International Journal of Innovative Studies in Sociology and Humanities
ISSN 2456-4931 | Open Access | Volume 7, Issue 6, 2022
DOI: https://doi.org/10.20431/2456-4931.0706007

Raw Earth Architecture, an Adaptation Lesson in Distress. The Case of Khanguet Sidi Nadji ksar, Biskra, Algeria

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Abstarct

The raw earth heritage is very important in Algeria. The human settlements of the arid and desert areas are built entirely of mud. Since the Middle Ages, these historical centres have provided a real living environment for sedentary populations. They have enabled man to live in a hostile environment and under extreme climatic and natural conditions. Unfortunately, these historic centres are today abandoned and left to the wear and tear of time by their occupants who have preferred a living environment that meets more modern requirements. The few remaining historic centres are threatened by the passage of time, lack of maintenance and acts of vandalism. (R. Daher.2015).

The Ksar of Khanguet Sidi Nadji is one of these fortified urban agglomerations, known for its history and its beauty, classified as a natural heritage site in 1968, because of its natural site, Oasis and geographical morphology, established most often on a rocky outcrop crossed by a wadi, it is organised in blocks and gives form to an urbanism resembling the citadels of medieval Europe. This urbanism is the product of a well-defined social organisation, which lives on agriculture and livestock and which builds its habitat with local materials and according to an ancestral know-how. The degradation and abandonment of the Ksar are due on the one hand to the precariousness of the built environment, which requires a lot of maintenance encouraged by the abandonment of the population, and on the other hand to the pathologies observed in the constructions and their implementation. All these consequences are accelerated by the effect of time and human action. The action of time which results in the ageing of constructions, following under-maintenance, or even the abandonment of certain buildings which no longer have any functional value and therefore no longer play their role. (M. Nasri, 2007).

The present article, which is part of a PhD research in science, aims to understand, through an observation of the place that we carried out on the ground as well as a prospection on site in the company of a specialist of the constructive pathologies of earthen constructions, "the pathology of adobe". We will try to make a comparative reading between some theoretical models on the various techniques of adobe and the forms of pathologies which can affect the earthen architecture and that of the constructions of the Ksar of KhanguetSidiNadji, in order to apprehend and diagnose it for the conservation and promotion of the use of the earth as an essential material in the construction. Also, the resumption of the regional methods of implementation of the raw earth brick by the knowledge of the practised techniques and the application of the most modernized of them. The elaboration of a regularisation of earthen construction on a national and regional scale (in the form of a technical guide) and to try to encourage the realisation of rehabilitation projects and new constructions in raw earth, by involving the public authorities to a greater extent, in order to stop the destruction by calling on specialists in the field, for the safeguarding of this rich and disappearing heritage.

Key words: Raw earth architecture, degradation, abandonment, Ksar, pathologies, heritage, Oasis, Khanguet Sidi Nadji.

INTRODUCTION

The quality of earthen architecture depends essentially on the mastery of architectural design. It is by reviving a tradition of "knowing how to design" and by exploiting the benefits of current technology that high quality earthen architecture can be produced.

Several regional sayings wisely remind us that a well-designed earthen house can endure the centuries without damage, and traditional earthen architecture proves this unambiguously.

Unfortunately, earthen architecture today is exposed to many risks, yet the beauty of earthen architecture often considered as world heritage illustrates the ingenuity of human construction. Indeed, since ancient times, people from

all continents have used earth as their main building material. Today, more than 150 World Heritage sites are built entirely or in part of earth, and almost one third of the world's population lives in houses and cities built with earth.

The World Heritage Earthen Architecture Programme (WHEAP) aims to improve the state of conservation and management of earthen architectural sites around the world. Pilot projects at earthen sites inscribed on the World Heritage List or included in the Tentative Lists of States Parties to the Convention will help identify best practices. They will provide examples for the development and dissemination of appropriate methods and techniques in conservation and management, and will build local capacity. The programme seeks to increase recognition of earthen architecture and to create an active global network for the exchange of information and experience. (UNESO).

In Algeria, the recognition of the Ksourian heritage started in 1968. It was followed by specific measures, cited by Law 98-04 (Law 98-04 of 15/06/1998 relating to the protection of the national cultural heritage), which involved the creation of safeguarded sectors with a particular protection regime that can be adapted and applied to the ksour. Unfortunately, these legal protection measures alone have not been able to guarantee the revitalisation of the ksour, which are today abandoned and left to the wear and tear of time by their occupants who have preferred modern housing to traditional housing. The few of these historic centres that still exist are threatened by the mimicry of the owners who are making them undergo transformations whose consequences have proved disastrous. The Ksar of KhenguetSidiNadji in the wilaya of Biskra, which is the case study in this work, is an edifying example.

According to the article published at the international conference Terra2003 (Yazd, Iran) by (H.Guilaud.2003), where he presents a synthesis of research that was carried out under contract with the Getty Conservation Institute (GCI), in the framework of the TERRA Project's scientific research action plan, proposes a critical review of the scientific literature produced during the last 20 years of the 20th century, when the specific field of earthen architecture conservation was being constituted and developed, notably under the impetus of successive international conferences, and then of the GAIA and TERRA projects, jointly defined and piloted by CRATerre, ICCROM and GCI. A complete inventory of the literature available in the documentary collections of these three partner organisations was carried out, which identified 1269 documents (books, research, articles, communications) from which a careful selection of 621 documents was made, constituting a corpus of reference texts that reflect the recent developments and contributions of research in the field. This research was structured in three main chapters. The first one concerns the knowledge and analysis of the earth material, the second one the pathology and diagnosis of earthen architecture, and the last one interventions, treatments and evaluation. (H. Guilaud, 2003).

Each of these parts covers a set of issues that are dealt with in the literature that have served as references in order to draw up a method to follow, practices in the field of rehabilitation of earthen architectures that will be developed in the present article.

Historical Reference to Mud Architecture

The earthen architectural heritage covers the whole of the buildings "masoned in raw earth, which testifies to a technical and artistic know-how of the traditional vernacular still alive and kicking recalling the glorious past. It is a richness at the social, environmental and symbolic level. Earth was not the first material used by man, he had recourse to elements already present in nature, such as stone, for example. Archaeological findings testify to the importance of earth in all civilizations, earth was associated with the decisive periods of the urban revolution and served the everyday life as well as the prestige of the most glorious civilizations of antiquity. (H. Guillaud, 1989).

Chronologically, the first traces of earthen construction in South America date back 11,000 years, while in Syria, earthen construction by piling up hand-made loaves of earth dates back 10,000 years. In Turkey the appearance of the mud brick in construction is 8500 years old. According to archaeological research, the use of earth in housing in Western Europe dates back 8,000 years and the appearance of the first cities of mud architecture in Mesopotamia dates back 5,000 years. During the Middle Ages and the modern era, the heyday of timber-frame and cob buildings. (C. Delbecque, 2011).

Raw earth was used in all geographical areas, by most civilisations. The technique used was the piling up of hand-made loaves of earth. This was done 8,500 years ago. Then, 7,000 years ago, earthen architecture made its appearance with fortification works, followed by the appearance of domes 6,500 years ago, monumental temples and temple cities 5,000 years ago with Sumer. Raw earth is probably the oldest building material in the world. 30% of the world's population lives in an earthen dwelling, yet the history of earthen construction is poorly known. The interest in this material,

which was considered ancient and mediocre, was overshadowed by that given to stone or wood, which were considered more "noble" materials. Yet it was earth that was associated with the decisive periods of the urban revolution and served the everyday life as well as the prestige of the most glorious civilisations of Antiquity. (L.M. Portal et AL, year not mentioned).

