They are constructed using locally sourced materials such as earth, stone, and palm wood and are often encircled by fortified walls.

Earth has long been a cornerstone in constructing vernacular architecture in Algeria, especially in the arid and semi-arid regions where other materials like wood and stone are scarce. The techniques used, such as rammed earth, cob, and mud brick (sun-dried mud bricks), have been refined over centuries and passed down through generations to create functional structures perfectly adapted to these regions' harsh climatic conditions.

The use of earth in vernacular architecture is shaped by specific requirements related to its composition and application, ensuring resilience to the extreme temperatures and occasional heavy rains characteristic of Algeria's desert and semi-desert regions. These principles are exemplified in the Ziban region (plural of Zab) in southeastern Algeria, particularly in the ksour of Lichana and Chetma, located in the northern Zab (Zab Dahraoui) and eastern Zab (Zab Chergui), respectively. Builders in these areas possess deep knowledge of local earth properties, enabling them to create durable structures well-suited to the harsh climate. Earth's natural ability to regulate temperature enhances the suitability of these buildings, providing cool interiors in the Ziban's hot, dry environment.

Significant research has examined the ksour of the Ziban, focusing on the thermal performance and climate adaptability of traditional architecture [28,29]. These studies highlighted how centuries of refinement have led to effective architectural strategies for managing extreme temperatures. However, despite this focus, there is a notable lack of detailed analysis regarding the composition and preparation of the building materials, primarily mud brick. While this material is valued for its thermal mass properties and durability, deeper insight into its characterization and preparation techniques are essential for preserving traditional practices and advancing sustainable construction.

This study aims to address this gap by characterizing, diagnosing, and comparing the earthen materials (mud bricks) used in constructing two ksour in southeastern Algeria: the ksar of Chetma and the ksar of Lichana in the Ziban region. It focuses on documenting the ancestral techniques and know-how, as well as material properties integral to their construction.

2. Brief Overview of Ksour as Generators of Oasis Environments

The ksour (plural of ksar) represents a type of human settlement widely distributed across the Sahara, with numerous examples in southern Algeria, southern Morocco, Libya, southern Tunisia, Mauritania, and Mali [22,23,25,30–32]. Romey [33] distinguished the ksar from the medina based on their economic and social functions rather than appearance. Public buildings like mosques serve religious and social purposes, while public squares host meetings and markets. The medina's architecture is characterized by two-level houses with decorated façades. However, Zerari [21], considers geographical location the main criterion for distinguishing between the medina and the ksar. The latter is generally located in arid and semi-arid regions. The author also highlighted several points of similarity: the centrality around a sacred building, the hierarchization of space (from public to private), and the strategies for fortification.

Undoubtedly, the ksar is an architectural model with the fascinating characteristic of being disseminated at different periods (likely since antiquity, as indicated by structures dated to the early first millennium BCE in Libya's Fezzan region) and enabling the construction of similar habitation modes adapted to desert environments. The origins of this type of settlement lie not only in the long-distance trade between the peoples of the Maghreb and Bilad Al-Sudan but also in the connections between Africa and the Mashreq and between Africa and Europe. Additionally, during the medieval period, the spread of Islam and the diffusion of Ibadism, one of the forms of Kharijism, played a role in forming the ksour. These settlements also reflect the interaction between sedentary and nomadic lifestyles, initially belonging to a semi-sedentary model and later becoming entirely sedentary. The ksour is often built on elevated ground, such as a rocky promontory, and typically near an Oued (water source). The morphology of the terrain on which the ksour are constructed, along with their immediate environment (such as a palm grove, erg, depression, or rocky plateau), determine the construction materials used, their overall shape, and the internal distribution of their spaces, which are most frequently arranged in a radio concentric or grid pattern [30].

Urbanization in the Ziban, as in other Saharan regions, took the form of ksour shaped by geographical, religious, historical, and economic factors. The ksour were often named after a sedentary community, a notable landmark, a revered figure, or the geomorphological features of the settlement site [34].

An “oasis” is a fertile area in a desert where water is available from springs or wells, enabling vegetation and often supporting human settlement. This water availability allows for the growth of plants, which can range from grasses and shrubs to trees and crops. Oases have historically been crucial for trade routes and settlements in arid regions, providing essential resources for survival and agriculture [35]. An oasis typically comprises three primary components: water sources, ksar, and palm groves. These elements work in harmony to create a sustainable living environment in arid regions [22,23,25,35–37].

3. Methodology and Data Collection

This article adopted a comparative approach, encompassing historical studies and architectural analysis to reveal detailed construction techniques. Additionally, in situ observations and examinations were conducted to assess the state of conservation and photographically document the building system. Moreover, the investigation concluded in-situ tests of the mud bricks used to construct each of the two studied ksour, Lichana and Chetma. To this end, a representative sampling [38,39] was set up to reflect the characteristics and overall composition of the mud bricks observed in the studied ksour. Accordingly, three (03) samples of mud bricks were selected and learned from the ksar of Lichana (S1; S2; S3), and Ksar of Chetma (S’1; S’2; S’3) to cover the predominant material’s characteristic. In this study, one representative sample from each ksar (S1 and S’2) was selected for presentation, as it effectively captures the key properties shared with the two remaining samples (S2; S3 and S’2; S’3).

The samples (S1 and S’2) for the said tests were prepared from mud bricks taken from specific locations in the two ksour and were finely crushed before testing. The protocol for these tests was based on CRAterre’s earliest and most recent work [15,16] and adapted by the authors (Fig. 2). These tests are:

- Sedimentation in a bottle: This test allows researchers to observe the different components of earth used in construction (sand, silt, and clay) and to compare their regularity in different samples. However, this test cannot provide information on the grain size proportions due to the more or less inflated character of grains such as clay. The test is done in 4 steps: 1) in a transparent bottle, fill 1/4 with earth and 3/4 with water; 2) shake vigorously; 3) leave to stand for at least 24 hours until the water is clean; 4) note the proportions of the different constituents: gravel and sand at the bottom, silt, and clay at the top.
- Cigar test: The “cigar” test allows us to identify a primary understanding of the cohesion of the earth. The test is done in 4 steps: 1) Eliminate particles larger than 5 mm from the sample; 2) Prepare the sample in the plastic state and let it rest. Thus, the clay has time to react with the water; 3) Make a cigar 3 cm thick and gently push it into the void; 4) Measure the length of the cigar (L): if L<5 cm, the earth is sandy; and if L>20 cm, the earth is of clay nature. Repeat the test three (3) times consecutively for accuracy.
- Pellet test: Like the cigar test, the pellet test is used to determine the cohesion of the earth and to check if the amount of clay in the earth is appropriate for making mud bricks. The test is done in 4 steps: 1) Remove the gravels from the sample and prepare the earth to achieve a plastic state; 2) Mould three pellets using a piece of PVC tube or similar; 3) After drying, observe any shrinkage phenomena; 4) Evaluate the resistance of the earth by breaking and crushing between the thumb and the index finger.

