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Tradition and Sustainability in Vernacular Architecture of Southeast Morocco

Teresa Gil-Piqueras * and Pablo Rodríguez-Navarro

Centro de Investigación en Arquitectura, Patrimonio y Gestión para el Desarrollo Sostenible–PEGASO, Universitat Politècnica de València, Cno. de Vera, s/n, 46022 Valencia, Spain; rodriguez@upv.es
* Correspondence: tgil@ega.upv.es

Abstract: This article is presented after ten years of research on the earthen architecture of southeastern Morocco, more specifically that of the natural axis connecting the cities of Midelt and Er-Rachidia, located North and South of the Moroccan northern High Atlas. The typology studied is called *ksar* (*ksour*, pl.). Throughout various research projects, we have been able to explore this territory, documenting in field sheets the characteristics of a total of 30 *ksour* in the Outat valley, 20 in the mountain range and 53 in the Mdagra oasis. The objective of the present work is to analyze, through qualitative and quantitative data, the main characteristics of this vernacular architecture as a perfect example of an environmentally respectful habitat, obtaining concrete data on its traditional character and its sustainability. The methodology followed is based on case studies and, as a result, we have obtained a typological classification of the *ksour* of this region and their relationship with the territory, as well as the social, functional, defensive, productive, and building characteristics that define them. Knowing and puttin in value this vernacular heritage is the first step towards protecting it and to show our commitment to future generations.

Keywords: *ksar*; vernacular architecture; rammed earth; Morocco; typologies; oasis; High Atlas; sustainable traditional architecture

Citation: Gil-Piqueras, T.; Rodríguez-Navarro, P. Tradition and Sustainability in Vernacular Architecture of Southeast Morocco. *Sustainability* **2021**, *13*, 684. https://doi.org/10.3390/su13020684

Received: 14 December 2020
Accepted: 7 January 2021
Published: 12 January 2021

1. Introduction

Earthen architecture is part of southern Morocco's history, being a characteristic element of both its landscape and its culture. From the first urban settlements to the present day, earthen architecture has been part of the historical and identity value of this society, bringing together the intangible and the symbolic value of its culture. However, this architecture is not only endowed with these values, but it is also of great scientific value for the rest of society. In it, we find urban models that are perfectly adapted to social needs, using construction techniques validated by practice and respectful of the environment. It is a sustainable architecture arising from the environment itself, using construction materials from its own surroundings; and, at the same time, is endowed with a great adaptation capacity, both to the climate and to the territory, being an example and model for contemporary architecture [1,2]. Furthermore, the *kasbah* and the *ksar* were built to meet the social needs of the day, without compromising the future.

Throughout our extensive research in the last decade, we have witnessed how this traditional heritage has suffered great deterioration, resulting in the loss of numerous architectural references, now irreplaceable [3].

Currently, the problems threatening these constructions are many, the most pressing being their abandonment, although it is obvious that the replacement of construction techniques and the use of incompatible materials also puts their life at risk. In any case, once the process of ruin and deterioration begins, if no immediate action is taken, it can no longer be stopped, and shortly after it becomes integrated into the natural environment that one day allowed its construction. It is true that in recent years the Moroccan government has contributed to the preservation of some of these villages [4], although further progress

should be made in this regard. Perhaps an aid policy and a program of social recognition launched by public administrations in favor of this life model would help put a stop to the generalized process of degradation that the traditional earthen architecture of southern Morocco is suffering.

A connoisseurs of the situation throughout southern Morocco, as a result of various research projects in which we have participated as researchers or have directed, we present this research aiming at characterizing the earthen architecture of southeastern Morocco, as an environmentally respectful habitat model, providing concrete data related to its traditional character and on the characteristics that make it sustainable.

