Earthen architecture in the Gourara region

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Abstract

This paper discusses the reality of earthen architecture in the Gourara region in Algeria, and the future of mud built heritage in the light of sovereign decisions taken by the Algerian state, especially the promotion of the region to a wilaya on 2021, and the accompanying direct impact on the oasian system distinguished by its fragile character. The research started by focusing on leader questions: What are the main reasons for the desertion of earthen architecture in the Gourara region? Moreover, what are the best ways to preserve it? In an attempt to study and understand these unique buildings, characterized by their diversity and sustainability, which have always been associated with a local identity and a civilization that extends back to prehistoric times, and its evidence still exists to this day. This prospective study aim to preserve what remains of them. These existence building was investigated in the region based on the descriptive and analytical approach including photographic documentation, building materials and techniques. In addition, the documentary historical approach relied upon. Finally, the author interviewed several qualified builder in order to collect data on local building culture. The research results recommending an urgency of thinking about a new perspective and strategies to preserving and protecting earthen architecture.

Keywords: *Gourara region, earthen architecture, agham, local building culture, ksar*

1. Introduction

Earthen architecture is considered an extension of the earth, as it seeks to reinforce the spiritual connection between humans and the material of clay, which is regarded as the primary component of human creation [1].

The earthen architecture in the Gourara region is distinguished by the diversity and multitude of its styles and forms, and it is the best example of the interaction of different cultures of successive human civilizations [2-3] with the harsh natural conditions. It is considering a part of the general human heritage, expressing identity and serving as a glimpse of national heritage. The preservation of earthen architecture has become a shared human responsibility and fundamental goal that should be prioritized by the Algerian state especially in the face of ongoing cultural invasion [4].

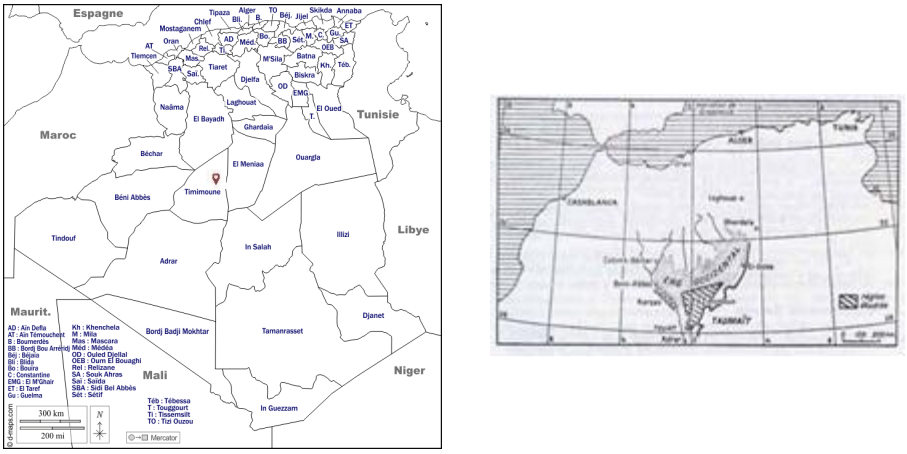
Through field surveys and observation of earthen buildings in the Gourara region, it is clear that their current situation urgently requires intervention due to their historical and architectural importance, before it is too late. Especially since periodic maintenance, operations, locally called "Touiza", have become very rare in light of the decline of the constructive custom [5] for several reasons, and the various interventions by the state have not benefited the region except for some projects under the United Nations Development Programme (UNDP). These interventions in some cases have been ineffective and far from professional and specialized, because of the scarcity of qualified builder, which their profession is going to disappear, and without any clear strategy to maintain it. In addition, with the promotion of the region to a wilaya [6], which will create an unprecedented, dynamic, it will accelerate the processes of built heritage deterioration if not taken seriously [7]. The topic of earthen architecture in the Gourara region poses us a deep problematic issue that carries within it many questions and contradictions. The main aim of this work is inventory the most important building techniques and materials of earthen architecture in the Gourara region as a first step towards preserving this ancestral architecture. In a final step, the research results could be very useful and helpful for preserving and making future actions of intervention on the earthen architecture.

2. Materials and Methods

2.1. Geographical and astronomical location of the study region

The study area is located in the southwestern of the Algerian desert. Geographically, it is bordering by the Great Western Sand seas to the north and west, the Tademait plateau and M'Guiden to the east, and the Touat région (Adrar) to the south. Thus formed a large triangle, where the northern tip plunges deeply into the Great Western Sand seas and the western side stretches far across the Tadmait plateau, and only the region in the southwest corner is truly alive, scattered with palm groves (*Figure 1)* .Its astronomical location is between the latitudes 31° 30' to 28° 30' north and the longitudes 1° east and 2° west of the Greenwich line [8]. And it appears clearly naturally isolated, and with this characteristic, undoubtedly the region has maintained its distinctive physiognomy, including customs and traditions that time has not had much impact on changing [9]

The capital of the region is currently the wilaya of Timimoun, the Ksours of the region are located within a radius of about 80 km, centered around the capital of the region, with Tabelkoza to the northeast, Oufrane to the south, and Bahammou to the west [10]. The region ends with the M'Guiden Valley, forming a large Sebkha.



(a) **(b)**

Figure 1. Geographical and astronomical location of the study region: (a) The location of Gourara region in Algeria [11]; (b) Gourara region and its borders [10]

2.2. Research methodology

The study relied on field research, which based on the descriptive and analytical approach and photographic documentation to obtain data and information to extract the various components of the buildings in the Gourara region. In addition, the documentary historical approach was also relied upon, which allowed us to access what was written and recorded about the region in order to enrich the cognitive aspect and interpret the various field data to be able to infer scientific facts. The author interviewed in semi-structured interviews several qualified builder in order to collect data on local building culture.

2.3. Research Goals

The objectives of this research lies primarily in attempting to identify and document the construction skills that are evidence of the genius of the desert dwellers. This settler with limited and simple means was able to create buildings that have stood for hundreds of years, reflecting their resilience and adaptation to the harsh desert environment. With the aim of preserving them from vanishing.

3. Historical Background

3.1 Historical background of earthen architecture

Earth construction techniques have been known for millennia; even today one third of mankind lives in earth buildings [12]. Kofi Agyekum indicated that history has extensively reported on how factors such as culture, weather, and geographical locations shaped the use of vernacular materials and technologies by indigenes of localities worldwide earthen architecture [13]. In the Gourara region, also the socio-cultural manifestations reflected in the composition and function of its architecture such as religious praises and dances [8] during "Touiza", however cultural manifestations are also those referring to the construction of physical spaces [14]. These construction customs are transmitted from generation to generation known as local building culture.

The use of earth as a building material has a disadvantage in that it can experience physical degradation over time, primarily due to its vulnerability to water. However,

several simple strategies can mitigate these issues. These include roof maintenance with suitable design. Additionally, using the stones foundations while raising them at the ground level to avoid the walls contacting the floor. K. Hadjri cite advantages and disadvantages of earth as a building material [15], (Table 1).