At the end of these tests, qualitative and quantitative information was provided, enabling a reasonably detailed classification of the earth used to construct two ksour. In addition to these tests, the soil texture triangle was used to classify the earth and determine the earth’s texture typology. Indeed, there are 12 earth textural classes. This triangle is used so that terms like “clay” or “loam” always have the same meaning.

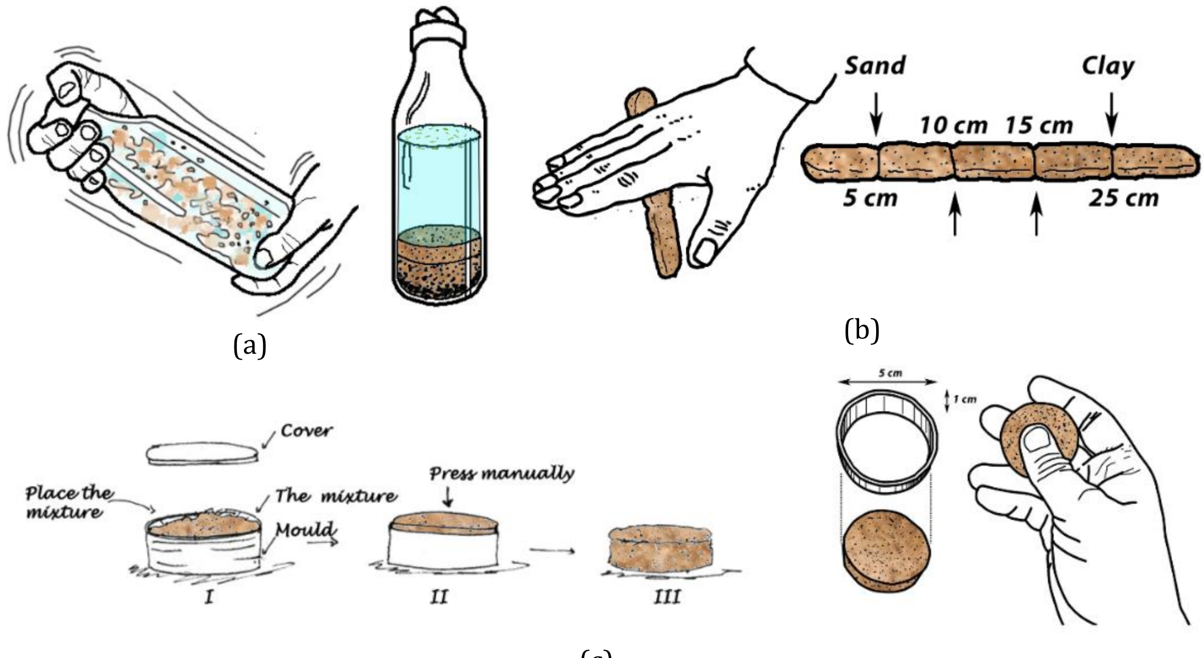


Fig. 2. Schematisation of the protocol of the three tests: (a) Sedimentation in bottle test; (b) Cigar test; (c) Pellet test. Developed by authors, 2024

Each texture corresponds to specific percentages of sand, silt, or clay (Fig. 3). The soil texture triangle is not an inherent part of the sedimentation test, but is an essential tool for interpreting the results. After performing the sedimentation test, record the proportions of sand, silt, and clay. These proportions are then plotted on the soil texture triangle to determine the sample's classification. Based on this position, the earth texture class, such as sandy loam or silty clay, can be identified using the standard classifications provided by the triangle. Finally, the findings should be documented, and recommendations should be made based on the soil texture analysis. At the end of these tests, qualitative and quantitative information was provided, enabling a reasonably detailed classification of the earth used to construct two ksour.

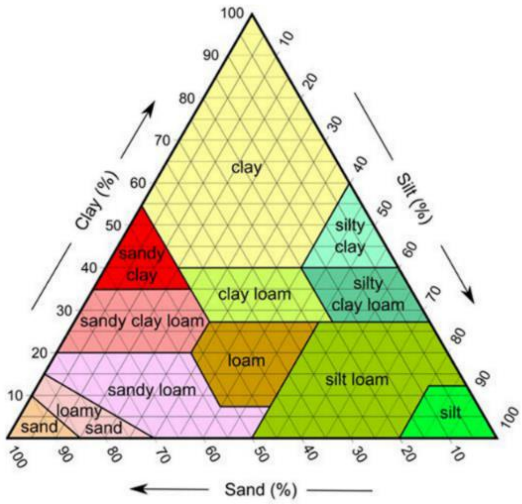


Fig. 3. Soil Texture Triangle [40]

4. Presentation of The Context of The Study: The Ziban Region

The Ziban region is located in southeastern Algeria. According to Cataldo [41], this region is divided into three distinct zones: Northern Zab, Southern Zab, and Eastern Zab. Each regroups a set of sub-regions represented by ksourian establishments (or oasis-cities). Largeau [42], considered Biskra an independent central Zab.

The Ziban is crossed by two main Oueds: The Oued Biskra (also known as Oued Sidi Zerzzour) and the Oued Djedai, which impacted the development and distribution of these ksourian establishments. However, each ksar has its particular shape. The common feature of all these ksours is their integration into the palm groves, which gave them a distinctive oasis landscape [43].

Algeria periodically experiences episodes of floods, which manifest catastrophically, posing a constraint on activities, hindering economic and social development, and creating a housing crisis [44]. The Ziban region, located in the Algerian lower Sahara at the hyper-arid zone's northern limit, faces water and wind. The risk of flooding is not specific to Saharan cities, but it is often underestimated due to its rarity. However, the characteristics of the Sahara lead to a distinction between risks related to Oueds (river flooding) and those related to closed depressions [45].