2. Research Aim

Since the 8th century, the constant tribal struggles for control of the territory and the existence of the trade route between Fez and Sijilmassa were determining factors for the establishment of the first fortified settlements along the Ziz river [5]. There are several authors who already at that time mentioned cities such as Sijilmassa, Amghak, or Igram n'Watub along the route between the current Midelt and Er-Rachidia [6–8]. There is evidence that in the 16th century, Ksar es Souq and Sidi Bou Adbdellan *ksar* already existed, both located in the Madgra oasis [9,10]. We also know that Zaouia Sidi Hamza [11], an important link between the Mdagra oasis and the Outat valley, was founded in the 16th century [12] and that the first settlements in the Outat valley took place at the beginning of the 19th century [7].

The area subject of our research covers the natural axis connecting the current cities of Midelt with Er-Rachidia, located North and South of the northern Moroccan High Atlas, respectively. If we move along this axis, we can distinguish three different geographical areas: the Outat valley on the northern slope of the mountain range; followed by a mountain section that, passing through the *Tizi n*'Tssardount hill and the Tiallaline oasis, serves as a connection between both areas and that from now on we will refer to as "the High Atlas pass"; and finally the Madgra oasis, located South of the High Atlas (Figure 1).

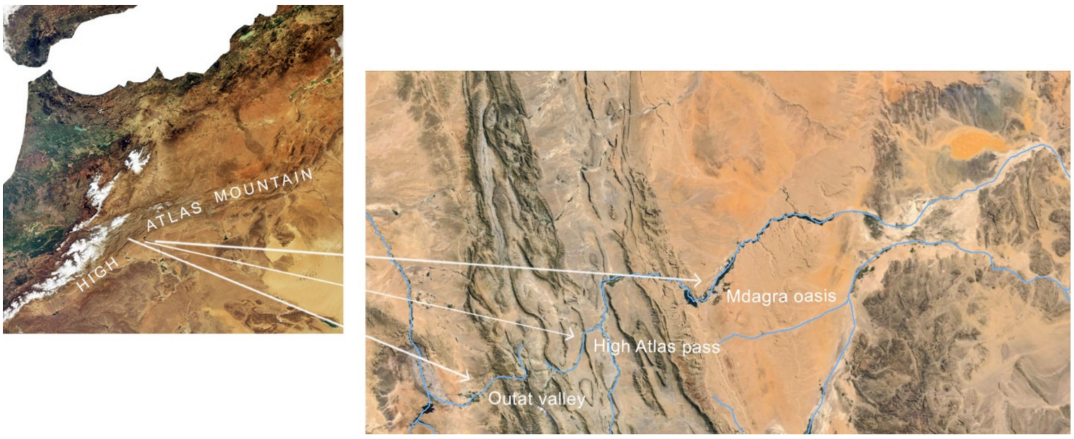


Figure 1. Area subject of study.

The Outat river leaves in its way a landscape characterized by green fields and well-organized terraces, remarkably contrasting with the arid and dry land that surrounds it [13]. In the upper Outat waters, since it comes out of the mountain to the vicinity of the Berrum and Flililou *ksour*, its course runs narrowly between the hillsides of the mountain. In this case, the geographical configuration causes the presence of fertile land to be reduced to the surroundings of the *ksour*, organized in terraces growing upstream and watered by ditches. From here, the riverbed opens up giving rise to a wide valley in which the fields extend over a large flat area until it reaches the city of Midelt. Past Midelt, the river seems to disappear, running along the Aghoudal plateau until it flows into the Moulouya river.

The entire valley is endowed with a network of ditches guaranteeing the supply of water to the fields and bringing the water closer to the *ksour* [14].

The second geographical framework is formed by the High Atlas natural pass connecting the Outat valley with the Mdagra oasis. Since the 16th century, this pass has witnessed the advancement of nomadic tribes who, escaping the conflicts in the South, sought refuge in the mountains until they reached Outat, where they settled in the early 19th century [15]. Along the way, we find a mountainous landscape, in which the waters of numerous rivers, tributaries, and ravines have witnessed the constant transhumance of nomadic tribes. In this place, the fertile area is very limited to the immediate surroundings of the *ksour*, which in turn are very distant from each other.