Table 1. Advantages and disadvantages of earth as a building material [15]

Advantages	Disadvantages
- Availability, - Versatility, - Low-cost/affordability, - Low environmental impact - Fire resistance - Excellent control of indoor air moisture - Low embodied energy - High thermal capacity - Low thermal conductivity - Good sound insulation properties - Highly recyclable - Easy workability - Easy to design with	- Durability - Maintenance - Socio-cultural perception - Structural limitations - Water absorption - Low resistance to abrasion and impacts - Specialist skills needed for plastering

3.2. The historical boundaries of the Gourara region

Before the French colonization, the region of Gourara was largely undiscovered and geographically isolated, with a few written sources mentioning it. These circumstances led to disagreements about its exact location. We review them as follows: Eugène Daumas considered it part of the Touat region, with its capital in Timimoun and containing 20 Ksar [16-17]. On the other hand, De Colombe and Henri Mager considered it a large group of oases adjacent to Aougrout, Deldoul, Deghamcha and Touat, that was created intentionally along the caravan trade route and compelled to take it due to the geographic topography of the region, it consists of 94 Ksar and a collection of Talmine Ksours [18-19]. On the contrary, V. Déporter [20-21] considered that strangers to the region, especially the Tuaregs, were the ones who use the name "Touat" to refer to the entire area extending from Tidikelt in the south to Gourara in the north. Meanwhile, the local inhabitants considered the name "Touat" to refer to the oases located in the Messaoud Valley. It is contains 12 districts with a total area of 500 km2 and 114 Ksar, starting from Tinerkouk to Sebaa. This viewpoint was supported by H. Bissuel, Henri Schirmer, De LA Martinière and N. Lacroix [22-24], and others. Even after the French colonization of the region in 1900, the same division remained in place with minor adjustments, as indicated by the 1901 census [25].

A series of amendments have been made to the organization of the Gourara region [26], starting with the issuance of the law of the creation of southern territories territories on December 24, 1902. The law of the creation the Common Organization of Saharan Regions (O.C.R.S) on January 10, 1957 followed this. Then, there was the decree establishing the

Saharan departments on August 7, 1957, and the decree of the creation the arrondissements in the departments of Oasis and Saoura on December 3, 1960.

The total number of Ksours in the Gourara region settled at 94 Ksar, including palm groves and tents of nomadic Bedouins. Administratively, they are dividing into seven caïdats [8], which are Caïdat Timimoun, Caïdat EL Hadj Guelmane surrounding Sebkha, Caïdat Tinerkouk in the north and northeast, Caïdat Chrouine, Caïdat Taghzi in the west, Caïdat Deldoul, and Caïdat Aougrout.

3.3. Social Stratification

Is the arrangement of people in society into a series of consecutive levels based on income, culture, prestige, or lineage, followed by the esteem, compassion, or contempt that people have for each other [27]. Morrow the French colonization, the social stratification was as follows:

3.3.1. Al-Shurafa (The Noble)

They inherited this title based on their descent from the Prophet Muhammad through his daughter Fāṭima al-Zahrā [28]. The majority of them owned palm groves and had strong influence and authority as they were from the people of the "Ahl al-Bayt" and protectors of the religion. Therefore, the inhabitants were keen to gain their approval and seek blessings from them [29].

3.3.2. Al-Murabitin (The Marabouts)

They come in the second position and enjoy a good social status. This category is reserved for the great companions "Asḥāba" of the Prophet such as Abu Bakr Al-Siddiq, Uthman bin Affan, Talha bin Ubaidullah, and Zubair bin Al-Awwam [30].

3.3.3. Al-Ahrar (The Free)

Individuals in this category descend from free fathers and mothers and represent the general population (commoner). They work in shops and foreign trade and own palm groves [29], and it is difficult to distinguish them from the Marabouts category, especially if their skin color and facial features are similar.

3.3.4. Al-Haratin (The Haratine)

This category consists of "Al-'Atqa", who have been granted freedom and "Mawālī", who were emancipated by their masters and remained bound to them by a bond of loyalty [31]. They perform hard work that the nobles and the free do not do, such as farming, building houses, and handicraft

3.3.5. Al-'abīd (The slaves)

Represent the base of the pyramid, and they perform very hard work. They were brought from Negroland "Bilād as-sūdān" as part of the slave trade, which was initially considered a means of managing and using criminals and prisoners of war for production purposes for a limited period. However, it soon turned into individual ownership and permanent enslavement [32]. By the end of the 18th century, global opposition to slavery had risen,

leading to its ultimate abolition. In addition, they characterized by black skin color such as the Haratine.

3.3.6. Al-Mehajriyah (Islamized jews)

Were the last lineage of Jews who converts to Islam [33]. They worked in traditional crafts such as tailoring and shoemaking [8], and their wealth placed them in the free class, but their origin still kept them in a morally inferior situation compared to that of Muslims [9].

From the foregoing, it can be said that the social stratification, with all carries several meanings, questions, and social complexities regarding the reasons and motives behind its formation in an Islamic society, and how Islam emphasizes that there is no distinction between white and black individuals, except through piety. However, we affirm that the distribution of individuals in society is also influenced by many factors such as lineage, birth, social status [29], and sometimes skin color. This, if anything, indicates that some practices of ignorance "Al-Jahiliyya" (pre-Islamic era) [31], are still ongoing even after the arrival of Islam in the region, this raises many intriguing questions. However, social stratification can be considered, in his time, as safety valve for the continuity and establishment of the oasian system. This stratification, was subject to prevailing customs "Al-'arf" and embodied in the system of the group "Al-jamāʿa", that remained in place until 1962 [34], reaching its peak weakness and collapse with the agricultural revolution in 1972 [35]. With some of its manifestations remaining in some ksours of Gourara region in different intensities including; marriage bonds between the various stratification social, imamate, endorsement and assumption of responsibilities. Even the burials of the dead are in different cemeteries between the different stratification social.

3.4. The latest contemporary developments and their impact on earthen architecture in Gourara region

These latest affect on earthen architecture in the region, which can be summarized as follows:

3.4.1. Social developments

It is one of the most important factors leading to the change of the traditional oasian system (Foggara, Ksours, palm groves). It encompasses a set of transformations that occur over time on social roles and systems (tribe, clan, family, and household), and the accompanying changes in social practices [36].

3.4.2. Cultural developments

The most important of these, is the development and diversification of media and communication networks, which have led to the openness of society and its influence by other communities [37]. This influence embodied by its buildings, which were dazzled by their other counterparts.

3.4.3. Technological developments (materials and building techniques)

The appropriate choice of building materials based on availability and scarcity [38], and the ease of obtaining it and the level of mastery in its use, with the aim of reducing construction costs.

3.4.4. Economic developments

• Transitioning from relying on agriculture and pastoralism as primary sources of livelihood to more income generating and less burdensome sources [39], resulting in a complete transformation in the economic pattern (agricultural, industrial and service), thus affecting the oasian system characterized by its fragility.

• The new state's orientations to promote the region to a wilaya, introduce new administrative divisions, and strengthen infrastructure such as water, gas, and electricity networks, leading to a new people settlement, an increase in displaced persons, and the emergence of modern building patterns and techniques that deviate from prevailing constructive customs;

• The adoption of wage labor [40] because of the transition from trade exchanges through commercial caravans to an open market [41];

• Establishing factories and mines to exploit local resources such as gas and petroleum [42], attracting investment and providing employment opportunities for workers. Leading to the development of urban centers and settlements.

Another character of human order adds to the great originality of Gourara region, are the presence of the Berber dialect locally called "Zenatiya", which has been preserved until today. In fact, more than two-thirds (2/3) of the ksours in Gourara speak Zenatiya [10]. The ancientness of the Zenete population of Gourara reflected in the toponymy of the ksour, sometimes typically Berber (Azekkour, Allamellal, Irhzer, Taoursit, Oudrar, Tindjillet...) [43]. The Zenatiya considered as a leader part in the Ahellil of Gourara, originally proclaimed in 2005 and inscribed in 2008 on the representative list of the intangible cultural heritage of humanity (UNESCO).

4. Results

4.1. Buildings patterns in the Gourara region

Through field surveys, buildings in the Gourara region classified into four types based on their function:

4.1.1. Military architecture

Locally called "Agham, pl. Ighamawen", they are buildings with military fortifications, including ramparts, towers, arrow slits, bridge and trenches locally called "Ahfir". These buildings are used as fortified granaries or may be residential; they can be isolated such as Agham Ba Salem, Aghlad or located inside fortified “Ksar, pl. Ksours” such as Agham Sidi Brahim, Agham At El mahdi in Ksar Timimoun.