In the second half of the 20th century, the Ziban and surrounding areas underwent one of the most significant natural disasters in the region's modern history. In 1969, heavy rainfall caused catastrophic flooding, affecting urban and rural areas. Indeed, the rains caused oueds to overflow, inundating vast portions of Biskra and its surroundings. The floodwaters caused widespread damage to houses, infrastructure, and agricultural lands, notably the palm groves essential to the region's economy. In addition, many people were displaced, and there were reports of casualties, though the exact figures vary. The flooding disrupted daily life, leaving communities isolated and needing emergency assistance. The 1969 flooding spurred discussions on water management and the construction of better infrastructure to mitigate the risk of future flooding in Biskra.

The case studies focus on two ksour: the ksar of Lichana and Chetma, located respectively in northern Zeb (Zab Dahraoui) and eastern Zab (Zab Chergui) (Fig. 4). These ksour were selected for several reasons. Firstly, the authors have in-depth knowledge of these sites, having been involved in research, academic, professional, and participatory/volunteer projects since 2013. Multidisciplinary teams, including architects, engineers, archaeologists, and craftsmen specializing in heritage conservation, have conducted extensive studies and interventions in these ksour, providing valuable data for this research. Secondly, the ksar of Chetma and Lichana were chosen for their heritage significance and potential to contribute to local development in the Ziban region.

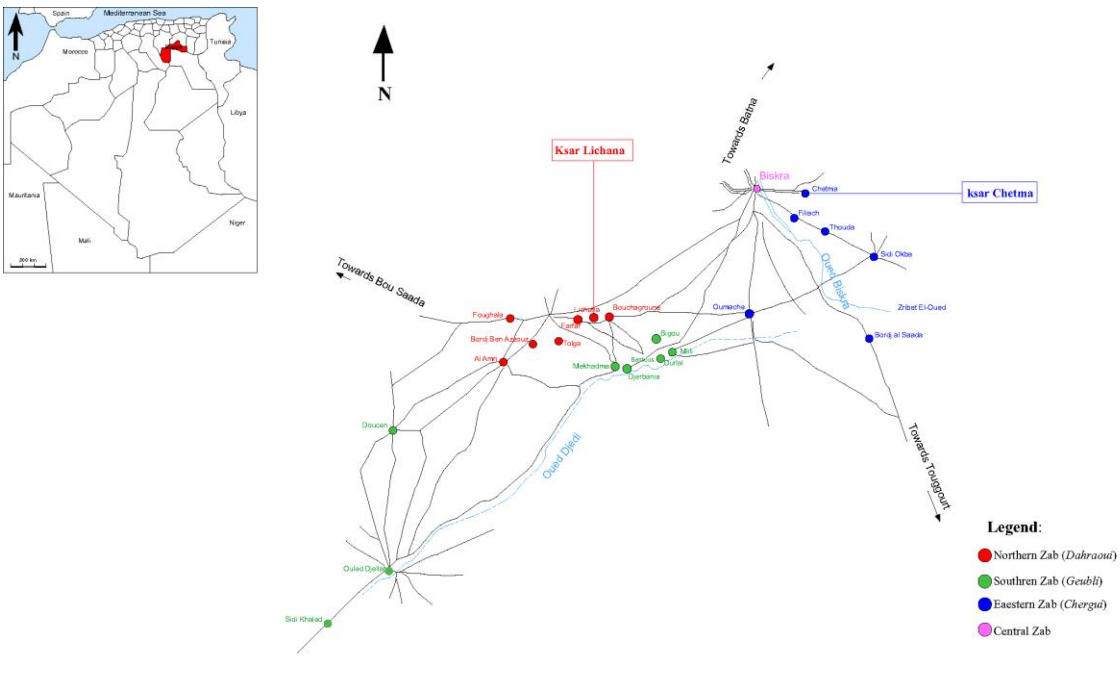
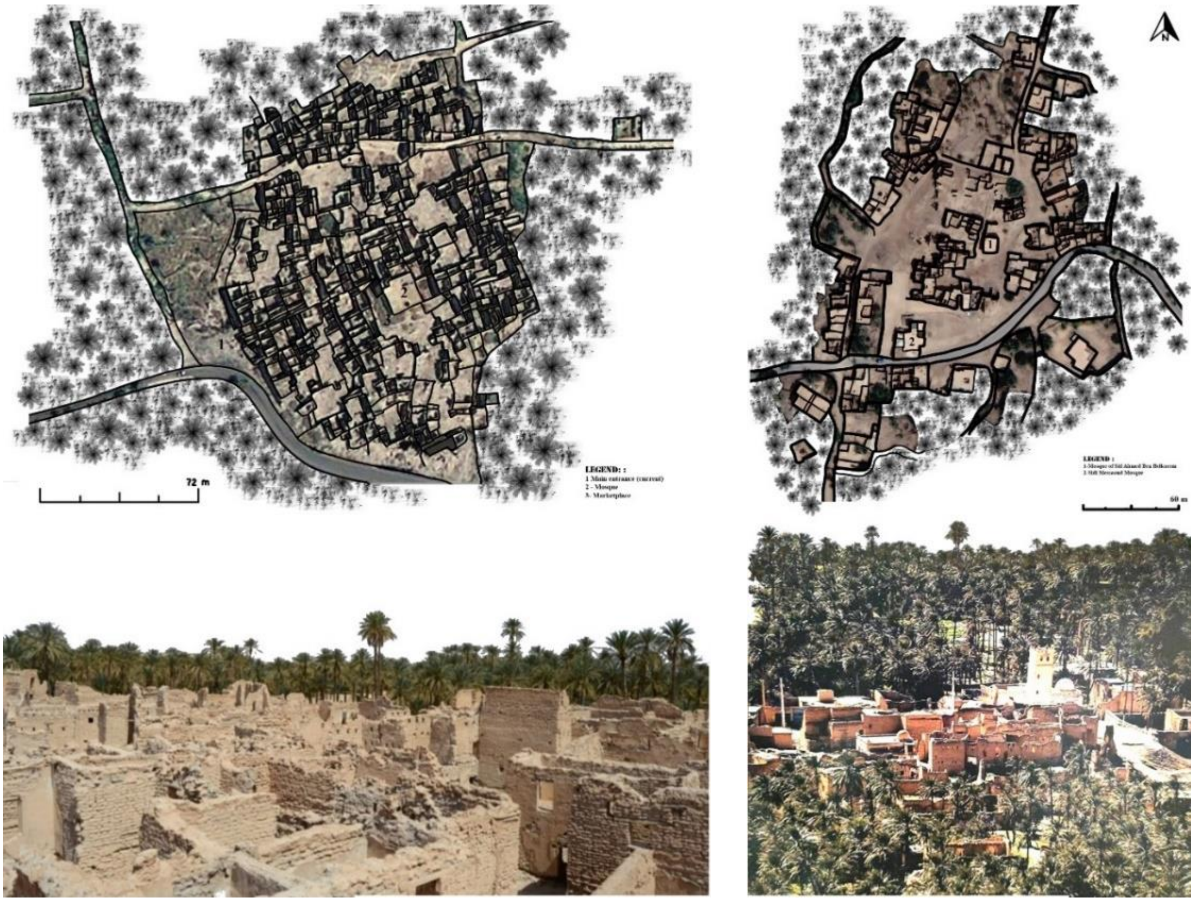