Arguments in Favour of Earthen Architecture

Earthen architecture is one of the most powerful expressions of the human ability to create a built environment by employing locally available resources. Earthen architecture is characterised by a great richness and diversity of architectural and urban productions. It is true that earthen architecture is threatened by natural disasters (floods, earthquakes), by the influence of industrialisation and the inappropriate use of modern technologies, and by the disappearance of traditional conservation practices, among others. But it should also be remembered that in recent years the specificities of earthen architecture have been studied and its advantages and qualities have been recognised. There is now a strong interest in earthen architecture on the part of many professionals and policy makers. The obvious importance of earthen architecture in cultures around the world has led to its recognition as a heritage of humanity, a heritage deserving therefore to be protected and conserved by the international community. In 2007, 106 earthen properties were on the World Heritage List. In 2001, the World Heritage Committee approved the establishment of a programme for the conservation of earthen architecture with the objective of developing policies for the conservation, revitalization and valorization of earthen architectural properties, as well as strengthening the property management capacities of regional and national representatives and technical experts. (UNESCO.2009-2017).

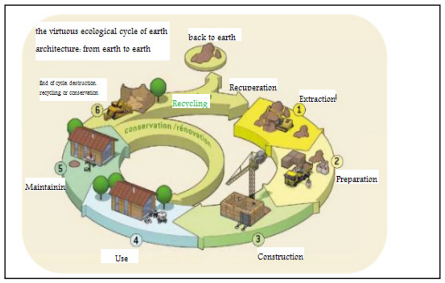

Figure 1. Life cycle of an earthen building
Source : P, Delot.2015.

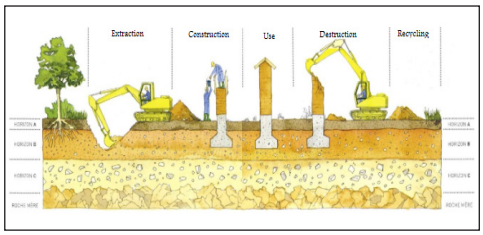

Figure 2. Life cycle of an earthen building.
Source: Anger & Fontaine, 2009

Raw earth as a building material is a sustainable solution for the construction of ecological houses. Earth is an inexpensive material that is found in many parts of the world and is easy to use without advanced tools. It has the ability to regulate air humidity, store heat, reduce energy consumption, produce virtually no pollution, is 100% reusable, preserves wood and other organic materials, and absorbs indoor air pollutants. The use of earth in brick form has the advantage of providing a solid module or modules on which to base the composition of the building. Raw earth is the most rationalised material in the construction field.

Earthen Construction Methods: Requiring Simple and Economical Equipment

The methods of building with earth are very varied. Earth can be moulded, shaped, compacted or compressed. For each case, there are several technologies, from the most natural and artisanal to the most industrialised. This diversity is due to both the types of earth encountered and the materials available and/or developed locally. It has thus led to a very varied architecture throughout the world. The main ways of using earth can be presented by classifying them according to the state of humidity of the earth at the time of its use, and according to the way the material is used, but it is important to know that there is no "good earth". There are only good masons who know how to use the available earth. The production of the earth material was done using simple tools as well as the implementation techniques, we will briefly discuss the four main construction techniques in raw earth (adobe, cob, and pisé) and focus specifically on adobe which is the technique used in the constructions of KhanguetsidinadjiKsar.

The Technique of Bauge

A massive earth construction technique where the earth, sometimes mixed with plant fibres, is piled up directly (without formwork) in successive layers running all around the building. This is a very old technique which probably preceded the adobe technique. The earth is similar to that of the adobes and prepared in the same way. The method of manufacture

is artisanal, and consists of manually modelling walls as they are built, by forming balls of earth approximately 60 cm high and thick. The material used is very clayey, and can be mixed with vegetable fibres or straw. The walls are usually load-bearing. (P. Pieux, 2012).

Figure 3. construction of a wall in bauge.
Source : https// : www.approche-ecohabitat.org/images/...../Ecopole/C6_bauge_v2.pdf.
Accessed on : 01/08/2019.

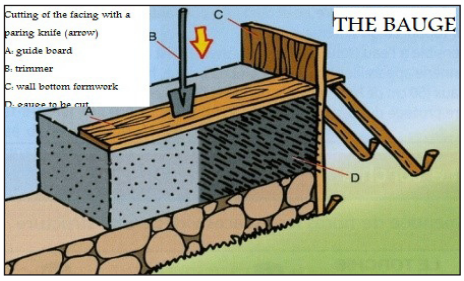

Figure 4. construction of a bauge wall.
Source : https//:www.batirama.com.

The Mudtechnique

In contrast to bauge, which is used as a monolithic wall, mud never has a load-bearing role and is only used to fill in wooden structures as floor slabs, or to fill in the laths protecting the wooden sides of houses in certain regions. It is therefore expected above all to have insulating qualities and not mechanical resistance to loads. Although it is generally used in a homogeneous manner on the entire façade of buildings, it can also be used on the upper part of timber-framed constructions that use other materials, such as stone, cob, adobe (which is common in Europe).

The straw torch, bound to clay in a plastic state and wound around a stick, is a vertical or horizontal wall element. In the latter case, cob is specifically used for insulation purposes.

In essence, mud is a technique that is compatible with a climate with high rainfall, and it is not installed until after the frame and roof have been laid. The workers who lay the mud therefore work under cover of the rain. (B. Pignal, 2005).

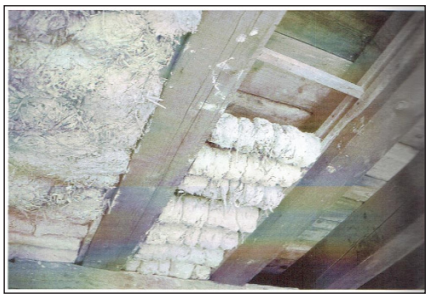

Figure 5. Insulating cob laid in the voids of the structure of a wooden floor. Source : B. Pignal.2005.

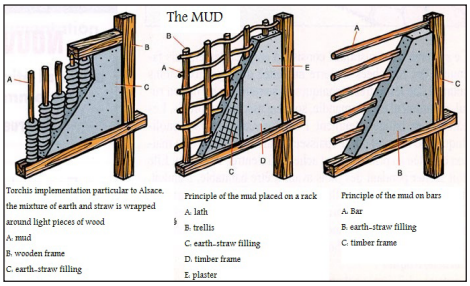

Figure 6. Construction of a cob wall.
Source : https//:www.batirama.com.

The Pisétechnique

This is a technique of building with formworked earth. The clayey and granular earth is compacted by hand in successive layers in a wooden formwork in the form of blocks built one after the other, the construction progressing as these blocks are built.

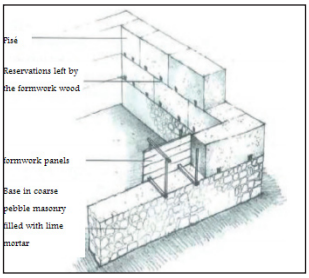

Figure 7. Implementation of a pisé wall. Source : P. pieux.2012.

Raw earth brick or adobe

Adobe is the most commonly used name for sun-dried bricks. Adobe bricks are moulded from moist clay soil. Originally, these bricks were formed by hand. Later (and still today), they are made by hand using moulds with various prismatic shapes made of wood or metal. Nowadays, machines are also used.