4.1.2. Civil architecture

It can be said that, these types of buildings emerged during a later phase in the region's architectural history especially with the expansion outside the walls of Ighamawen, because of provide security in the region, Also, it was not devoid of military fortifications

as ramparts, towers. These buildings including: facilities residential, administrative facilities, markets and shops such as Souk Sidi Moussa in Ksar Timimoun, public laundries such as laundries of Bouhdi in Ksar Timimoun. After national independence (1962) and until a later period, the expansion of Ksours continued to exist, but without military fortifications.

4.1.3. Islamic religious architecture

These buildings accompanied the spread of Islam in the region, include mosques, Quranic schools, Zawayas, worship nook. They may be located in isolated Ighamawen such as mosques, which are probability, have been added after the arrival of Islam to the region, or located in the arms of the Ksar's walls such as mosques, Quranic schools, Zawayas, or located in extremely isolated places such as worship nook.

4.1.4. Funerary architecture

These buildings relate to humans after their death, include mausoleums, which are do not contain a corpse, tombs, mortuary washing facilities and outdoor chapel for funeral prayer locally called "Al-maṣallá".

4.2. Building materials

The building materials used in the Gourara region varied and differed from one area to another, depending on the availability, local abundant, that were easily and accessible without much effort or fatigue to obtain it, building methods and techniques according to the knowledge and know-how of its builders, these materials are:

4.2.1. Stones

According to the international classification, stones are any rock piece with a diameter varies between 20 to 200mm [12], they are divided into three main families: sedimentary, igneous, and metamorphic. It is noteworthy that the use of stones in the buildings of the Gourara region occupies a significant position for several reasons, including its historical significance, as [33] considered in his typology of the Ighamawan in Gourara region that what was built with stones, dates back to the Gétules period, which extends from prehistory to 100 AD. Other reasons include the scarcity of specialized and qualified labor [3], the high cost of construction, and the slow-ness of construction processes for the reason that stones are brought from some relatively nearby quarries or distant places such as Reg and Hamada [44] after being collected there. Stone have been used in various parts of the building such as walls, towers, foundations, and roofing in rare cases. Through field surveys, we have found three distinct types of stones locally called "Tafza", "Hajar Al-Safah", "Hajar Al-Sami", and described respectively (*Figure 2)*

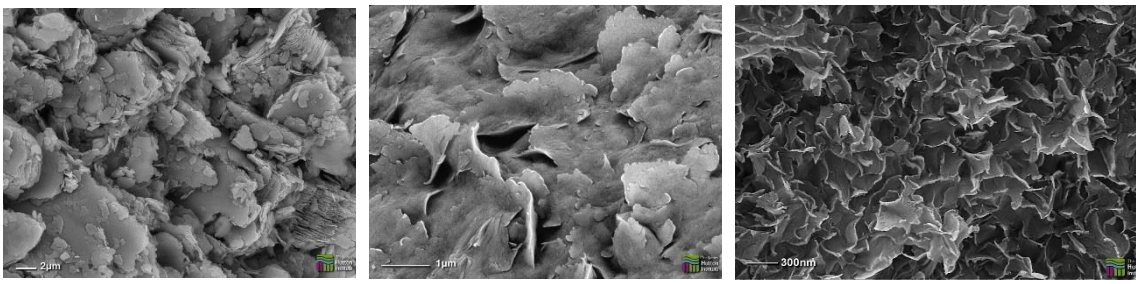
1. Tafza; sandstone, from the siliceous sedimentary family, which extracted from the hills on which the Ighamawan are built, then it is built in the same context, and the lower part (Burrowing) is left as summer nap dwellings;
2. Hajar Al-Safah; which means slate stones, from the sedimentary family, which are extracted frome some places and plateaus of the Gourara region such as in the Ksar of Aghlad;
3. Hajar Al-Sami; which means deaf and nonporous stone, from the igneous family, and are found on the ground in Reg , Hamada, hills and plateaus of the Gourara region, it is characterized by hardness and durability more than the any others stones.

(a) (b) (c)

Figure 2. Various types of stone in Gourara: (a) Tafza stone; (b) Al-Safah stone; (c) Al-Sami stone (photos by Y. Kassou).

4.2.2. Clay

Is one of the oldest building materials known to humans, it has been used in construction since the beginning of time. Researchers have proven the use of this material in many regions and civilizations such as Mesopotamia, the Nile River, and the Greeks adopted it from them [45], similarly, Ibn Khaldun talked about the use of clay in building construction among Muslims in the East and the West [46]. Technically, clay is a Hydrated Aluminosilicates formed by the filtration process that occurs on basic minerals in rocks, with a size smaller than 0.002 mm (2µ), sensitive to swelling and shrinking, these minerals give it a certain color, such as black, white, yellow, or red. Researchers agree that clay minerals can be classified into three major families [12] based on their crystal structure: kaolinite, illite, and montmorillonite. *Figure 3*, shows a view of different clay families by scanning electron microscope (SEM).



(a) (b) (c)

Figure 3. SEM images of clay families: (a) Kaolinite; (b) Illite; (c) Montmorillonite [47].

Clay is considered one of the most abundant materials in the region, it has been widely used such as the production of bricks, mortar, earthen plaster, the handicraft household and in other uses. What helped the spread of clay techniques is that it do not take a long time to prepare and do not require much effort [41], especially if the process is associated with the volunteer work " Touiza", as a social phenomenon at that time.

4.2.3. Adobe bricks

Adobe bricks have been used as a building material since the dawn of civilization, and their use has become widespread in various civilizations, as indicated by research, for example, samples of bricks dating back to 9000 BC were found in Mesopotamia [48]. The methods of adobe production have been similar across successive civilizations up to the present day. *Figure* 4, shows a Pharaonic scenes of adobe production [49].

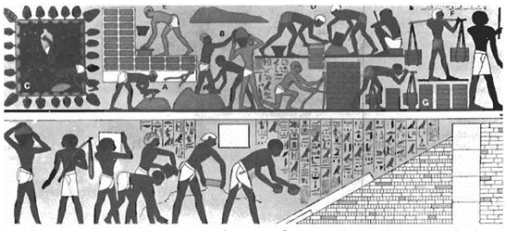


Figure 4. Pharaonic scenes of adobe production [49]

Similarly, what the Roman architect Vitruvius [50], and others [12, 45], have mentioned about adobe production. It is production varies in some of its details from one region to another [51], according to the type and quality of the clay used, the additives and stabilizers used, the shape and size of the mold and other consideration. It can be said that, the local building culture are the main determinant of this variation. Based on local building culture, the production of adobe bricks in the Gourara region can be limited in four steps (*Figure 5)*:

1. Clay extraction by digging, than transportation by animals;
2. Preparation of the clay paste by:

2.1 Dry mixing with available sand;

2.2 Wet mixing with the addition of water;

2.3 Maceration of the clay paste for the longest possible period, and adding water periodically

3. Shaping and molding;
4. Sun drying and storage (the process is relatively new).

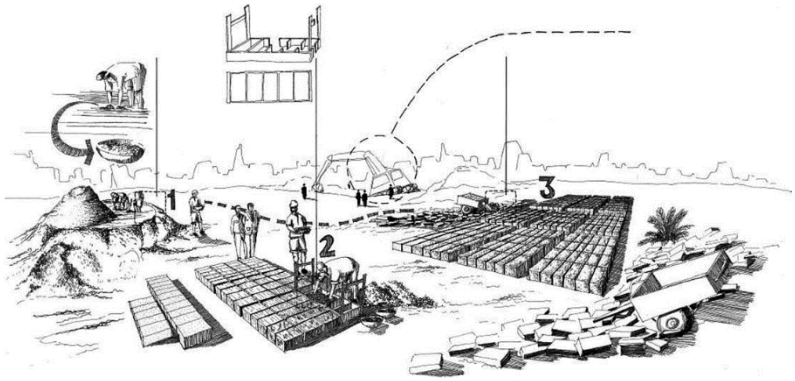


Figure 5. Steps of adobe production similar as the Gourara region [52].