Fig. 4. Map showing the location of the ksar Lichena and Chetma. Developed by authors, based on [46]

The ksar of Lichana and Chetma exhibit similarities: they are prime examples of earthen architecture, reflecting the ingenious use of locally available materials. The architecture of these two ksour integrates environmental adaptability, such as thick walls for insulation and compact layouts to reduce exposure to heat and sandstorms [47]. Their construction primarily employs earth and palm wood, which are abundant in the region and have historically been central to vernacular building practices (Fig. 5).



(a) (b)

Fig. 5. Views of the two ksour: (a) the ksar of Lichana; (b) the ksar of Chetma. Elaborated by authors, based on Google Earth, 2024, and CAPTerre [48]

In the ksar of Lichana and Chetma, the load-bearing walls were built in an English bonding pattern (in French: *Appareillage debout*) and coated on both the outside and inside with an earth-based plaster, giving the walls a harsh texture (Fig. 6 and Fig. 8). In addition, the mud bricks used are rectangular with dimensions of 40x20x10 cm. However, it is possible to find mud bricks 36 or 37 cm long. Palm trunks are utilised for vertical and horizontal structural elements like pillars, beams, and joists (Fig. 7 and Fig. 9).

In the studied ksour, the load-bearing walls rest on foundations laid in the form of trenches filled with large river stones brought from oueds. Certain walls have a stone base to prevent capillary rise. Building materials of Roman origin, such as stone blocks and columns, were sometimes reused in vernacular architecture. These walls are in a better state of conservation than walls without a stone base. As confirmed by Zerari, Pace, and Sriti [34], the reuse of building materials is a common practice in the Ziban region, particularly in areas close to the Limes line.

The mosque of Lichana features a distinctive building element: its roof was constructed using IPN joists (I-beams) filled with fired hollow bricks, a building technique that reflects French colonial influences (Fig. 7), as stated by Dali and Belakehal [20]. However, the locals have managed to preserve the authenticity of the two ksour, as no significant changes in construction techniques or new materials have been observed. This resilience is primarily attributed to *Touisa*, an ancestral practice of community mutual aid in Algeria [49]. It involves members of the same family or tribe taking turns to carry out collective tasks. Particularly widespread in the southern Saharan regions, *Touisa* has played a crucial role in the construction and maintenance of buildings, ensuring the continuity of traditional practices and know-how across generations.

The ksar Lichana is in an alarming state of conservation, with most buildings either fully or partially in ruin. During our visit, the first noticeable feature was the widespread debris. Many remaining walls show significant erosion and extensive plaster detachment, exposing the underlying mud brickwork on nearly all surfaces. Rising damp due to capillary action is a prevalent issue in the ksar, attributed to the water-retentive nature of the earth used in construction, which promotes the upward movement of moisture.

Like many of the ksour in the Ziban, the decline of the ksar of Chetma began after the floods of 1969, which forced its inhabitants to relocate to the new city of Chetma, just a few kilometres away. The Ksar has also been transformed following a poorly executed conservation intervention two decades ago, during which many houses around the mosque were razed, further impacting its integrity. Today, the ksar stands largely abandoned, with many homes in ruins or completely collapsed. Its current state of conservation is marked by severe pathologies, including erosion, rising damp, top wall erosion, extensive plaster detachment, structural deformation, and damage to wooden beams. This situation closely mirrors the condition of the Lichana ksar, emphasising the urgent need for conservation efforts to protect this invaluable cultural and historical heritage before it disappears entirely.

(a)

(b)

Fig. 6. Views of the wall systems in the ksar of Lichana: (a) load-bearing walls (base, wall, and top); (b) construction systems of the base of load-bearing walls (with and without stone footing). Photos by authors, 2024

(a)

(b)

Fig. 7. Views of the roof structures in the ksar of Lichana: palm wood post-and-beam; b) IPN joists of the mosque. Photos by authors, 2024

(a)

(b)

Fig. 8. Views of the wall systems in the ksar of Chetma: a) load-bearing walls (base, wall, crowning, and surface); b) construction systems of the base of load-bearing walls. Photos by authors, 2024

Fig. 9. Views of the roof structures in the ksar of Chetma: palm wood post-and-beam. Photos by authors, 2024

5. Nature of the Earth Used in The Ksar of Lichana and Chetma

Field tests were carried out on two samples: one taken from the ksar of Lichana (S1), specifically a piece of mud brick that was retrieved from a ruined house near the western gate of the ksar. Despite the deterioration of its original structure, the piece of brick appeared in relatively good condition, making it a viable specimen for detailed earth analysis (Table 1). The second sample (S'1), concerning the ksar of Chetma, was taken from a ruined property between the two mosques of the ksar. According to the local people's oral history, the brick-making earth originated from Ouldja, north of the ksar, and was transported by donkeys. The mud bricks appeared in relatively good condition, making them viable specimens for detailed earth analysis (

Table 2 and

Table 3).