Figure 8. Manufacture of adobes. Source : P. Delot.2015.

Presentation of the Study Context: The Earth Material in Algeria

The heritage of earthen architecture in Algeria, which is essentially made up of the ksour of the south, is represented in two cases.

- The ksour that have broken down, that have continued to live, that have expanded, joined the road, this is done in spatial continuity, form, materials ... "It is this formula that allows the ksar to transform and persist, with degrees of adaptation to the modern world" (COTE, 2010).

- The abandoned and ruined ksour often have extrinsic causes, particularly climatic (the 1969 rains), which caused the population to break away from this type of construction.

Efforts to rehabilitate the architectural heritage of the Algerian ksour are not new. The first operation to classify a monument in the region dates back to 1972, the date of the promulgation of a law classifying the M'Zab Valley as part of the national cultural heritage, which shows the renewed interest of the international community in the architectural heritage of the oases. But if the ksar has been admitted into the legislative sphere, as an element to be preserved, it remains to this day confined to the aesthetic aspect alone.

The Ksour are even often considered as precarious, unhealthy and peripheral housing and not as cultural heritage to be requalified or archaeological and historical capital to be revalorised or socio-economic way of life to be maintained. Today, at the local level, comfort, as it is conceived, can only be achieved through the construction of a dwelling made of new materials away from the old Ksar. The habitat of the Ksour, which fulfilled vital functions in the life of traditional oasis society, can no longer meet today's requirements in terms of well-being. "Algerians are not very interested in their heritage, nor are the public authorities. They are not interested in the history of their country and even less in the history of the world. This leads us to seek the reason for the lack of interest in memory" (Ferdi. S, 1996).

The measures taken over the last ten years concerning cultural goods, historical monuments and urban or rural ensembles, notably the creation of protected sectors and classification, represented by a panoply of laws fixing the modalities of protection and enhancement of the cultural heritage (see Annex 01), have not succeeded in giving the desired image to our cities in the south, this image of earthen architecture (Ksour) which is devalued because of a mistaken vision of development. A vision based on the construction of modernity in the negation and contempt of the product of a thousand-year-old tradition.

The ksour have existed for centuries but have never melted under the rain and the houses do not require costly maintenance operations. The state of ruins is also linked to the abandonment of these places (ksour) by the local populations. This is a dramatic case of abandonment of the entire Algerian heritage. Sometimes, there has been voluntary destruction to rebuild concrete houses presented as modern.

However, since 2001, the mediation between domestic architectural design and ancestral construction processes has been the subject of general interest, and this through civil society. Indeed, several exhibitions and study days have been organised in order to change the archaic vision that users have of earthen architecture. The speakers, architects, social partners and local elected officials, take advantage of each meeting, official and unofficial, to underline the importance

of the valorization of the earth material, and its integration as an architectural mode in modern constructions, as they plead for the implementation of operational mechanisms able to allow the use of this mode of urbanization, the initiation of its techniques, the creation of opportunities for the commercialization of building materials intended for earthen architecture. (Boutabba et al.2015) A return of raw earth is announced in particular in compressed earth bricks BTC or stabilised BTCS. Amongst those, Yasmine Terki, curator of the "ArchiTerr" festival and director of the Algerian Centre for earthen cultural heritage "CapTerre", which is based in Timimoune and institutionalised in July 2011, explained the Algerian strategy for the rehabilitation of the image of earthen architecture, amongst its missions.

- The rehabilitation of earthen architecture.
- The design or realization of contemporary buildings that use earthen materials.
- Training in the field of earthen architecture.
- The creation or development of a company's activities in the earthen sector.
- Carrying out studies or research on the earthen architectural heritage or on earthen construction.
- Develop projects or activities in the framework of the conservation of earthen architectural heritage or the promotion of earthen architecture.
- To make a building or a group of buildings of exceptional value benefit from a legal protection measure of the Ministry of Culture.

The case study: The Ksar of Khanguet Sidi Nadji

Khanguet Sidi Nadji means the gorge of Sidi Nadji and is called Khangua (the gorge) for short. The Ksar is located in the region of the Eastern Zab, in the extreme East of the wilaya of Biskra, it is in the intermediate zone between the mountain and the Sahara, built on a steep side of the mountain at (254m) of altitude, oasis of (16000) palm trees, one hundred and ten kilometres separates it from Biskra, one hundred and twenty from Khenchela, it represents the Eastern limit of the wilaya of Biskra. KhanguetSidiNadji is administratively linked to the daïra of Zeribet El Oued from which it is distant 25km. It covers an area of 80km^2 and is limited to the North by the commune of El Oueldja (wilaya of Khenchela), to the South and South-West by Zribet el Oued, to the East by the commune of Djellal (wilaya of Khenchela) and finally to the South-East by the commune of Babar (wilaya of Khenchela)

The creation of the first nucleus of Khanguet Sidi Nadji dates back to about four centuries ago, and the mosque of SidiLembarek is a witness to this. In the absence of a graphic document that illustrates the evolution of the urban fabric of the Ksar of KhanguetSidiNadji, we can distinguish three main periods.

-A first period during which was made the creation of the core of Khanguet Sidi Nadji, the construction of the mosque SidiLembarek and some constructions which surround it in addition to the appearance of some dwellings in first beside the current water tank which were demolished thereafter because of their location at the end of the escarpment.

-A second period which represents the colonial period where the inhabitants grouped together in a very dense way in the Eastern region especially by building houses, with local materials, earth bricks, tree branches, giving birth to a compact and dense fabric.

-A third period, this one represents the independence where the urban extension grew, the introduction of new building materials, the use of stone, cement, brick, a great densification of the dwellings which generated a complete use of space, which induced to a lack of necessary equipment and services. This has led to a lack of necessary facilities and services, which in turn has led the inhabitants to locate their buildings in the new municipal headquarters (El Bordj). (M. Nasri. 2021).

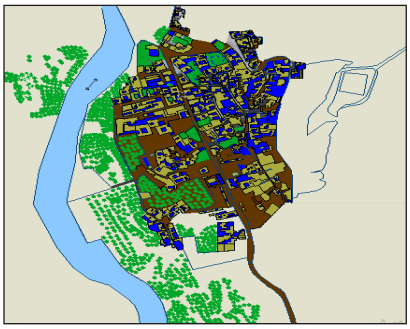

Figure 9. The Ksar of Khanguet Sidi Nadji. Source : Author.2022.

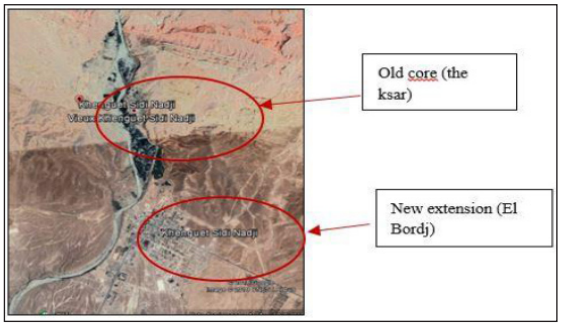

Figure 10. Commune of khanguet sidi Nadji.
Source : Google Earth 2019.

Figure 11. Some views on the ksar of khanguet sidi nadji.
Source : Author 2022.