Finally, we find the Mdagra oasis as soon as we descend the High Atlas, occupying a large area around the city of Er-Rachidia. This oasis of 29 km in length and a maximum width of 2 km, approximately, is the result of human intervention, carried out in a sustainable and environmentally respectful manner. Through the construction of *khetaras*, water is extracted from underground springs located at the base of the Atlas and conducted until it reaches the surface, from which it is channeled by ditches throughout its extension, creating a large area of arable land whose limits are clearly distinguished from the arid and dry landscape that surrounds it [16].

Along this natural axis we can observe how the *ksar* (Figure 2), typical of the pre-Saharan oases, extends exceptionally northward [17], consolidating from the Tiallaline oasis and the *Tizi n'*Tssardount hill to the Outat river valley [13].

Figure 2. (**a**) Berrum ksar at the Outat valley; (**b**) Ait arab Jdid ksar, at the Mdagra oasis.

Throughout the ten years during which we have been investigating this region's earthen architecture, we have traveled this territory, visiting, studying, documenting, and analyzing a total of 30 *ksour* in the Outat valley (Table 1), 20 along the mountain range (Table 2), and 53 at the Mdagra oasis (Table 3), each of them representative of the identity of the population that inhabits them. In the following tables (Tables 1–3), an inventory of the studied *ksour* is displayed in alphabetical order, ordered according to the geographical area in which they are found:

Table 1. Original names of the ksour subject of study [18]. Area 1.

Ksour Outat Valley					
Aït Ali Oulhsan	**Al Zaouiat**	**Berrum**	**Iguerrouane**	**Tabenaâtout**	**Tamoussa ou Ali**
Aït Alla	Assaka	Bouzmellah	ikremjiouine	Tachaouit	Tatiouine
Aït L'Caïd	Asselim Aït Amo	Flililou. Taffraout	Otmane ou Moussa	Tachiouine	Tissouit Aït Seghrouchen
Aït Ouafella	Asselim Aït Echo	Flililou. Tahinoust	Smoura	Taddamout	Tissouit Sidi Hamza
Ait sidi L'Hbid	Asselim Aït Saïd	Ibnzazan	Taâkit	Tajilalit	Ugerja
Ait sidi L'Hbid	Asselim Aït Saïd	Ibnzazan	Taâkit	Tajilalit	Ugerja

Table 2. Original names of the ksour subject of study. Area 2.

Ksour High Atlas Pass				
Ait Ameur	Ait Immas	Ait Outmane	Ifri	Tighremt n'Addi ou Bihi
Ait El Fkih	Ait Khomane	Ait Youssef	Isseghdane	Tighremt n'Aït Oussaadane
Ait Hikkou	Ait Menzou	Amalou	Taffrout Sidi Hamza	Tillicht
Aït Ikha Ou khalifa	Ait Ossoumour	El Hain	Tamarrakecht	Zaouia Sidi Hamza

Table 3. Original names of the ksour subject of study [19]. Area 3.

Ksour Mdagra Oasis					
Ait Akka	DD'Akhla L'Tahtani	Kasbah Kdima Oulad Mohamed (north)	Oulad Bounafi	Taghzout	Tighiourine
Ait Arabt Akedim	DD'Akhlani Fokani	Kdima Oulad Mohamed (south)	Oulad el Haj	Taghzoute	Tissagdelt
Ait Arabt Oujdid	El Barrani	Ksiba	Oulad el Haj L'Akedim	Tagounite	Titaf
Ait El Haj Housseine	Gaouz	Lagssira L'Akedim	Oulad Mohamed	Taourirt	Tizguidelt
Ait M'Saud	Guiriourgaz	Mediouna Jdid	Rahba Jdida	Targa	Tizuka
Ait Ouaraine Akedim	Hdibouz (north)	Mediouna L'Akedim	Rahba Kedima	Tazemmourit	Zaouia Moulay Abdellah
Asrir	Hdibouz (south)	Meski	Unidentified 1	Taznakht L'Akedim	Zaouia Moulay Ben Ali
Azemmour L'Akedim	Ibaghaden	Mouchkelal	Unidentified 2	Tazrout Beni Fousse	Zaouia Sidi Bou Abdellah
Beni M'Hali	Kasbah Ait Zammou	N'Ait Moha Ou Ali	Unidentified 3	Tazuka	

3. Background and Methods

To begin, we will approach the meaning of the traditional and sustainable terms. Consequentially, we will start by specifying what is understood by traditional architecture to later define the concept of sustainability.