Table 1. Collection and preparation of mud brick samples (S1 and S'1) for testing. Elaborated by authors, 2024

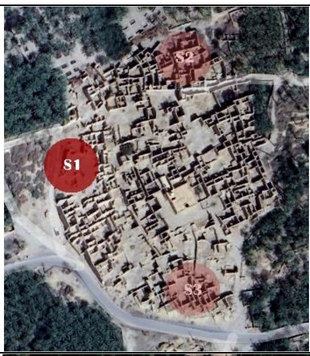
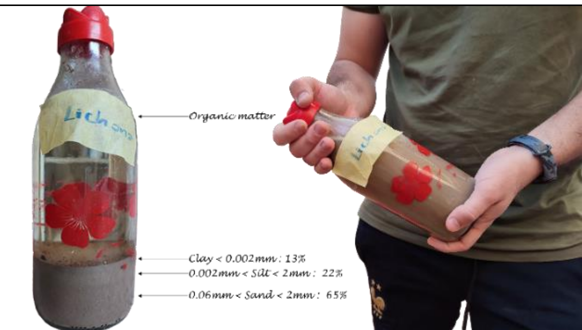
Ksar	Source of the mud-brick	Samples	
		Mud brick samples	Crushed mud brick
Lichana			
Chetma			

Table 2. Stages and explanation of the results of the three in-situ tests performed on the sample (S1) from Lichana. Elaborated by authors, 2024

Tests	Observation and interpretation	Tests' illustrations
Sedimentation in bottle	This earth comprises grains of different sizes (clay 13%, silt 22%, and sand 65%). The test indicates a sandy earth with probably some clay and silt.	
Cigar test	The cigar is cut to an average length of 11.73 cm, indicating a significant level of earth cohesiveness.	

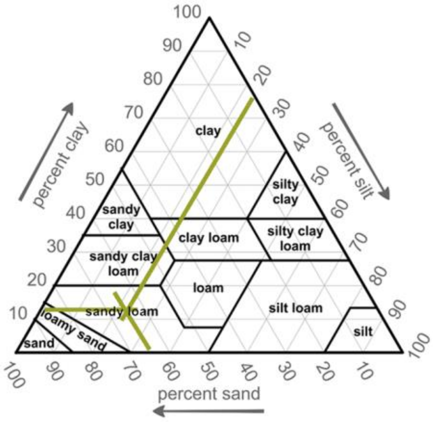
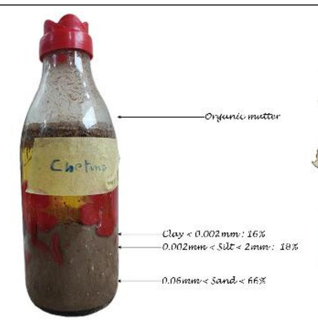
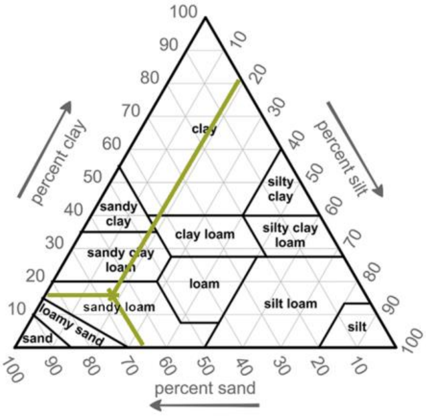
Pellet test	No shrinkage was observed, and the breakage required little force and was easy to reduce to powder. This indicates sandy earth.	 
Soil Texture Triangle	The earth is a balanced mixture of sand (65%), silt (22%), and clay (13%), which means it is a sandy loam earth.	

Table 3. Stages and explanation of the results of the three in-situ tests performed on the sample (S’1) from the ksar of Chetma. Elaborated by authors, 2024

Tests	Observation and interpretation	Tests’ illustrations
Sedimentation in bottle	This earth is a mixture of different grains (16% clay, 18% silt, and 66% sand). The test conducted indicates that it is sandy in nature.	 
Cigar test	The cigar is cut to an average length of 13.67 cm. This earth is more cohesive than the first sample from Lichana.	 
Pellet test	The shrinkage of the pallet was greater than 1 mm. Breaking it required significant force, and the sample was not very friable. This demonstrates the excellent cohesion of the clay in the earth.	 

Soil Texture Triangle	The earth is a sandy loam, a mixture of sand (66%), silt (18%), and clay (16%).	

The conservation of the mud bricks' integrity suggests that it can provide valuable insights into the composition and quality of the building materials historically used in the said ksour, shedding light on the construction techniques and material resilience employed in traditional Saharan architecture. The mud bricks used in both ksour are uniform in size, measuring 40x20x10 cm. Although the earth in both locations is similarly classified as sandy loam, their composition has notable differences. The earth in Ksar Lichana exhibits good cohesion due to its clay content. However, the earth in Ksar of Chetma demonstrates even greater cohesion, attributed to adding wheat straw, a component absents in Lichana's mud brick sample. This difference highlights a variation in material choice and construction techniques between the two ksour.

Adding wheat straw to the mud paste reduces shrinkage and improves the tensile strength of mud bricks, while strengthening the resistance of mud plasters to rain-induced erosion [50,51]. In mud materials, straw is used in mud brick masonry and other techniques, such as cob construction [52], where it primarily enhances performance by bridging microcracks, which prevents crack propagation [53]. This crack-bridging effect increases the material's ductility and toughness, helping to maintain its integrity under stress and significantly improving its overall mechanical properties. In Algeria, wheat straw is one of the most commonly used vegetable fibres in mud materials [54,55], due to its abundance and availability in the region.

6. Synthesis

The structures of the two studied ksour are remarkably similar in design (Fig. 10). Both utilise a construction system centred on load-bearing walls made of mud bricks measuring 40x20x10 cm. Particular walls stand on a stone base up to 60 cm high to protect them against rising damp. Mud bricks are sun-dried bricks made from earth, mixed manually, and containing a blend of clay, silt, sand, aggregate, and sometimes natural fibres like the ones of Chetma that contain the wheat straw. Floors are crafted from palm tree trunks, overlaid with palm rib branches (*jerides*), and finished with a layer of raw earth. Foundations consist of trenches filled with large river stones brought from the oueds. In both studied ksour, certain buildings rest on large cut stone bases, stone columns, and other architectural elements, potentially of Roman origin.