The Ksar of Khanguet Sidi Nadji is a historic complex full of symbols and memory, with an architectural heritage of great value. This historic centre is now undergoing a process of transformation, degradation and rapid abandonment. The causes of this state of affairs are essentially due to the increased marginality of the Ksar in the urban structure of the city and in local planning. These conditions mean that the Ksar is abandoned to the various factors causing its degradation.

Concerning the phenomenon of the abandonment of the Ksar of Khanguet Sidi Nadji, we put forward the hypothesis that the abandonment of the Ksar is the result of the modernization of the way of life which has led to the loss of many traditions and contributed to the current decadence of the Ksar and the unsuitability of the Ksar to the requirements of the population. The method of investigation used to test the hypothesis is the «survey». The data collection tool is the «question form» focusing on the reasons for the abandonment of the ksar to El Bordj as the first destination.

To this end, the population studied through the survey represents 46% of the households that left the Ksar of KhanguetSidiNadji. Our choice of sample was made because of the scattering of households in the different regions of the city of Biskra and on the national territory. This made the survey difficult to carry out. In order to be more representative, we took 30 families (150 people) who had abandoned the Ksar and who reside in the wilaya of Biskra.

Method and Materials of Analysis

The management of the data collected on the analytical level made use of the various statistical tests offered by the STATISTICA software. These tests are of two kinds: firstly, the uni-varied descriptive tests which make it possible to identify the surveyed population in relation to its characteristics (number, sex, level of education, activity, etc.), and secondly, the differential tests, i.e. bi- or multi-varied tests which make it possible to evaluate the variance or the relationship between two or more variables.

The reasons for the abandonment of the Ksar are multiple (lack of employment, lack of equipment and the dilapidation of the built environment, etc.). We will demonstrate the results applied by the STATISTICA software on the dilapidation of the built environment, since this is the reason that interests us in this article.

The application of the Mann-Whitney test for the calculation of the relationship between “the dates of the abandonment of the Ksar” and “the obsolescence of the built environment” estimates the value of (Z: 1.381108) and (α: 0.14706> 5%). Therefore, the null hypothesis cannot be rejected.

It can be seen that only 12% left the Ksar between 1954 and 1962 because of the dilapidation of the built environment, compared with 57% between 1962 and 1990 and 50% after 1990 for the same reason. To this end, and based on an

observation of the current state of the Ksar, notably its degradation and abandonment, we can distinguish the classic degradation factors from those due to the upheaval of living conditions. Also, the construction techniques present pathologies that cause important degradations in the structures. The action of time which results in the ageing of constructions, following under-maintenance, or even the abandonment of certain elements which no longer have any functional value and therefore no longer play their role.

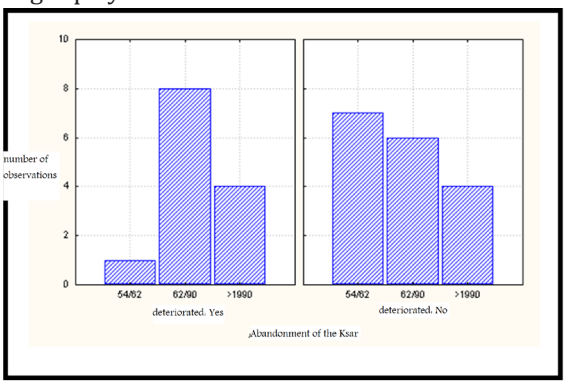

Figure 12. Categorised histogram: Calculation of the relationship between "the date of the abandonment of the Ksar" and "the dilapidation of the built environment" as a reason for abandonment.
Source : Author 2022.

The degradation and abandonment of the Ksar are due to the precariousness of the built environment which requires a lot of maintenance on the one hand, and to the pathologies observed in the constructions and their implementation on the other. All these consequences are accelerated by the effect of the climatic conditions of the region, leading to the degradation and decay of the Ksar without neglecting the action of man.

To this end, we have used some theoretical models on the different techniques of adobe and the forms of pathologies that can affect the earthen architecture, as a reference to diagnose the action of climatic effects on the ksar of Khanguet Sidi Nadji.

We also called upon engineers in civil engineering and the specialist Mr. H. Taoutao (Architect and doctor in archaeology graduated from the Sorbonne) who enlightened us by his knowledge on the various pathologies caused by the climatic effects on the constructions of the Ksar.

Building System

Foundations

According to the surveys carried out and the people interviewed, the majority of the houses in the ksar are made of adobes, built on the stone foundations. They are shallow, not exceeding 40 cm in depth. Their width varies between 50 and 70 cm. In other cases, the foundations are made with a few layers of dry stones or rolled el oued (oued el Arabe) with earth mortar. The foundations are not often made of natural stones extracted from Oued El Arabe. They are sometimes cut by hand.

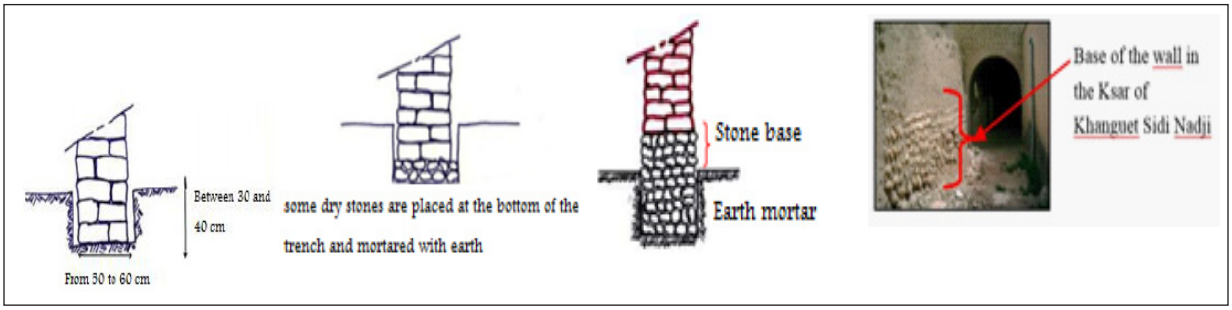

Figure 13. Layout of the foundations. Source : Author .2022.

Supporting Elements

The adobe walls are load-bearing and are between 40 and 50cm thick. The layout differs according to the thickness of the walls; two variants have been noted. In some cases, a secondary structure can be seen with large posts (up to one metre square).

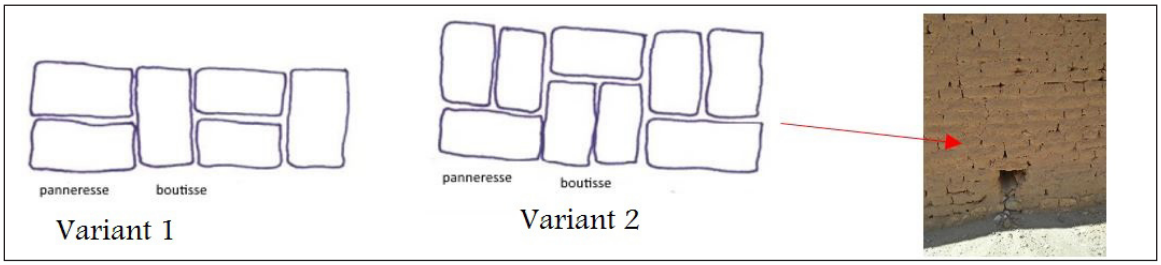

Figure 14. Types of adobe layout. Source : Author 2022

Floors

The roof or the covering of the houses is in the form of an accessible terrace, it receives most of the solar radiation, but its constitution plays the role of thermal insulation consisting of: "Khechbate" or palm beams formed by a quarter of a palm trunk, 2 to 2.5 cm in length, supported at their ends. This layer is then covered by a bed of Djrid (to avoid infiltration). A significant layer of earth is added last to consolidate the whole, which is 10 to 15 cm thick. The thickness of this layer depends on the location of the floor (first floor or terrace). The whole is protected by a waterproofing layer of whitewashed lime mortar.