The process of extracting clay in some areas of the Gourara region (Talmine) is subject to the constructive custom. Which are a set of social norms governing construction and its regulations including identifying the locations of clay extraction, allowed quantities and the period of extraction, which predetermined and announced by the herald of Ksar, locally called "Al-Barah", and any violation of the constructive custom shall be fined.

The clay is prepared by mixing it in sand (dry mixing), then with water (wet mixing). Other materials can be added as wheat straw, and left the clay paste to dry. Water is periodically added to the clay paste to prevent hardening. This process is called maceration locally called "Al-takhmār", and is considered mandatory in local building culture on the Gourara region, whoever the longer its duration, the longer the lifespan of the building. The clay paste is used for several purposes, such as making adobe bricks,

preparing the mortar used to bond bricks or stones or in coating walls or even painting. Technically, maceration causes a change in the crystalline structure of the clay and saturates it with water, which explains the durability of mud buildings in the Gourara region.

The clay paste is poured into wooden or iron molds of different dimensions. This method is relatively new as the original method of making bricks was done by hand [49-50, 53].

In the local building culture, it is preferred to make bricks in the spring or fall season, when temperatures are relatively moderate, and sunlight is less intense, which are coincide with what vitruve said [50]. Technically, making bricks in the summer season leading to cracks in the bricks due to the massive water evaporation. However in the winter season with low temperature, the production of adobe bricks is prohibited due to the harm it causes to builders, especially since the wet mixing process is done barefoot, in accordance with the rule saying " There should be neither harming (ḍarar) nor reciprocating harm (ḍirār)" [54].

4.2.4. Wood

Talking about wood in the Gourara region, leads us to talk primarily about the date palm tree (Phoenix dactylifera). It means a lot to the people of the region and is referred for them the tree of life, it is a source of food for both humans and animals, provides shade and fuel for fire, and has many other uses, and as evidenced by the finding an oldest manuscript in Talmine about the usufruct of date palm [55]. Date palm wood is considered one of the primary materials used in building in the Gourara region. Every part of the palm tree is used in various parts of the building such as roofing, door and lintel, staircases, wall reinforcement, locks, ropes and permanent scaffolding as in domes (*Figure 21).* In the local building culture the selected date palm trees are those, undamaged as well as those with dried dates are the best one. *Figure 6,* illustrates the components of the palm tree [56].

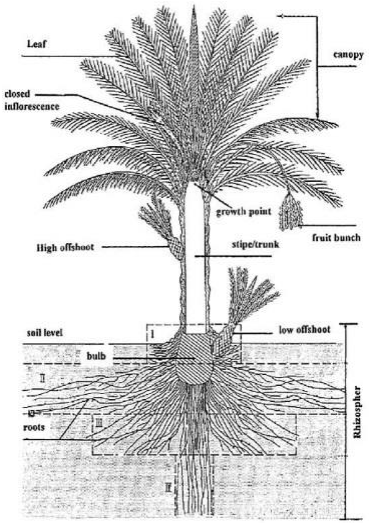


Figure 6. Components of the date palm tree [56].

From the date palm, the following parts can be extracted:

1. Trunk: Locally called "Al-jada' ", it is a long cylindrical unbranched stem with a rough surface covered with petiole and ends with a dense crown of large leaves. The average height of the trunk is about 15m and sometimes reaches up to 35m, however the diameter of date palm trunks varies with different date palm cultivar, ranging from 40-90 cm [57]. According to Arifi Mohamed in the local building culture [58]: the trunk is cut transversely into pieces of 4 to 5 cubit lengths. Then each of these pieces is cut longitudinally into two halves and each half is divided into four pieces in extreme cases, these pieces locally called" Khashaba". In addition, left to dry in the open air for several days. After they are trimmed before use to obtain a flat surface that is easy to work with it. The tools using to cut trunk longitudinally are a carpenters slick chisel locally called "Imri" made from trunk of the Acacia nilotica subsp. adansonii, locally called "Agga" [59];

2. Fronds: They are the leaves of the date palm, much like as a large feather. In adult date palms and depending to the cultivar [57] fronds length varies between 3 to 6m, and produces between 10 to 20 fronds annually, with a total number of green fronds varies between 30 to 150 fronds, present in the head of date palm. Each frond consists of the two parts; blade and leaf base (*Figure 7):*

- Blade: Locally called "Djerid", it represents the upper part of the frond and consists:

• Midribs: It is the central vein of the frond, completely devoid of leaflet and spines, locally called "Al-ʿaṣāy". Its appearance is shiny and strong, and its width reaches up to 20 cm from the bottom, and its loose end at the top is about 1 cm [57]. Midribs are used in roofing, arches and in the handicraft household such as chairs, tables, crate and other items;

• Leaflet: Locally called "Zaaf", they spread on both sides of midribs, their length and width varies respectively between 15 to 100cm, and 1 to 6 cm. While their number on a single frond ranges between 120 to 240 leaflet [57]. Leaflet are used until now to encourage handicrafts such as hand woven baskets, mats, lifeguard hats, hand fan, bread plate and other items;

• Spines: Locally called "Al-shwak", they are mutated leaflet with variable lengths, located between leaflet and the base of the leaf. They cover an area of about 28% of the length of the frond. Their length and thickness can respectively reach up to 24cm, 1cm. While the number of spines varies between 10-60 spines [57].

- Leaf base: it represents the lower part of the frond it consists of:

• Petiole: Locally called "Al-Karnaf", it is the base of the frond, and its length ranges between 25 to 50cm [57]. Petiole are used in roofing and handicraft such as creativity in plastic art;

• Leaf sheath: Locally called "Al-Fadam". It is a network of fibers surrounding the petiole, used in roofing to fill small gaps and holes, as well as in making ropes, threads, water container covers.

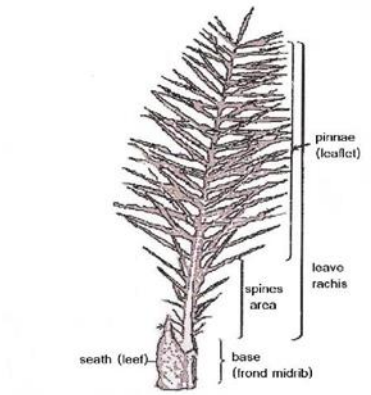


Figure 7. Date palm leaves and its parts [57].

In addition to the use of date palm, some trees and plants resistant to termites [60] have been used in the Gourara region. Especially in areas adjacent to the Grand Erg Occidental, such as Talmine, Taghzouti, Tinerkouk, including Tamarix aphylla locally called "Taberket", Tamarix galica locally called "Azwa", Retama raetam, Acacia raddiana, Juniperus phoenicea, Limoniastrum guyonianum, Calligonum azel, and Aristida Pungens Desf, *(Figure 8).* Currently, exploiting these trees and plants in any way is considered illegal [61-62], except for scientific research with specific methods and techniques [63], in order to preserve them and the ecosystem in desert areas.

(a) **(b)** **(c)** **(d)**

Figure 8. Some trees and plants using in Gourara region building: (a) Tree of Tamarix aphylla; (b) Tree of Tamarix galica; (c) Tree of Retama raetam; (d) Plants of Aristida Pungens Desf (photos by Y. Kassou).