Since mud brick is the primary building material in both the ksar of Lichana and Chetma, it is essential to note that it is fragile and highly susceptible to water damage (Fig. 10). Indeed, rainwater, rising damp, and even splashing water can cause major problems, such as erosion at the top and the base of walls and plaster detachment, which threaten the structure's stability. In addition, wind erosion can affect the conservation of earthen buildings, particularly the protruding elements and the exterior plaster. To mitigate these risks, earthen buildings require adequate protection at both the base and the top of walls; the exterior skin of walls, including mud plaster, also needs regular maintenance. In the said ksour, stone bases, sometimes as high as 60 cm, were used by locals to protect mud brick walls from rising damp. However, in cases where no stone base was used, and the mud brick walls were in direct contact with the ground, these structures were more susceptible to moisture damage.

The walls were coated with a thick layer of mud plaster, often applied in multiple layers, specifically designed to shield the walls and their tops from erosion caused by rainwater. Locals regularly repaired the plaster after each rainy season to maintain its protective properties. This regular maintenance was crucial for preventing water damage and preserving the structural integrity of the building. Similarly, the layers of mud on the floor required regular maintenance, with new layers of mud added on top of existing layers, particularly after the rainy season. While this process helped preserve the floors, the cumulative weight of the layers increased the load on the structure. Over time, the additional weight could strain the beams, leading to bending or deformation. Furthermore, the lack of roof maintenance could result in rainwater stagnation, causing water infiltration that leads to rotting of the palm wood.

The preservation of earthen structures is critically dependent on regular maintenance to prevent deterioration and ensure their longevity. This challenge is particularly pronounced in the ksour of Lichana and Chetma, where the departure of the local population has significantly disrupted the upkeep of these buildings. Following the exodus of the inhabitants, the responsibility for maintaining the structures was neglected, leading to the gradual erosion of the ancestral know-how essential for their care. As a result, this expertise, passed down from generation to generation, has been lost. The absence of such knowledge within contemporary local communities has accelerated the decay of these culturally and historically significant structures.

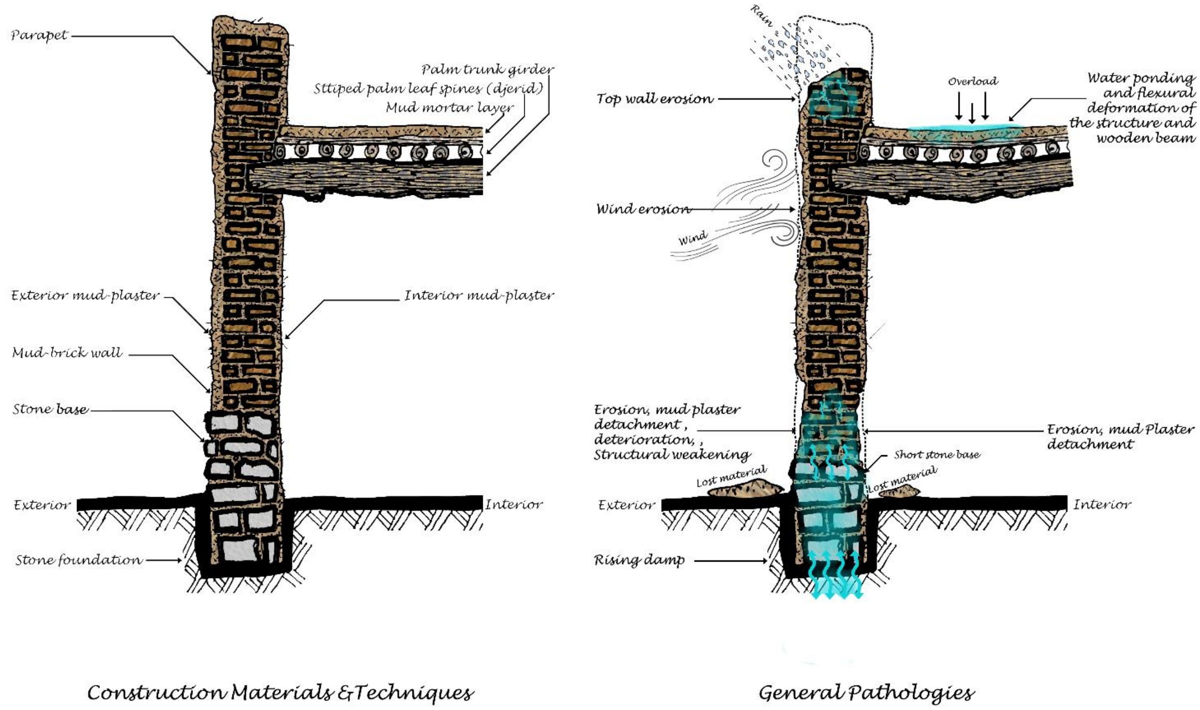


Fig. 10. Construction details and general pathologies in the ksar of Lichana and Chetma. Elaborated by authors, 2024

Knowing the earth's condition directly on-site is not just a technical step; it plays a central role in shaping how conservation work should be approached. In Chetma, where the earth is richer in clay and the mud is mixed with straw, preserving the traditional technique of adding organic fibres becomes essential. It helps control shrinkage and improves the strength of repairs, staying true to how the original builders worked. In contrast, at Lichana, where the earth shows lower clay content and less use of straw, conservation efforts must focus more on protecting surfaces from erosion, without introducing materials or methods that were not originally there. Respecting these small but essential differences ensures that preservation strategies stay faithful to the spirit of the vernacular architecture while helping these fragile structures endure over time. Moreover, any new mud materials produced for conservation efforts must be compatible with the traditional ones identified and characterised in this study, ensuring material coherence and long-term preservation success. Specifically, in conserving the two ksour, sandy loam earth should be used as a base material; however, for the ksar of Chetma, the mixture should include wheat straw fibres to replicate the original technique, while for Lichana, a sandy loam without added straw would be more appropriate.

7. Conclusions

This article analyzed the use of earthen materials in the construction of two ksour located in the Ziban region of south-eastern Algeria: the ksar of Lichana and the ksar of Chetma. Based on a comparative approach, the study combines historical research and architectural analysis with in situ tests (sedimentation in a bottle, the cigar test, and the pellet test) on the mud bricks used in constructing these two ksour. In addition, field observations and visual examinations were carried out to assess the state of conservation of the structures, together with photographic documentation of the construction techniques observed.