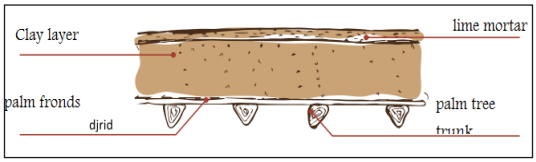

Figure 15. Flat floors made of palm trunks and branches. Source : A.Baghbagha. 2013

Figure 16. Example of a floor in the ksar of khanguet sidi nadji. Source : Author 2019.

The Destructive Effect of Rainwater on the Buildings of the Ksar

The greatest enemy of earthen constructions is water in its various forms. Rainwater is the most catastrophic for earthen constructions, especially when it comes in the form of a downpour. It attacks the top of the walls, the bottom of the walls and the terraces, which are not sufficiently protected.

Whatever its origin, the water that generates humidity in buildings comes in three main forms: liquid water, water vapour and water in capillary circulation. (J and L. coignet.2003).

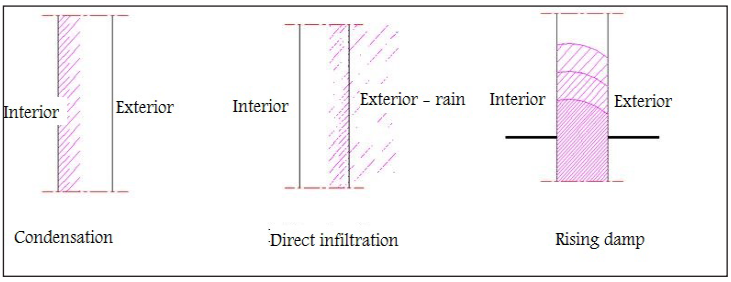

Figure 17. The three forms of moisture in construction. Source: J and L. coignet.2003.

The rain wets the ground deeply, feeds the water table, then the moisture rises by capillary action in the load-bearing walls. The bonding mortar of the base wall of this part of the building has completely disintegrated under the action of the capillary rise of water.

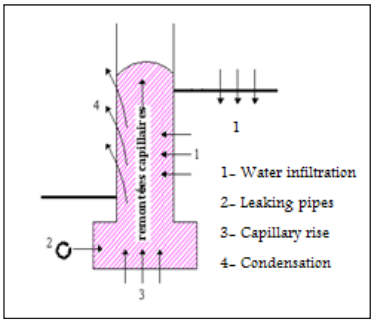

Figure 18. The different sources of water. Source: J and L. coignet.2003.

Figure 19. Erosion of the bottom of the wall in a building in the ksar of khanguet sidi nadji. Source : Author.2022.

Rainwater flows directly into the alleys of the ksar, causing damage to the bottom of the walls. The stagnant water seeps into the wall due to the action of capillary rise. With time the wall loses its firmness and resistance and becomes fragile. It has been noticed that when the wall has a stone base it is more resistant.

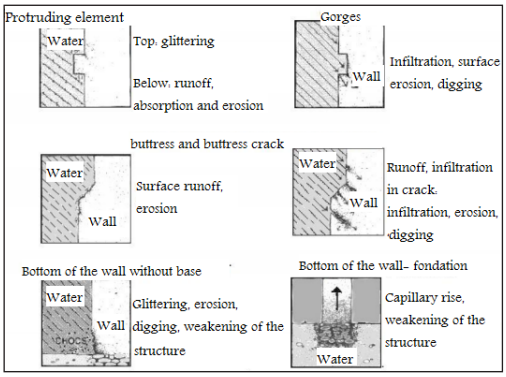

Figure 20. Behaviour of earth structures with moisture. Source : CRATerre.

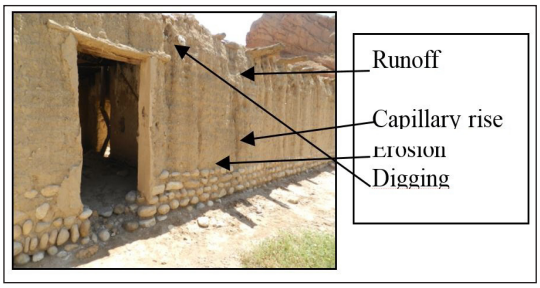

Figure 21. The disintegration of the material by the action of the runoff water which ended up causing cracks, is more important in the lower level of the wall and on the jamb of the doors. (Ksar of Khanguet Sidi Nadji). Source: Author.2022.

In figure 21, the wall is relatively preserved. It was built in adobe, which has disintegrated on the surface, and rests on a base of squared rubble. This wall encloses a dwelling, which has partially lost its roofing, with the façade walls stripped in places, disintegrated on the surface and sometimes cracked. This damage is caused by the action of run-off water.

In the event of a severe storm, the runoff can be heavy and sudden enough to invade the entire house. The water is not always collected in the absence of a sewerage system and sometimes wastewater is added to the rainwater. Their abundance in the event of a storm is almost always underestimated. The inhabitants of the Ksar sometimes protect the doorways of their houses when a storm threatens to turn the street into a river, with a step and some tiles.

The disappearance of the covering structures opened the way for the action of run-off water which, by disintegrating the earthen material, caused a large hole in the wall.

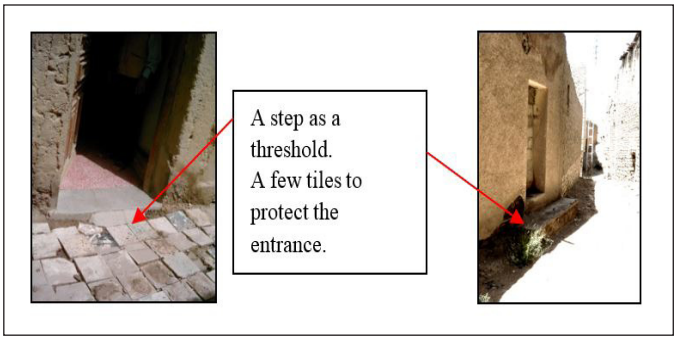

Figure 22. Protection device of the sills against run-off water. (Ksar of khanguet sidi nadji). Source : Author 2022.

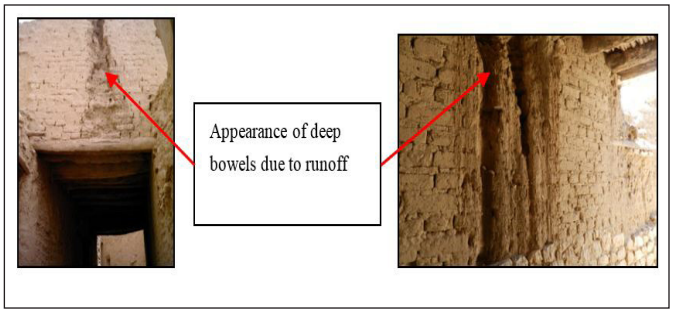

Figure 23. Deep cracks (passantes) caused by the effect of runoff of puviales waters. (Ksar of khanguet sidi nadji). Source: Author. 2022.

The disintegration of the earth masonry bonding mortar caused by run-off water eventually formed continuous vertical cracks along the wall.