4.2.5. Lime

Locally called "Al-Jeer" is a substance that is used after being cooked to peinted tombs and mausoleums. According to Ouamar Abdelhai in the local building culture [64], using lime in construction is completely absent, and the best example is the confusion between it and tuff locally called "Tabshamat" which are a soil currently used in roads

4.2.6. Wheat straw

Locally called "Aramo" they are primarily used as animal feed and for roofing, where is placing under the thick layer of mud to fill potential gaps, prevent the leakage of mud and rainwater, and to keep dust from falling through the roof when walking on it.

4.2.7. Animal hides

After being tanned (leather tanning), this process locally called "Ad-dabbāgha". According to Arifi Mohamed in the local building culture [58] the process is started by the immersion of animal hides with fruits of the Acacia nilotica subsp. Adansonii in water,

and leave them for a period. It is used to link various parts of date palm doors *(Figure 26),* and it can also be used in roofing by placing it under the thick layer of mud to prevent rainwater leakage. Moreover, it is used in handicraft, with varying and high prices, such as sandals, boots, shoes, bags, camel saddles and sword sheaths [41].

4.2.8. Ironwork

The activity of blacksmiths is based on imported iron from the trade caravans that come from areas known for their iron industry such as Fes (Morocco), which was a center for metal industries in the western countries and Bejaia (Algeria), which was a hub for many countries [65]. In the Gourara region, blacksmithing is limited to the production of axes, chisel, knives, swords, keys, and spikes [41] used in wooden doors *(Figure 26).*

4.3. Building methods and techniques

Paying attention to the technical aspect of building is essential to ensure the safety and stability of the building's various parts and its durability, and to prevent its damage. To achieve these two basic elements, qualified builders have resorted to using familiar building techniques throughout ancient times, using locally available materials with minimal intervention in nature. Building methods and techniques varied in defensive, civil, and religious buildings in the Gourara region, including:

4.3.1. Foundations

Are the element on which the building rests and work to unload and distribute loads to the suitable ground, ensuring sufficient resistance to prevent damage to the foundations or the building. In some cases, foundations also prevent the building from slipping. Through field surveys and inspections, foundations in the Gourara region can be classified into two categories:

1. Rocky hill as foundations: They are buildings built on a rocky hill, with or without earth working *(Figure 9).* It can be said that the security and defensive aspect was the reason for choosing hill to build these structures, also the soil may be rocky and have built foundations.

(a) **(b)**

Figure 9. Ighamawen built above rocky hill as foundations: (a) Without earth working in Ksar Aghlad; (b) Built foundations on rocky hill in Agham Basamad Daldoul (photos by Y. Kassou).

2. Stone foundations: Through field surveys and inspections, it is clear that the presence of foundations is not related to the soil type *(Figure 10).* Moreover, it may not have them. According to Ouamar Abdelhai in the local building culture [64], qualified builder get up:

• Digging a trench in the ground with a depth ranging from 50 to 100cm and preparing it;

• Placing stones in an irregular manner and joined with earth mortar. The average depth of the foundation may reach 80cm, and the foundation may rise above the ground surface to build walls.

(a) **(b)**

Figure 10. Stone foundations: (a) Stone foundations on rocky soil in Agham Aourir Daldoul; (b) Stone foundations on Ksar Timimoun (photos by Y. Kassou).

4.3.2. Walls

After completing the preparation and construction of the foundations, qualified builders begin to construct the load bearing walls. Through field surveys and inspections, walls can be classified into three categories based on construction materials:

1. Stone walls: It is commonly known that buildings in Gourara region, partially or entirely constructed with stone, are among the oldest buildings in the region. Two methods have been used for stone construction, including:

• Rubble stone walls: This is the most common type in the buildings of the Gourara region, where composed of undressed stones, without any regular courses. Different sizes and types of stones are used *(Figure 11)*, earth mortar is usually used to link stones where the average thickness of the fortified walls at the base reaches 80cm.

(a) **(b)**

Figure 11. Rubble stone on fortified walls: (a) Built walls with Tafza in Agham Tihdayine Ksar Faroun; (b) Built walls with slate stones in Agham At-Youcef Ksar Aghlad (photos by Y. Kassou).

• The wheat spike method: The stones are arranged like grains of wheat in the spike, where the stones are placed at an inclination of up to 45° *(Figure 12).* This method has been known since ancient times as opus spicatum [45], but is rarely used nowadays

Figure 12. The wheat spike method in Agham N'khzin Ksar Aghlad (photos by Y. Kassou).

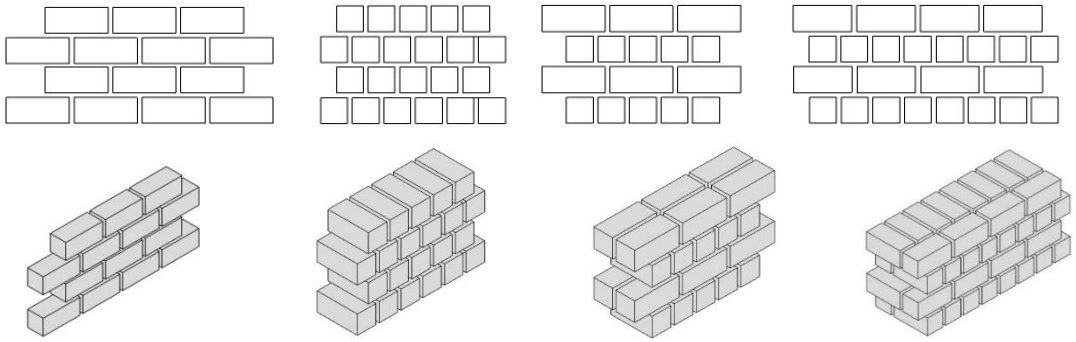
2. Mud walls: It's can be classified into two methods based on the shape of the bricks:

• Triangular prism mud walls: This is one of the oldest forms of mud brick in the Gourara region and formed manually without a mold *(Figure 13).* The dimensions of its face are 10x10x10cm. Later, this type of brick was only used as a decorative element placed at the top of walls, believed to protect against evil spirits [53].

Figure 13. Triangular prism mud walls in Agham Tidji Ksar Kali (photos by Y. Kassou).

• Brick mold walls: These are walls made of clay bricks, formed in wooden or iron molds, and connected together with mud mortar. Their sizes and bricklaying patterns vary from one region to another. Through field surveys, and measurements, their sizes can reach up to 40x17x17cm (Ksar Timimoun), resulting in a wall thickness of up to 60cm. The currently used size is 30x15x15cm and 35x15x15cm. Depending on their uses, we find four typical bonds *(Figure 14)* are:

- Stretcher bond: Used especially in the exterior party wall on the ground floor of buildings, and do not exceed a height of 1.5m;
- Header bond: Used in the partitioning between the spaces of the house on both floors, and in the upper walls overlooking the streets;
- English bond with one brick walls: used for the same subject as the header bond;
- English bond with one and half brick walls: used especially on exterior walls.



(a) (b) (c) (d)

Figure 14. Brick mold walls bond: (a) Stretcher bond; (b) Header bond; (c) One brick walls bond; (d) One and half brick walls bond (photos by Y. Kassou).

3. Mixed walls: These walls intentionally mix different building materials that vary in shape, nature and size in the same wall *(Figure 15).* Then the qualified builder must fill wall gaps with suitable stones or bricks with earth mortar, finally walls can be plastered or without.

(a) (b)

Figure 15. Mixed walls: (a) Mixed walls using salt stone in Agham Sidi Belkacem Ouled Abou Daldoul; (b) Mixed walls using stone, mud bricks in Agham Am'zaghakh Ksar Massine (photos by Y. Kassou).