The tests, sedimentation in a bottle, the cigar test, and the pellet test revealed that, although the composition of the mud bricks used in the construction of the two ksour is broadly similar, specific differences were identified, reflecting the natural variability of the raw earth, even in geographically close locations. The mud brick from Chetma contains more clay content and exhibits a greater shrinkage rate. However, incorporating straw fibres into the bricks' composition mitigates this issue, enhancing their quality and performance. These analyses have enabled the mud bricks from each ksar to be identified and characterized, providing essential data for documentation and informing future conservation efforts that require compatible building materials. It is reasonable to assume that the earth produced mud bricks, mortar, and plaster often originates from the same local source. This is mainly due to practical considerations such as ease of access, cost-effectiveness, and traditional building knowledge. As these materials derive from the same soil, they are likely to share similar physical and mechanical characteristics, such as clay content and shrinkage behavior. However, variations in preparation methods or adding specific additives can lead to distinct differences between the properties of bricks, mortar, and plaster.

The investigation into the conservation state of the ksar of Lichana and Chetma highlights their critical condition. Currently abandoned and neglected, these structures face significant conservation issues. Many buildings have partially or entirely collapsed, leaving much of the architectural heritage in ruins.

In situ investigation and analysis are fundamental to the conservation of heritage sites. Before any intervention project, a thorough preparatory study focusing on the characterization of building materials is essential. The methodology employed in this study serves as a valuable framework, highlighting the importance of systematic analysis in understanding the properties of materials. In-situ testing of mud bricks plays a vital role, particularly in contexts where laboratory analyses are unavailable, impractical, or constrained by logistical limitations. Although laboratory testing provides more precise measurements and comprehensive data, in-situ methods are essential for obtaining direct, real-time assessments of material conditions in their actual environmental context. These field evaluations offer critical insights into the current state and performance of the materials, thereby informing appropriate conservation strategies.

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References

[1] Hugo V. Notre-Dame de Paris. Paris: Charles Gosselin Libraire; 1831.
[2] Azizi-Bondarabadi H, Haji Sadeghi N. Local seismic culture in Iranian vernacular architecture: evidence from Yazd earthen architecture. Built Heritage 2022;6. https://doi.org/10.1186/s43238-022-00051-3
[3] Parracha JL, Lima J, Freire MT, Ferreira M, Faria P. Vernacular earthen buildings from Leiria, Portugal - Architectural survey towards their conservation and retrofitting. Journal of Building Engineering 2021;35. https://doi.org/10.1016/j.jobe.2020.102115

[4] Tomasi J, Barada J. The technical and the social: challenges in the conservation of earthen vernacular architecture in a changing world (Jujuy, Argentina). Built Heritage 2021;5. https://doi.org/10.1186/s43238-021-00034-w
[5] Dali AI, Belakehal A. Style architectural des monuments de l'époque coloniale : cas de l'Hôtel du Sahara à Biskra, Algérie. In: Conservation and promotion of architectural and landscape heritage of the Mediterranean coastal sites. Milano: Franco Angeli; 2019. page 154-67.
[6] Porada K. Earthen Forms in Landscape Architecture-from Geoglyphs to Contemporary Urban Parks. 2018; https://www.researchgate.net/publication/340127001
[7] Gandreau D, Delboy L. Inventory of earthen architecture [Internet]. Unesco; 2012 [cited 2025 Feb 17]. http://catalogue.bnf.fr/ark:/12148/cb316787287
[8] Metallaoui MA, Dali AI. Sustainable Building Materials in the Architecture of Saudi Arabian Oases: Past and Present Examining AlUla. 2025. page 441-51. https://doi.org/10.1007/978-981-97-8588-9_42
[9] UNESCO, WHC-CRATerre. World Heritage. Inventory of earthen architecture [Internet]. Grenoble: 2012 [cited 2024 Nov 9]. https://whc.unesco.org/document/116577
[10] Le Corbusier. Les Constructions "Murondins." Paris: Étienne Chiron; 1942.
[11] Fathy H. Gourna : A tale of two villages. Cairo: Ministry of Culture; 1969.
[12] Guillaud H, Doat P, Rollet P, Houben H, Garnier P, Fontaine L, et al. Technologie de construction et architecture de terre. Proposition de directions prioritaires de recherche pour la République de Corée : Rapport final (Volume 1/2) [Internet]. 2022. https://hal.science/hal-03716122v1
[13] Dreyfus J. Manuel de construction en terre stabilisée en Afrique Occidentale Française. Rufisque: Impr. du Gouvernement général; 1954.
[14] Bardou P, Arzoumanian V. Archi de terre. 1978;103.
[15] Doat P, Hays A, Houben H, Matuk S, Vitoux F. Construire en terre . Paris: Édition Alternative et Parallèles; 1979.
[16] Houben H, Guillaud H. Traité de construction en terre. Marseille : Édition Parenthèses; 1989.
[17] Texier C. Exploration de la province de Constantine et des Zibans. Revue Archéologique [Internet] 1848 [cited 2024 Nov 9];5:129-35. http://www.jstor.com/stable/41745678
[18] Cauvet C. Les marabouts : petits monument funéraire et votifs du nord de l'Afrique. Revue africaine : journal des travaux de la Société historique algérienne [Internet] 1923 [cited 2024 Nov 9];274-329. https://gallica.bnf.fr/ark:/12148/bpt6k57297525
[19] Didier G. Souvenirs d'Algérie : de 1877 à 1882. Bibliothèque nationale de France, département Cartes et plans; 1882.
[20] Dali AI, Belakehal A. Hotel Architecture in the French Colonization Era. The Case of Biskra City, Algeria. Prostor [Internet] 2023 [cited 2024 Oct 31];31:154-67. https://doi.org/10.31522/p.31.2(66).2
[21] Zerari S. Contribution à la caractérisation morphologique et architecturale du patrimoine religieux musulman en Algérie. Cas des mosquées du Bas-Sahara. 2021;
[22] Melouka N. Stratification entre Ville Coloniale et le Ksar Traditionnel de Ouargla. 2024;
[23] Dali AI. Matériaux et techniques de construction des hôtels de Biskra : Entre influences locales et expérimentations coloniales. 2023;
[24] Zerari S, Sriti L, Mensouri K. Dégradation du patrimoine ksourien du sud algérien. Cas du tissu résidentiel des Ziban (Biskra). Al-Sabîl : Revue d'Histoire, d'Archéologie et d'Architecture Maghrébines [Internet] 2019;7. https://www.researchgate.net/publication/349120388
[25] Dali A. Étude et revalorisation du patrimoine architectural de terre, cas des ksour dans le sud algérien . 2001;
[26] Zine A. Les ksour. L'espace Ksourien ou la mémoire en risque de péremption. Habitat Tradition Modernité. HTM 1994;2:17-21.
[27] Marouf N. Lecture de l'espace oasien. Sindbad; 1980.
[28] Boumerzoug A. L'apport référentiel de l'habitat vernaculaire pour assister la production d'une architecture contemporaine localement située et climatiquement performante : l'exemple des ksour des Ziban. 2023;
[29] Boumerzoug A, Rais M, Sriti L. Thermal analysis of the vernacular architecture in the Ziban, Algeria. Pollack Periodica 2022;17:123-8. https://doi.org/10.1556/606.2022.00648
[30] Chekhab-Abudaya M. Les Villes Du Sahara : l'exemple des Qsûr (Algérie). In: Histoire du Maghreb médiéval - XIe-XVe siècle. Malakoff (Hauts-de-Seine): Armand Colin; 2021. page 239-42. https://doi.org/10.3917/arco.bures.2021.01.0239
[31] Moukhenachi S. Evolution Urbaine Des ksour : Permanences Et Mutations. Cas De Timimoun. 1997.
[32] Guide Michelin. Maroc 1972. In: Medina et Ksours, une culture millénaire. Grenoble: Association les 2Rives; 1991.
[33] Romey A. Les Saʻīd ʻAṭbā de N'Goussa: Histoire et état actuel de leur nomadisme. Paris: L'Harmattan; 1983.