The evaporation of capillary rise was blocked, causing cracks in the facades, and the action of the driving rain completed the wall's ruin. The continuous cracks along the wall show the final stage of the disintegration process of the earth masonry and its binding mortar.

Condensation is due to an accumulation of moisture in the adobe equipment and under a waterproof plaster that is peeling off. Its action contributes to the weakening of the structure. The phenomenon appears mainly in the kitchens, where the beams weakened by rot end up

Figure 24. Trace of condensation with water run-off because of the bad junction of the beams and the wall. (Ksar of khanguet sidi nadji). Source: Author.2022.

Figure 25. TCondensation trace that affected the beams (black colour of the mould). It also caused the roof to sag. (Ksar of khanguet sidi nadji). Source : Author.2022.

bending until they break, thus causing the ceiling to fall. The traces of the condensation in the kitchen are visible on the wall below the chaining beams. To prevent the ceiling from collapsing, juniper wedges are often used to stop the bending movement under the beam.

The poor condition of the unprotected acroteria has caused the mortar between the gargoyles and the walls to deteriorate. The gargoyles are poorly made and unprotected at their exits, which means that water not only seeps into the wall, which is the greatest danger, since the infiltration is not apparent. But it also runs over the surface causing an apparent crack which, over time, makes it fragile and destabilises it.

Figure 26. Degradation of the wall - detachment of the plaster of the interior space and the façade - erosion of the head of the wall. (Ksar of Khanguet Sidi Nadji). Source : Author 2022.

The slopes are not respected when the roofs are built, which causes rainwater to be retained. In addition, there is a risk of collapse due to overloading caused by the accumulation of soil. On the (Fig.27), the roofs of the buildings have suffered a lot of damage due to these two phenomena. The irregular shape of the mud bricks, mainly due to the mould of the Touba (adobe) itself, favours overlapping joints and sabre cuts, especially as the vertical joints are never filled.

Figure 27. Degradation of the roofs of the houses due to the retention of rainwater. (Ksar of khanguet sidi nadji). Source : Author.2022

Wood material is also subject to water damage. This can take different forms. First of all, wood rot occurs when there is a constant presence of moisture either inside or outside the building (immediate environment). This situation creates a favourable climate for the development of micro-organisms and insects that cause the degradation of the wood, it should be noted that the parts embedded in the wall are the most affected by this phenomenon. Secondly, we have the loss of solidity of the wood due to dimensional variations. This occurs when water stagnates in contact areas (junction points) between the masonry and the wood. (Y. Baret, 2014).

Figure 28. Deterioration of palm wood due to water retention. (Ksar of khanguet sidi nadji).
Source : Author.2022

Deterioration of structural wood due to poor embedding

Effect of physical pathologies on the buildings of the Ksar.

Given the uneven configuration of the Ksar, especially on the eastern side, and the poor state of the foundations, entire dwellings have disappeared and many others have collapsed due to landslides.

According to the survey carried out among the inhabitants of the Ksar, 90% answered that at least one landslide had occurred in the Ksar. We noted some damage concerning the outward tilting of the wall, which refers to the movement of the wall away from the plumb line as a result of lateral thrust or landslide. (Fig. 29).

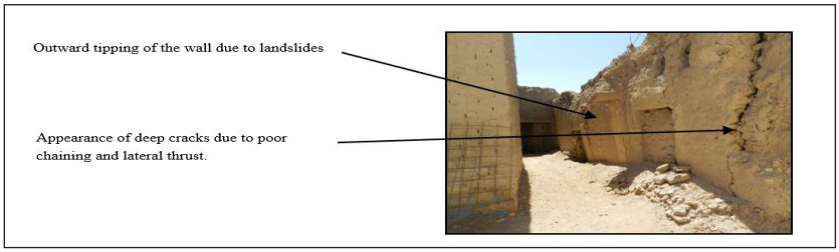

Figure 29. Spilling of the wall towards the outside. (Ksar of khanguet sidi nadji).
Source: Author 2022.

-Formation of bellies under the effect of the thrusts (differential terminal settlement), this is explained by the uncoupling of the wall due to a bad chainage (Fig.30 -(a)).

- Crack formation and according to their size we can distinguish between microcracks, cracks, fissures or crevices.

- Punching cracks due to poor load distribution (weight of the roof or floor). (Fig.30 -(b)).

- Shrinkage cracks in some adobes caused by long periods of drought (Fig.30 -(c)).

Figure 30. a). Passing crack due to differential settlement. Sabre stroke (Ksar de khanguet sidi nadji). b). Inter-intermediate differential settlement. (Ksar of khanguetsidinadji). c). The removal of mud bricks. (Ksar of khanguet sidi nadji).

We can also note some inopportune interventions by owners and masons who use waterproof materials and exclude the so-called “breathing” solutions (lime plaster, lining over an air space, ventilation, etc.) or “draining” solutions (internal

or external drain, waterproofing of the roof, etc.), eliminating the stone bases and removing the roofing. The damage caused by this process is reflected in the detachment of recent plasterwork, the loosening of adobe courses and the opening of breaches.

Figure 31. Detachment of the plaster due to the use of waterproofing materials unsuited to the properties of the adobe. (Ksar of khanguet sidi nadji). Source : Author.2022

Discussion of Recommended Solutions

Before starting the rehabilitation or restoration of the affected structures, the causes of the pathologies must first be eliminated. In the case of the Khanguet sidi Nadji ksar, this is a manifestation of wet pathologies. An earthen construction, whatever the method used, must have good boots and a good hat so that it can resist the effects of humidity which are the first enemy of this type of architecture.

The remedy against humidity in this case is the installation of a perimeter drain, which is a device that controls the humidity present at the foot of the wall. The system consists of intercepting rainwater and preventing it from reaching the base of the walls, channelling it to a drain connected to the rainwater network. (Collombet et al, 1989).

The primary purpose of the perimeter drain is not to evacuate water but to allow the foot of the wall to dry. It favours the ventilation of foundations in an environment where there is little exchange. It is recommended that the base coatings be formulated differently so that they are both «breathable» and impact resistant. A little pozzolan can be added to improve their performance.

Figure 32. Peripheral drain. Source : I. Kadoui et al, 2015.

Figure N°32, taken in Maatkas (village of Ichaouadienwilaya of TiziOuzuo), illustrates a peripheral drain. According to the owner, its installation is the solution to finish with the rainwater infiltrations from which his house was suffering. To do this, the owner first stripped the soil beneath the wall and removed both the vegetation and the waterproof paving. Finally, he made a sloping trench and a gutter to channel the water to the main drain. As a safety measure, the owner installed a wooden barrier to act as a guardrail for passers-by (I. Kadoui et al, 2015).

If the water infiltration is due to a broken pipe, which is rare in the case of the ksar of khanguetsidinadji, as the majority of the houses do not have a sewage pipe, the pipe must be repaired and the plastering must be repaired, preferably with a lime plaster. If the upper part of the wall is affected, the roof should be extended. If the lower part of the wall is affected, it will be sufficient to give a slope to the floor and to remove the waterproof paving which prevents the natural evaporation of water (Fig. n°33-a).

The harder you make the foot of the wall (pavement, gutter), the more you raise the area weakened by the water splash. On the contrary, the culvert should be placed as far away from the wall as possible and in line with the roof edge. Wall feet left in grass, above a drain, greatly reduce the effects of rainwater splashing and contribute to a better drying of the base.