According to the Charter on the Built Vernacular Heritage [20], Traditional Heritage can be recognized by:

- Having a way of building emanated from the community itself.
- Being endowed with a recognizable local or regional character linked to the territory.
- Possessing consistency of style, shape, and appearance, as well as the use of traditionally established architectural types.
- Having traditional wisdom in design and construction, which is informally transmitted.
- Meeting the functional, social, and environmental demands.
- Applying traditional construction systems, trades, and techniques.

In this sense, the National Plan of Traditional Architecture published by the Ministry of Education, Culture, and Sports of Spain in 2015 defines traditional architecture as the "set of constructions that arise from the implementation of a community in its territory and that manifest, through their diversity and evolution, their ecological adaptation, both to the conditions and natural resources, as well as to the historical processes and socioeconomic models that have developed in each place" [21]. This same plan remarks that the characterization of traditional architecture is based on the following parameters:

- It is a substantial part of the Cultural Heritage, being a hallmark of the society that inhabits it.

- It is linked to the way of life and the social organization of the territory, forming part of its landscape.
- It adapts to the natural conditions of the territory, the climate and the materials.
- It is dynamic and lacks an individualized author.
- It uses materials from its environment, facilitating the conservation and land regeneration.
- It employs traditional techniques, resulting from long historical processes which have been hand down and readapted over time, reusing materials if necessary.

To define the concept of sustainability, we must begin by introducing the concept of sustainable development that arose in the Report of the World Commission on Environment and Development entitled "Our Common Future" published in 1982 by the United Nations, known as the Brundtland Report [22]. It claimed that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Based on this concept, in 1998, the School of Architecture and Urban Planning of the University of Michigan published a document that summarized the principles of sustainable architecture in three concepts [23]: life cycle design, analyzing processes and their impact on the environment; design in relation to the end-user, with a focus on the interaction between humans and the natural world; and an economy of resources concerned with reduction, reuse, and recycling.

Although the research work presented in this article is mainly aimed at characterizing the traditional architecture of this region, all these aspects related to its sustainability will be tackled in a tangential manner [24]. The methodology followed is based on case studies. Throughout the ten years that this investigation has lasted, a total of 17 expeditions have been carried out to the area, with stays of a minimum duration of one week. The study began in 2010, in the Outat valley. In 2012, we expanded to the south, reaching Mdagra oasis. After making a first inspection visit to the area, we located the ksour through the google earth viewer. After, we visit all the ksour and take the field data. Throughout our field work, we have been recording their relationship with the territory through data sheets, which include their morphological, defensive, social, functional, productive, and domestic conditions as well as the materials and construction systems involved in their construction. All these parameters are typical of traditional architecture, but many of them are also related to the concept of sustainable architecture. The data sheets are organized into three sections: the first includes general information about the ksar and its relationship with the territory; the second collects information on its urban planning and facilities; and the last one includes the construction system and the materials used.

4. Data Analysis

4.1. Habitat and Territory Interaction

In this area characterized by a mountain environment to the North and a pre-desert setting to the South, the fertile area is of great value and must be protected, since land cultivation guarantees the human presence (Figure 3). For this reason, the first of the aspects analyzed has been the placement of the *ksar* with respect to cultivable land.

In this case, we have established two categories to differentiate the *ksour* built within the oasis and those built in its perimeter area. In the comparative data analysis, it is observed that, in the three areas of study, there is a clear predisposition to locate the settlements at their extreme limits, leaving the fertile area free (Figure 4a). This occurrence is even clearer in Mdagra, where a greater concentration of *ksour* is observed outside the oasis rather than inside, possibly due to the level and open character of its perimeter.