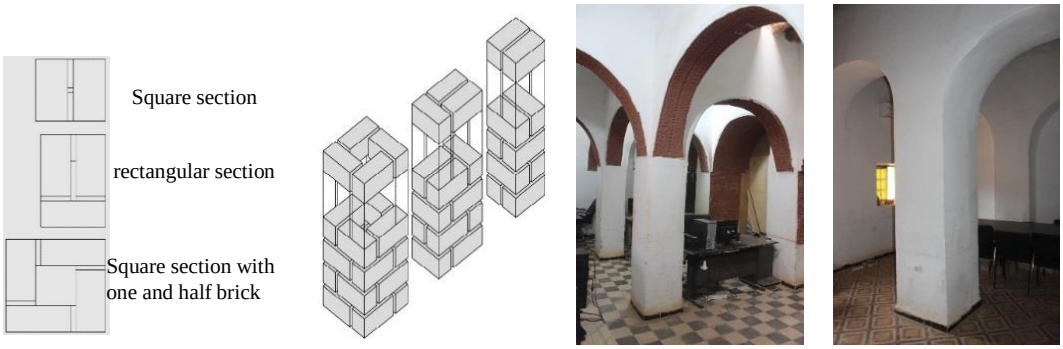
4.3.3. Column and arch construction technique

In the Gourara region, they used especially in religious buildings *(Figure 17),* as load bearing elements for the roof. Generally, these columns did not have a base or capital. Moreover, they were built using mud bricks or rubble stones with different sizes and shapes *(Figure 16),* depending to available materials. The arches were usually built on top of these columns using two methods according to Ouamar Abdelhai [64]:

• Filling the gap between the two columns with rubble stones or mud bricks to give it the shape of the desired arch, after the arch solidifies, they are removed to obtain the desired arch;

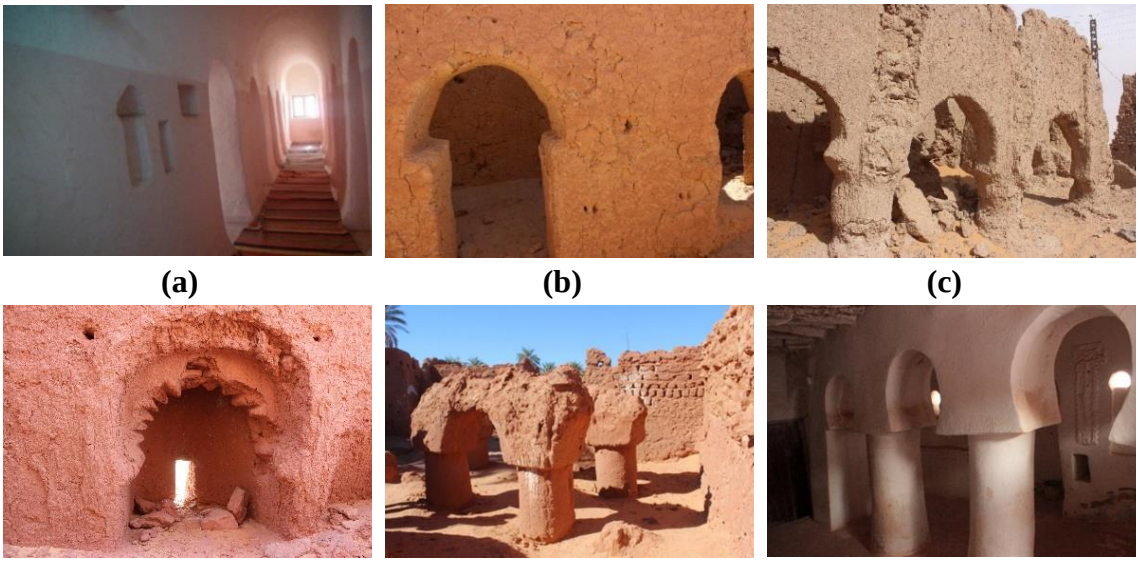
• Building the arch using green date palm midribs that arched and attached between the two ends of the wall or columns, as needed, to form the desired arch. After the arch solidifies, the midribs are removed.

During the French colonization in the Gourara region, sizes of arches are extend because the introducing of iron arch centering, so its use is no longer limited on religious buildings



(a) (b) (c)

Figure 16. Column construction techniques: (a) Possible ways to build columns; (b) Square columns in Algerian Center for Cultural Heritage built with mud (CAPTERRE); (c) Square columns with one and half brick in CAPTERRE (photos by Y. Kassou).



(a) (b) (c)

(d) (e) (f)

Figure 17. Various types of arch in the Gourara region: (a) Stilted arch in mosque Sidi Mousa -Timimoun; (b) Local arch in Agham Tala Aougrout; (c) Keyhole arch in mosque of Agham Da Ou-Ali Ksar Kali; (d) Multifoil arch in mosque of Agham Bag'laghi; (e) Semicircular arch in the mousque El-Boulghitia in Agham Sidi Belkacem Ouled Abou; (f) Semicircular arch in the mousque El-Boulghitia in Agham Sidi Belkacem Ouled Abou (photos by Y. Kassou).

4.3.4. Roofs

In the Gourara region the roof is an important architectural element, is flat and used for benefiting from them. Roofing techniques can be grouped into four main categories:

1. Using date palm trunks: This group is similar in using date palm trunks as beams, which are at most in length five cubit locally called "Dharāʿa ", with a spacing of 15 to 25cm between them, then they are fixed with stones and clay to prevent them from rotating around their axis. Wheat straw, leaf sheath of date palm or animal hides are sometimes placed on top of various types of joists, then covered with a thick layer of mud that can reach up to 50cm. The different disposition of roofing are as follows *(Figure 18):*

• Date palm trunks are placed, above them date palm midribs are laid out in rows as joists;

• Date palm trunks are placed, above them date palm midribs are posed as joists with a maximum spacing of 15cm between them, on top of them date palm blades are laid out in rows, side by side, without any space between them in the same direction of beams. which is the common method in roofing in the Gourara region;
• Date palm trunks are placed, with a spacing of up to one cubit between them, above them pieces of date palm trunks locally called "Alqashab" are placed;
• Date palm trunks are placed, with a spacing of 25cm between them, above them petioles are placed as joists. which is a method perhaps introduced in the Gourara region during the French colonization;
• Date palm trunks are laid out in rows, side by side, without any space between them, which is a commonly used roofing technique in religious buildings, particularly in Zawayas;
• Date palm trunks are placed, above them slate stones are placed as joists, while the distance between trunks depends to the length and width of the stones;
• Date palm trunks are placed with a maximum spacing of 30cm between them, above them tree branches are placed as joists.