Damaged or missing adobes should be replaced by other adobes of the same nature or by a salvaged material which should be applied with a hydraulic lime mortar or an old mortar stabilised with hydraulic lime.

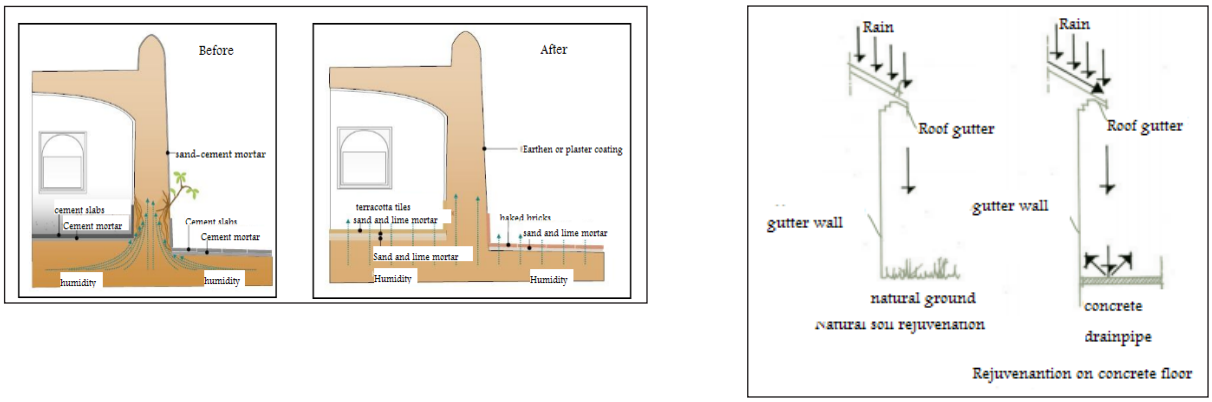

Figure 33. a) Baked brick and sand-lime mortar pavement. Source: Moriset et al. 2011. b) Effect of rainwater backwash. Source : Yves Baret, 2011.

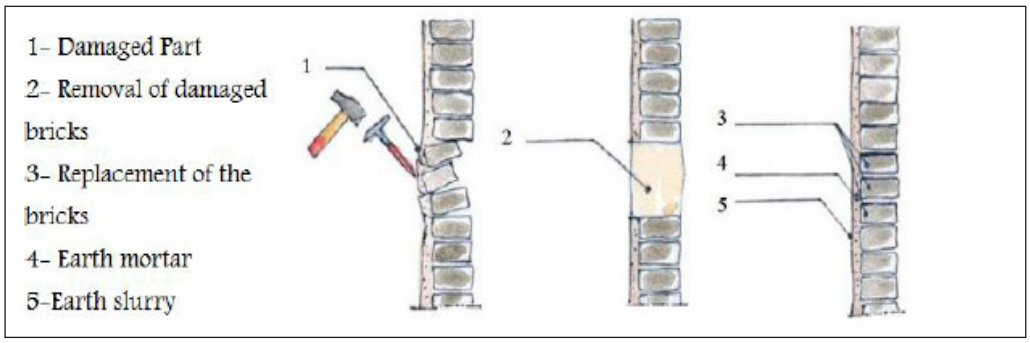

Figure 34. Method of partial repair of an adobe wall. Source : I. Kadoui et al, 2015.

If rainwater runoff has created a large cavity along the wall, fill it with a mixture of earth and straw and cover it with a vapour-permeable, waterproof plaster. Re-establish the gutter system to facilitate the drainage of rainwater. The treatment to be used against condensation-related pathologies consists of removing the cement plaster, which is waterproof, and re-establishing the hygrometric transfer inside the material.

In order to re-establish the plaster, the traditional technique par excellence is recommended on a bare and pitted support. The mortars used can be homemade or ready-made but must have a decreasing dosage of binder. The first layer, called «gobetis», regulates the porosity of the masonry support and ensures the adhesion of the subsequent layers of rendering. Sprayed in a 5 mm thick layer, the surface of this mortar with a high proportion of binder must remain rough to facilitate the adhesion of the second layer. It is necessary to wait at least 48 hours before applying the second coat which forms the body of the rendering. Applied on the re-wetted base coat the day before, the 15 to 20 mm thick rendering body is applied in two or more passes, levelled with a ruler, tightened with a float but not floated to preserve its roughness. It is used to waterproof and straighten the support. The cumulative thickness of the first two coats must be between 15 and 20 mm and ensure an overlap of at least 10 mm at all points. After a minimum of 7 to 9 days of drying, depending on the nature of the binder of the rendering, the last stage consists of a finishing coat of 3 to 7 mm thick, applied in one or more passes depending on the type of mortar and the desired appearance (floated, smoothed, structured, etc.).

In addition to its decorative role, this finishing coat protects the rendering body so that it retains all its waterproofing characteristics.

In the case of cracks, before any repairs are carried out, the origin of the problem must first be determined and remedied in order to stabilise the structure. Depending on the degree of the pathology, there are several types of interventions, such as: tie rods, wooden chains. It is recommended to install them at equal intervals, figure n°36 shows the detail of the key, it is made of wood, consisting of male and female pegs. Once the keys are installed, the cracks are filled in and then covered with earth and straw mortar, taking care to fill in the remaining spaces between the key and the wall.

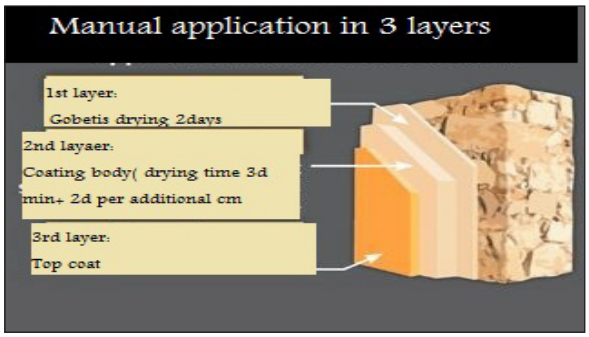

Figure 35. Render on a mud wall.
Source : https://www.batirama.com/article/4467-enduits-a-la-chaux-quel-type-d-application-of-renovation.html.
Consulted on :07/08/2019.

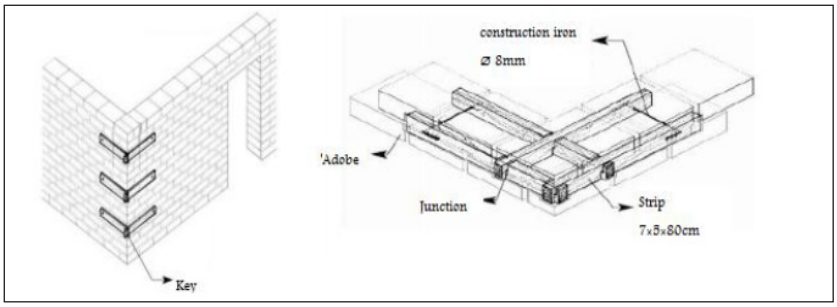

Figure 36. Reworking of corners in an adobe construction. (Chainage des angles).
Source : I.Kadoui et al, 2015.

If the cracks are superficial and do not affect the stability of the building, the cavities can be cleaned and filled with an earth-based mortar (Moriset et al, 2011). Cement mortar should be avoided altogether, as the repair of cracks should be done with materials compatible with the earth material. Finally, and to homogenise the surface, a plaster can be applied.