Figure 3. Satellite image of the Mdagra oasis where you can see various ksour: (**1**) Titaf; (**2**) Unidentified1; (**3**) Kasbah Kdima Oulad Mohamed; (**4**) Oulad Mohamed; (**5**) Tazuka; (**6**) Hdibouz; (**7**) Tissagdelt; (**8**) Asrir; (**9**) Beni M'Hali. Google Earth.

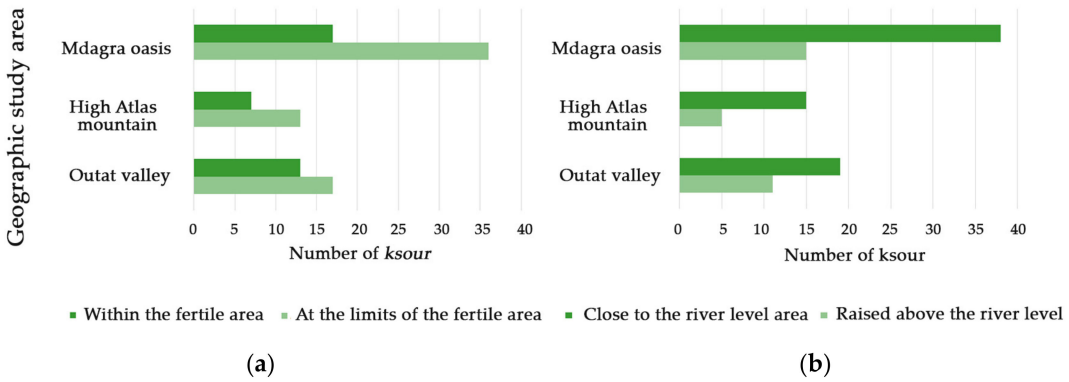


Figure 4. (**a**) Number of *ksour*, related to their location with respect to the fertile area; (**b**) Number of *ksour*, as a function of their elevation with respect to the river level.

We then studied the location of the *ksar* in relation to the altitude of the settlement with respect to the river level. Both the Outat and the Ziz rivers have a flow that experiences substantial seasonal changes, meaning that at certain times of the year the riverbed overflows, flooding the nearest banks [25], which may affect the stability of these constructions. The results of the analysis are reflected in Figure 4b.

The data analyzed shows that most of the *ksour* are located close to the river level. Most probably, it obeys to the fact that in this way it is easier to guarantee the supply of water to the *ksar* through the ditch network. In Mdagra, in spite of the *ksour* being mostly located at the limit of the fertile area, we see how the great majority of them are situated near the river level (Figure 5). This could be justified by the slight difference in level between the edge of the oasis and its interior.

Figure 5. View of the oasis of Mdagra.

Throughout our expeditions to this area, we have had the opportunity of observing the impact of river flooding. When a *ksar* is repeatedly flooded, its inhabitants choose to abandon it, building a new settlement on higher ground in nearby locations. In such cases, the *ksar* keeps the same name, adding the adjective *Akedim* (to indicate the old *ksar*) or *Jdid* (to designate the new *ksar*). When this happens, the material from the old *ksar* is reused for the construction of the new one, being recycled and adapted to the new requirements according to an economy of resources. The original *ksar* thus comes to the end of its life cycle, becoming a series of earthen mounds that soon disappear into the landscape [26].

4.2. Shape Design

One of the factors defining traditional architecture is that of having a "Coherence of style, form and appearance, or the use of traditionally established building types" [20]. As we are concerned with traditional architecture, our first objective in this part of the research has been to identify its forms and characterize its typologies. To this end, we have focused the study on the analysis of the *ksar*'s outer morphology and plan surface. Here, the *ksar* is defined as an urban settlement delimited by a wall, which tangibly marks the boundary between rural and urban spaces while protecting its inhabitants. Generally, the *ksar* has only one access through a monumental gateway. Inside, the dwellings are organized around an orderly grid integrated by narrow streets, between 2 and 3 m wide, covered for most of their route as a result of the expansion of the houses above their surface. In addition to the residential area, the *ksar* may have community use facilities located next to the *ksar's* entrance.