[34] Zerari S, Pace V, Sriti L. Towards an Understanding of the Local Interpretations of the Arab Mosque Model in the Saharan Regions. Re-exploration of the Ziban in South-Eastern Algeria. ArcHistoR 2023;19:96-129.
[35] Barker G. Oasis. In: The Oxford Companion to Archaeology. Oxford: Oxford University Press; 2012.
[36] Ben Charif H, Belakehal A, Zerari S. Earthen Architecture in Southern Algeria: An Assessment of Social Values and the Impact of Industrial Building Practices. Open Archaeology [Internet] 2023 [cited 2024 Oct 31];9. https://doi.org/10.1515/opar-2022-0324
[37] Jouve P. Les oasis du Maghreb, des agro-écosystèmes de plus en plus menacés. Comment renforcer leur durabilité ? Courrier de l'environnement de l'INRA [Internet] 2012 [cited 2024 Oct 31];62:113-22. https://hal.science/hal-01222196/file/C62-Jouve-04-02-13.pdf
[38] De Singly F. L'enquête et ses méthodes: le questionnaire. Paris: 1992.
[39] Ghiglione R, Matalon B. Les Enquêtes sociologiques. Théories et Pratiques. Paris: 1978.
[40] Bhandari BP, Dhakal S. A multidisciplinary approach of landslide characterization: A case of the Siwalik zone of Nepal Himalaya. Journal of Asian Earth Sciences: X 2021;5:100061. https://doi.org/10.1016/j.jaesx.2021.100061
[41] Cataldo H. Biskra et les Ziban. Montpellier: SupExam; 1988.
[42] Largeau LV. Le Sahara algérien, les déserts de l'Erg. Paris: Hachette; 1881.
[43] Zerari S, Cirafici A, Sriti L. Issues in the Expression of Local Identity in the Saharan Regions of Algeria: In Search of References to Vernacular Architecture. Conservation Science in Cultural Heritage 2022;22:181-206.
[44] Lahlah S. Les inondations en Algérie. In: », Actes des Journées Techniques/ Risques Naturels : Inondation, Prévision, Protection. Batna: 2004; 43-57.
[45] Côte M. La ville et le désert. Le Bas-Sahara algérien. Paris: Karthala; 2005.
[46] Zerari S, Sriti L, Pace V. Morphological Diversity Of Ancient Minarets Architecture In The Ziban Region (Algeria): The Question Of Form, Style And Character. METU Journal of the Faculty of Architecture [Internet] 2020 [cited 2024 Nov 9];37:127-52. https://doi.org/10.4305/METU.JFA.2020.2.6
[47] Alkama D, Tacherift A. Essai d'analyse typo-morphologique des noyaux urbains traditionnels dans la region des ziban. Courrier du Savoir [Internet] 2001 [cited 2024 Oct 31];1:81-8. https://revues.univ-biskra.dz/index.php/cds/article/view/195
[48] Terki Y. De Terre et d'Argile. Catalogue de l'exposition dédiée aux architectures de terre dans le monde. Alger: Les presses de l'imprimerie En Nakhla; 2013.
[49] Aboudil R, Dali A. Civil participation in the restoration of the ancient nucleus of the M'cid mosque in Biskra, Algeria. In: LiMeS Project. Life between Mediterranean and Sahara. Padova: Padova University Press; 2024. page 141-8.
[50] Facey W. Dir'iyyah and the First Saudi State. London: Stacey International; 1997.
[51] Alnowaiser M ibn AA. Khasais al-Turath al-Omranie fie al-Mamlaka al-Arabiah al-Saudia (Characteristics of Urban Tradition of Saudi Arabia). Riyadh: Darat Al-Malek Abdul Aziz; 1999.
[52] Manel N, Abdellah F. Raw Earth Architecture, an Adaptation Lesson in Distress. The Case of Khanguet Sidi Nadji ksar, Biskra, Algeria. International Journal of Innovative Studies in Sociology and Humanities 2022;7:60-76. https://doi.org/10.20431/2456-4931.0706007
[53] Xie L, Chen Z, Hu X, Cai W. Effect of straw and starch on mechanical performance of mud mortar for rubble masonry. Journal of Building Engineering 2025;104:112268. https://doi.org/10.1016/j.jobe.2025.112268
[54] Baiche B, Osmani M, Walliman N, Ogden R. Earth construction in Algeria between tradition and modernity. Proceedings of the Institution of Civil Engineers - Construction Materials 2017;170:16-28. https://doi.org/10.1680/jcoma.15.00048
[55] Kassou Y, Alkama D, Bouzaher S. Earthen Architectural Heritage in the Gourara Region of Algeria: Building Typology, Materials, and Techniques. Heritage 2024;7:3821-50. https://doi.org/10.3390/heritage7070181