In the case of tilted walls, the installation of tie rods is highly recommended. A tie rod is a metal device that holds together two opposite walls that tend to move apart. This method consists of attaching steel cables to two opposite walls to prevent them from moving further apart. The cables should be laid in such a way that they do not interfere with human activity inside the house. One of the two anchoring elements should also allow for periodic adjustment of the tension to compensate for the effects of possible elongation of the tie rod. There are several types of tie rods which can be used to stop the spreading of the walls (Fig. 37).

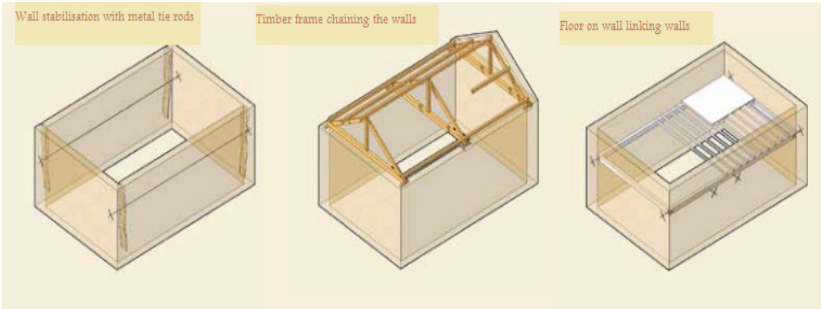

Figure 37. Chainage of the walls by metallic tie rods. Source : Moriset et al, 2011.

The main causes of deterioration of the wood due to ageing are insects, fungi and moisture due to lack of maintenance. Fungus and termite attacks are often concentrated on the supports of wooden beams and joists, especially on the side of external walls, due to the special conditions of humidity and darkness that characterise them. In these cases, it is usually necessary to functionally replace or reinforce the supports damaged by wood decay. In order to prevent such damage, annual or even multi-year maintenance is carried out, consisting, depending on the case, of repeated application of whitewash, maintenance of lime and earth mortar, regular tamping of the clay surfaces and maintenance of the clay sealing layer.

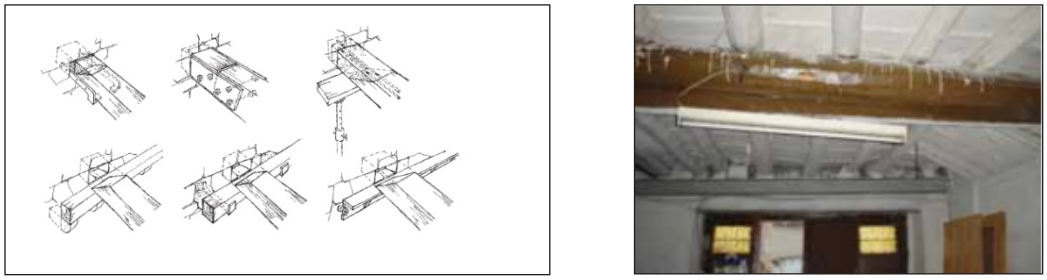

Figure 38. a) Scheme for the replacement of wooden beams Source: C.D. Gomez.2015. b) Rehabilitation of the floor with whitewash. Source: C.D. Gomez.2015.

In the case where the beams have undergone deflections, additional resistance for the beams and joists is necessary. This technique consists of adding new elements that will collaborate in absorbing the forces acting on the beam or beams, when the dimensioning is considered insufficient or when the effects of wood creep have created excessive deformations. The reinforcement materials used are usually timber or steel sections, positioned laterally, inferiorly or superiorly to the element to be reinforced. The upper position is chosen in all cases where the appearance of the original floor is to be preserved, where there are valuable paintings or false ceilings. The lower position is most often used to reinforce beams when the free height at ground level allows for a reduction, while the lateral position is more common if the wooden beams to be reinforced support whole sections of beam floors, in which case it is sufficient to fix two elements with dowels passing through the beam. The assumptions for the calculation of the reinforcements are different, depending on the possibility of resistant collaboration of the under-dimensioned or damaged elements and the preliminary deformations (counter deflections) to be considered to obtain their joint load entry with the reinforcement.

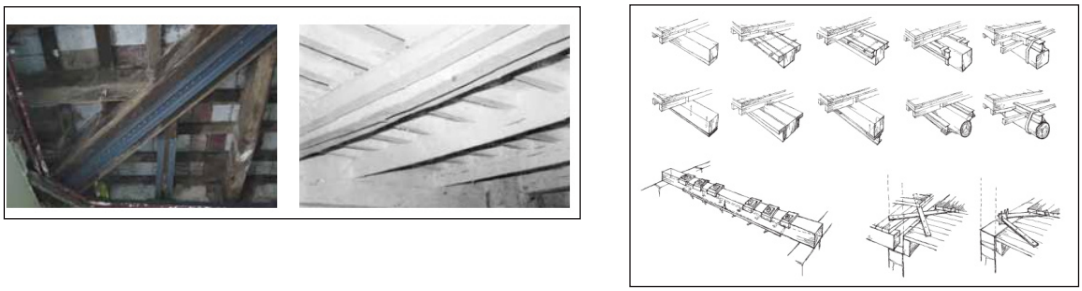

Figure 39. Additional resistance for beams and girders. Source : C.D. Gomez.2015.

CONCLUSION

Collapsed walls, abandoned houses, alleys cluttered with blocks of earth, such is the image that the Ksar of Khanguet Sidi Nadji offers. This deterioration is due not only to the action of time (effects of the climate), but also to the absence of maintenance which adds to the defects of the constructive system. The Ksar of KhanguetSidiNadji is exhausted by its abandonment. Most of the abandoned dwellings are in a state of ruin and even beyond repair. The remodelled or abandoned dwellings of the Ksar are rapidly deteriorating and degenerating, as all the conditions are combined to favour a total disaffection of this traditional habitat. This causes the degeneration of the urban image of the Ksar at the risk of erasing its trace.

In spite of this, it is possible to save what remains standing, by conducting awareness campaigns among the inhabitants. By explaining to them the heritage value of the Ksar.

It is urgent to take basic measures to stop the destruction and to slow down this phenomenon of accelerated deterioration. It is also important to associate the prescriptive measures with actions of valorisation, mediation or accompaniment. However, the general public must be made aware of the advantages of the earthen habitat, and an attempt must be made to integrate it into its environment in accordance with a sustainable development policy. The elaboration of an idea on how to rehabilitate the earthen architectural heritage, taking into account the socio-economic realities of the country in general and the particularities of each region. The promotion of the use of earth as an essential material in construction and also, the recovery of the regional methods of implementation of the raw earth brick by the knowledge of the practised techniques and the application of the most modernized of them. The elaboration of a regulation of the earthen construction on a national and regional scale (in the form of a technical guide) and to try to encourage the

realization of rehabilitation projects and new constructions in raw earth, by involving the public authorities more. The training of the workforce and the people involved and the establishment of a Rehabilitation and Revalorisation of the Earthen Heritage in the form of conferences and seminars to create a link between the different actors (project owners, architects, construction companies, operators, etc.), in order to have a mastery of the earthen sector, remain to be done. Finally, the creation of a financing fund that will reduce the expenses of the operator and encourage him to maintain his property.

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Citation: *NASRI .MANEL, FARHI .ABDELLAH. Raw Earth Architecture, an Adaptation Lesson in Distress. The Case of Khanguet Sidi Nadjiksar, Biskra, Algeria. Int J Innov Stud Sociol Humanities. 2022;7(6):60-76. DOI: https://doi.org/10.20431/2456-4931.0706007.*