According to their plan, we have made a first classification of *ksour* into two types: those composed of a single structure and ones composed of two or more structures [16,27]. In the case of *ksour* with a single structure, their exterior morphology can follow a regular shape, adapting their plan to simple figures such as the square, the rectangle or the pentagon (Figure 6a); or be irregular, polygonal, or organic (Figure 6b). In the case of the *ksour* formed by groups of two or more structures, we observe regular shaped structures combined with organic shaped ones, as well as different combinations of regular shaped structures (Figure 7). The *ksar* formed by the grouping of two or more structures arise as a result of the need to expand its surface, usually due to a demographic growth. Only in one of the *ksour* of the Mdagra, the Targa *ksar*, we observe a concentric-type enlargement in which a square central nucleus has been surrounded by two additional regular shaped structures in order to segregate different social groups.

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

Figure 6. (**a**) Regular plan *ksar* of rectangular type. Gauz *ksar*, Mdagra oasis, (**b**) irregular plan *ksar* of organic type. Outmane ou Moussa *ksar*. Outat valley.

In Figure 7, we observe an outline of this classification:

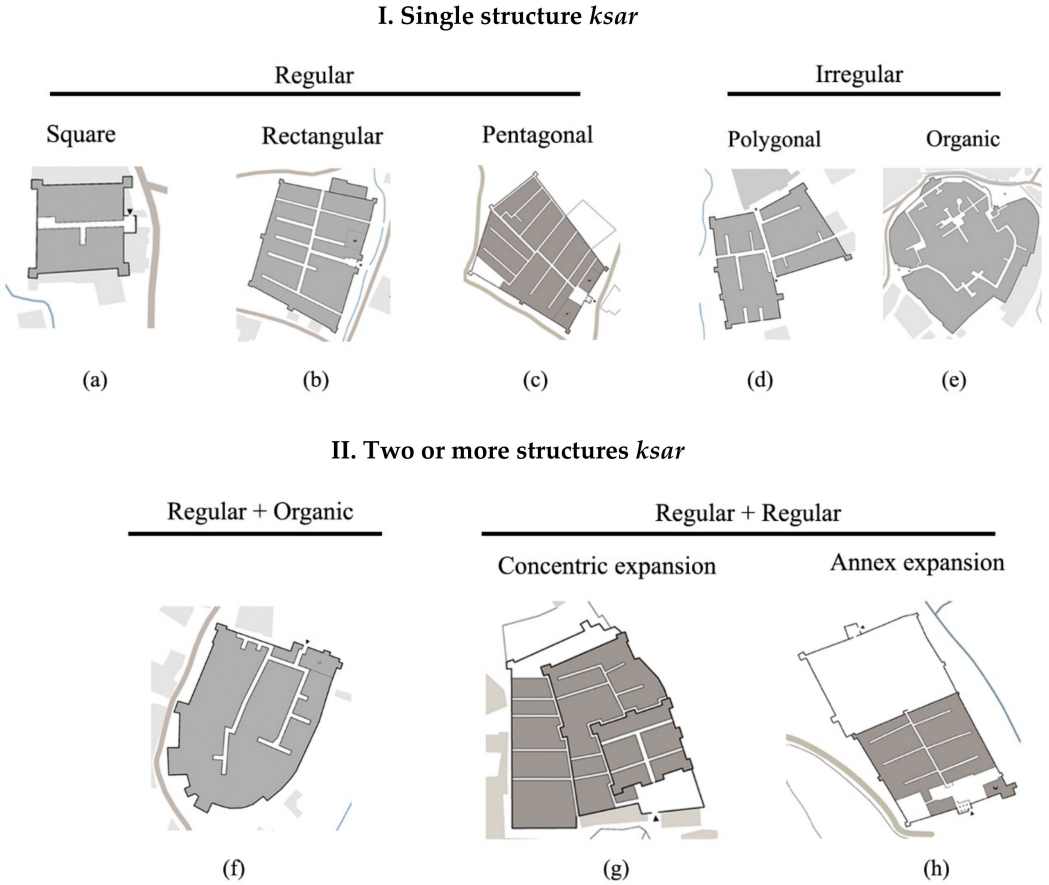


Figure 7. Typological classification of the *ksour*, according to their shape, with scheme of the plans of some of the *ksour* studied. I. Single structure ksar: (**a**) Ait ali Oulhssan; (**b**) Bouzmellah, Titaf; (**d**) Aselim ait Amo; (**e**) Outmane ou Moussa. II. Two or more structures ksar: (**f**) Tachaouit, (**g**) Targa; (**h**) Beni M'hali.