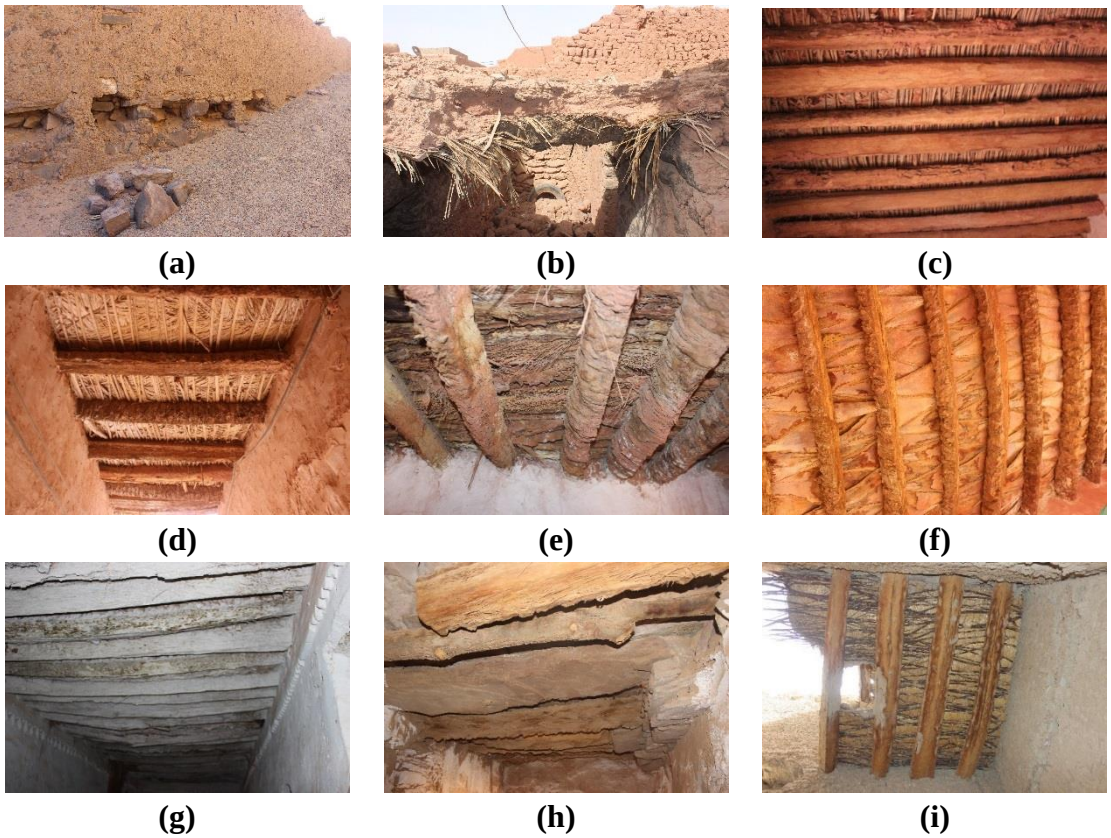


Figure 18. Underside of roofing with date palm trunks as beams, above them different constitutes, over them a thick layer of mud: (a) Fixation of date palm trunk using stones; (b) Section in a thick layer of mud; (c) Using date palm midribs; (d) Using date palm midribs and date palm blades; (e) Using pieces of date palm trunks; (f) Using petioles; (g) Using date palm trunks in rows. (h) Using slate stones; (i) Using tree branches (photos by Y. Kassou).

2. Roofing with stones: In this method, slate stones are used which play the role of beams and joists at the same time *(Figure 19)*, and covered with a thick layer of mud.

Figure 19. Roofing with stones in Ksar Aghlad (photos by Y. Kassou).

3. Using tree trunks: This method is less commonly used due to the mechanical properties of local tree trunks. The trunks are used as beams, and covered with stones, which act as joists *(Figure 20)*. Then covered with a thick layer of mud. In addition, tree trunks can be used in the same roof with date palm trunks.

(a) **(b)**

Figure 20. Roofing using tree trunks: (a) Mixed roofing using date palm trunks and tree trunks; (b) Using tree trunks and stone in Ksar Timimoun (photos by Y. Kassou).

In the local building culture, giving the roof a significant slope to get rid of rainwater is the best way to protect it. The inclination ends towards the gutters, which are mainly made of the trunk of the date palm, after removing its interior.

4. Domes: are used in some tombs and mausoleums, it is building technique considered as a lost skill in the Gourara region. It is said that the dome builders came from Negroland [66], which is supported by the similarity between the domes in the Gourara region and those found in Negroland such as the Djingarey Berre mosque and Sankoré in Timbuktu, and the Larabanga mosque in Ghana. Domes can be pyramidal or conical in shape and may be built on a square or rectangular base or without a base, starting from the ground up *(Figure 21)*. The building material can be bricks, stones, or both. The process involves determining the center of the base, building flat corners with straight edges as transition areas that allow the base of the dome to be converted into a circle [58], and gradually curving the dome walls as the building rises until they meet at the dome's center, which is the highest point. Noted that on all field surveys we find just 05 conical dome.

(a) **(b)** **(c)**

(d) (e) (f)

Figure 21. Domes on Gourara region: (a) Conical dome above the Foggara of Tyouchi't in Timimoun; (b) Conical dome above the Foggara of Amghayar in Timimoun; (c) Conical dome on the tomb of Lala Zahia in Timimoun; (d) Corbelled walls in the pyramidal dome of the tomb of Sidi Mohamed cherif in Touki-Deldoul; (e) Pyramidal dome on the tomb of Sidi Othmane in Timimoun; (f) Pyramidal dome on the tomb of Moulay cherif in Tinkline-Aougrout (photos by Y. Kassou).

4.3.5. Floors

Floors are made of mud plaster covered with smooth, pure sand *(Figure 22)*, which is periodically replaced every six months.

Figure 22. Floor covered with sand, Dar Zawaya Sidi Omar in Aougrout (photos by Y. Kassou).

4.3.6. Staircase construction techniques

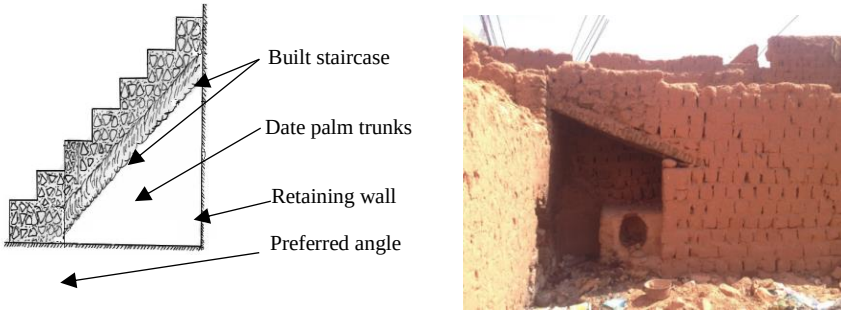
Based on field surveys there are two main techniques for building stairs:

1. Built staircase*:* This is the most common and easiest method, where the stairs are built between two walls, and the void under stairs is filled with soil and stones, where the step are built gradually until reaching up. Also can be built between the wall of the building on one side and another point based on half wall without using balustrade *(Figure 23)*, and in both cases it is not possible to exploit the space under the stairs

(a) (b) (c)

Figure 23. Built staircase: (a) Between two walls; (b), (c) Between wall building and half wall in mosque of Agham Al-Gabli Talmine (photos by Y. Kassou).

2. A staircase built on a sloping roof of date palm trunks*:* where the roof is sloping and leaning against the wall from the upper side of the staircase and fixed from the lower end to a wall with built-in steps, after determining the angle of inclination *(Figure 24).* Then the steps of the staircase are built using stone or mud bricks, with a height ranging between 20-40cm. One of the advantages of this technique is that the space below the staircase can be utilized



(a) (b)

Figure 24. A staircase built on a sloping roof of date palm trunks: (a) Detail of the staircase; (b) Using space below the staircase like a traditional bread oven (photos by Y. Kassou).

4.3.7. Buttress construction

A buttress is what a wall leans on to prevent it from collapsing *(Figure 25).* Locally called "Al-Arsa", it is built using the same method as wall construction, its purpose is structural more than aesthetic, and it is built to strengthen the walls to reduce the intensity of the wind, especially in higher walls or at the entrances of building. It can also be added to the building over time with specific regulations respecting such as respecting the right of street.

(a) (b) (c)

Figure 25. Buttress construction: (a) Added buttress on Agham N'Tini in ksar Kali; (b) Buttress on the interior entrance of Agham Amaro N'amaro in ksar Aghlad; (c) Buttress marqued the exterior entrance of Ksar's house in Timimoun (photos by Y. Kassou).