After travelling through all the *ksour*, we have been able to identify the plan morphology of 93 of the 103 *ksour* visited (Table 4), due to the fact that 10 of them are in such a state

of ruin that it is not possible to define their boundaries. Hereunder, in Table 4, the number of *ksour* attending each of the typologies described is given:

Table 4. Relationship of the number of *ksour* according to their shape and location.

Tipology of *Ksar*	Morphology of the *Ksar*	Mdagra Oasis	High Atlas Pass	Outat Valley
I. Single structure *ksar*	Regular Square	16	11	13
	Regular Rectangular	13	0	4
	Regular Pentagonal	1	0	0
	Irregular Polygonal	2	6	4
	Irregular Organic	2	2	4
II. Two or more structures *ksar*	Organic + Polygonal	3	0	1
	Concentric expansion	1	0	0
	Annex expansion	5	1	4

For the purpose of easily comparing the results, we provide the following figures collecting the data from the comparative analysis between typologies and study areas (Figures 8 and 9).

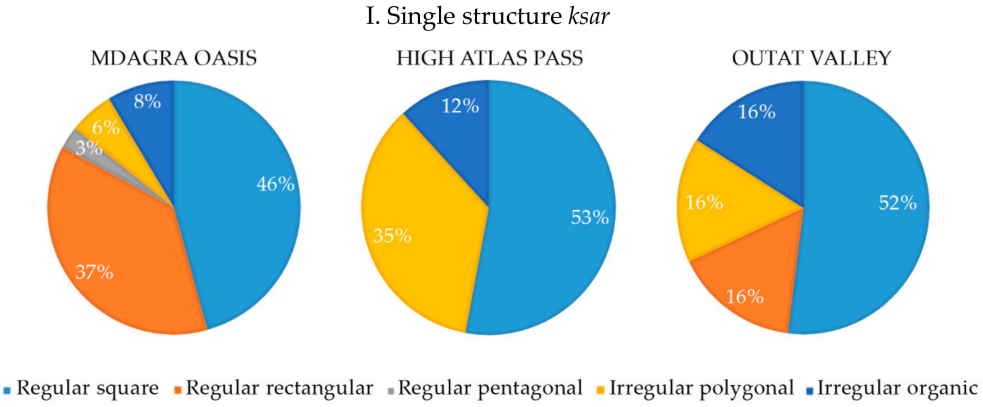


Figure 8. Classification of the single structure plan typologies depending on the settlements' location.