4.3.8. Door installation

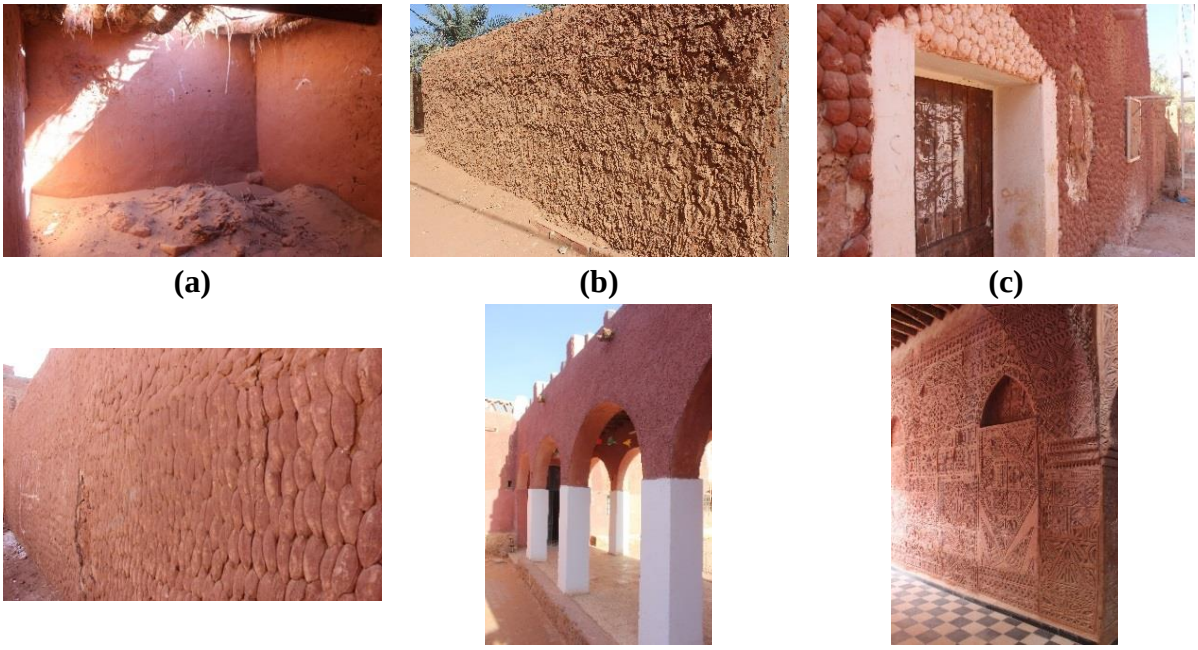
Doors are made by assembling wooden pieces from date palm trunks after treatment, which are attached to wooden beams, secured with iron spikes or tied with animal hides ropes. The installation is done by placing two protruding wooden pieces in the form of vertical dowel. The upper is fixed to the lintel, and the lower one is fixed to the threshold, the system allows the door to rotate *(Figure 26).* Doors was used in main entrances, granaries' storage rooms and was entirely absent in living rooms.

(a) (b) (c)

Figure 26. Door installation: (a) Door components; (b) Fixing in the lintel; (c) Fixing in the threshold (photos by Y. Kassou).

4.3.9. Earthen plaster techniques (mud plastering)

Gourara buildings are characterized by simplicity and lack of complexity, and yet they are not devoid of aesthetic touch. Perhaps habits, traditions, have diverted them from the manifestations of luxury. This technique provides protection for the building from various damages that may affect it. It is made of clay plaster, where gaps and joints of walls are filled to obtain a relatively flat surface, then adding the final coating. The surface of the coating is treated with various techniques such as, hand float, hand fingers, or by using spadix stems (date palm) technique or throwing earth hand-balls or trowel balls on a wall *(Figure 27).* The appearance of coating differs between inside and outside the building. Where it is smooth and coated and may have decorative patterns inside, while it is rough outside, or it is sufficient to fill the joints in walls or leave them without it. Otherwise, tombs and mausoleums are painting until now with milk of lime seasonally as a form of dressing in the religious ritual.



(a) (b) (c)

(d) (e) (f)

Figure 27. Various techniques of earthen plaster: (a) Hand float; (b) Hand fingers; (c) Throwing earth hand-balls; (d) Throwing earth trowel balls; (e) Spadix stems; (f) Decorative patterns (photos by Y. Kassou).

5. Discussion

The results show that, earthen architecture in the Gourara region is characterized by using three principals' materials are stone, clay, wood of date palm tree, which serves as the vertebral column of Gourara's buildings and are available throughout the region. In addition, other building materials are used sparingly such as, lime, straw, animal hides and iron. The use of stone is limited especially in Ighamawen, in the foundations and occasionally in roofing, due to the high skill required for stone construction, even now. On the other hand, clay is extensively used as a building material and plays a major role in earthen building, being utilized as mortar, wall construction and plastering, its applications are more extensive compared to stone.

The walls in the Gourara buildings are thick for functional purposes and are load bearing to support the roof. There are three main groups: stone, clay, and mixed walls. Stone walls, as mentioned above, are found in Ighamawen, indicating military fortifications, mud walls are of two types, triangular prism and molded, while mixed walls involve a combination of available building materials.

With the decline of the local building culture, especially in relation to clay maceration, the use of clay materials and techniques began to be viewed negatively and tarnishing its image.

The use of arches was primarily limited to religious architecture. Through studying, some arch shapes were found to resemble those of neighboring countries, which can be explained by the extension of its architectural character to the Gourara region, especially with the location of the region along the commercial caravans. The introduction of iron arch centering during the French colonization in the region led to the expansion of arch sizes. As a result, the use of arches was no longer limited to religious buildings.

The noticeable diversity in roofs consists of four groups, including seven types of date palm wood roofs, one type of stone roof, one mixed roof, and the use of domes for roofing. The roofing variety is indicative the urgent need for technical roofing solutions, especially due to the prevalence of termites in the region. Considering the discussion above, we confirmed that:

1. The earthen architecture in the Gourara region is an exceptional natural architecture, perfectly in harmony with its physical and geographical environment, and a response to the social, economic, and cultural conditions;
2. Many earthen buildings in the Gourara region have suffering of deteriorated due to various reasons and not up to date to contemporary latest developments and the changing of lifestyle. If not taken seriously, it will undoubtedly disappear. However, this has not prevented some of their inhabitants from benefiting from their social, environmental, and economic advantages, despite the available opportunities to abandon them;
3. The lack and decline of qualified expertise have made earthen building expensive and unpopular in the job market;
4. Some modern individual attempts in the Gourara region have presented a new concept of earthen architecture, contributing to reviving the idea of earthen building in the local memory. However, they may need review due to technical errors resulting from

unfamiliarity with the constructive custom and an attempt to imitate cement architecture due to the absence of approved earthen building standards by the Algerian state and specialized laboratories in the field of quality control, similar to cement buildings.

6. Conclusions

The paper is a first attempt in presenting the variety of earthen architecture in the Gourara region. This architecture was not a coincidence, but a product of human interaction with their desert environment, producing buildings that responded to their social, economic, and cultural needs, using materials and building techniques that contributed to the diversity of these buildings, under the prevailing customs of that time.

Finally, the results show that with the passage of time and changes in lifestyle, returning to traditional earthen architecture is almost impossible, while the alternative may lie in preserving it with awareness about its various benefits, and in an attempt to reproduce according to contemporary requirements. Moreover, in this context we believe that in order to achieve preserving this ancestral architecture addressed in this study, it is essential to:

1. Introduce concepts of earthen architecture in the Algerian school and university curriculum, as a step to preserve it;
2. Enacting laws with less complexity and more effectiveness in protecting heritage, while adapting them to the circumstances and involving the community in the mechanisms of protecting their heritage, as traditionally done, without resorting to centralization in decision-making;
3. Establish state-approved building standards (codes) for earthen construction with official encouragement of earthen building by government projects built with earthen technique, to stimulate people to return to using earthen materials;
4. Establishing specialized laboratories to test earthen materials and develop standards for quality control;
5. Provide facilities to encourage earthen construction (direct financing, tax reduction) such as creating factories for high-quality materials and techniques of earthen building at a competitive price with cement materials, and also contribute to create job opportunities for local communities;
6. Promote earthen architecture through various media channels to change negative perceptions of earthen construction.

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