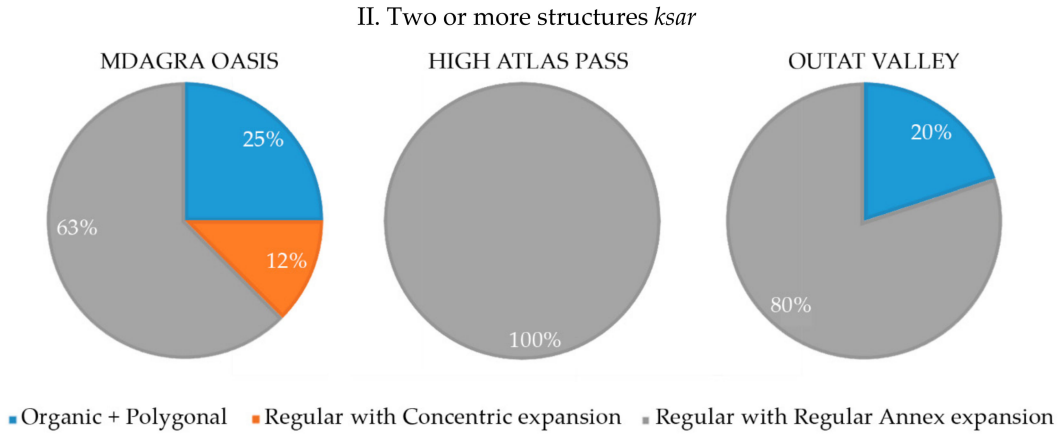


Figure 9. Classification of the two or more structures plan typology depending on the settlements' location.

From the data obtained (Figure 8) we see that in the case of single structure *ksour*, the most common typology in the three areas of study is the regular square shaped. Meanwhile, in the case of the two or more structures *ksour*, the most common typology is that of the *ksar* with a regular plan and a regular annex expansion (Figure 9).

In summary, if we analyze the group of all the *ksour* within the entire study area (Figure 10), we see that the great majority of *ksour* is based on a single structure, with less than 20% of the total being integrated by two or more structures.

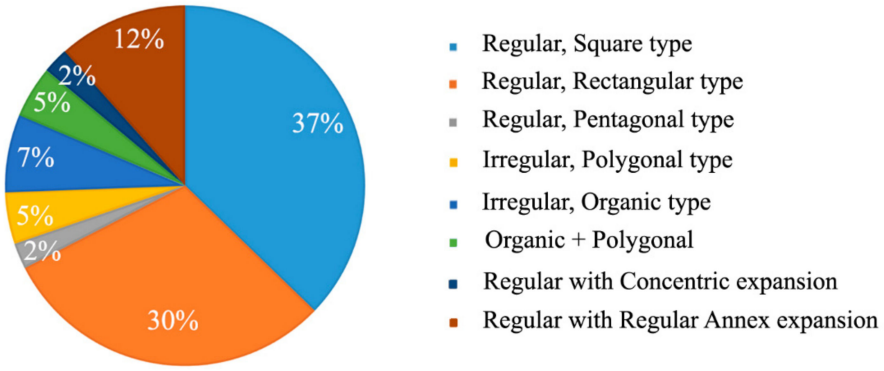


Figure 10. Quantitative analysis of the ksar typologies according to their plan.

The next parameter studied is the *ksar* surface. For that purpose, we have taken a direct measurement of the surface of each of them, not to have the precise measure, since we are aware of the lack of accuracy in the data, but to be able to compare them with each other, since the relative error affects them all equally. From the calculation of their surfaces, we have classified the *ksour* into 9 groups (Table 5), ranging from less than 1000 m^2 of surface, to those with an occupation area greater than 40,000 m^2.

Table 5. Units of ksour according to their surface and geographical area.

Ksar's Occupation Area (m^2)	Mdagra Oasis	High Atlas Pass	Outat Valley
<1000	1	0	2
1000–2500	4	5	10
2500–5000	9	7	10
5000–7500	10	3	3
7500–10,000	5	1	2
10,000–20,000	13	3	2
20,000–30,000	6	1	0
30,000–40,000	0	0	0
>40,000	2	0	0

In the graph below (Figure 11), we can see that in the Outat valley and in the High Atlas pass most of the *ksour* have a surface area that ranges from more than 1000 m^2 to less than 5000 m^2. In the Mdagra oasis, the great majority of *ksour* is between 10,000 m^2 and 20,000 m^2, although we also find a significant amount of *ksour* in the 2500 m^2 to 5000 m^2 and 5000 m^2 to 7500 m^2 ranges. Exceptional cases are the Sidi Bou Abdellah *ksar* [18] and the Oulad el Haj *ksar*, whose surfaces exceed 40,000 m^2.

The data indicate the importance of the Mdagra oasis with respect to the other two places, which is justified by the greater number of inhabitants at the oasis.

Finally, we have tried to assess the aspect of the orientation of the *ksour* from the direction of their entrance and main street, but the disparity of results has made us discard this analysis.

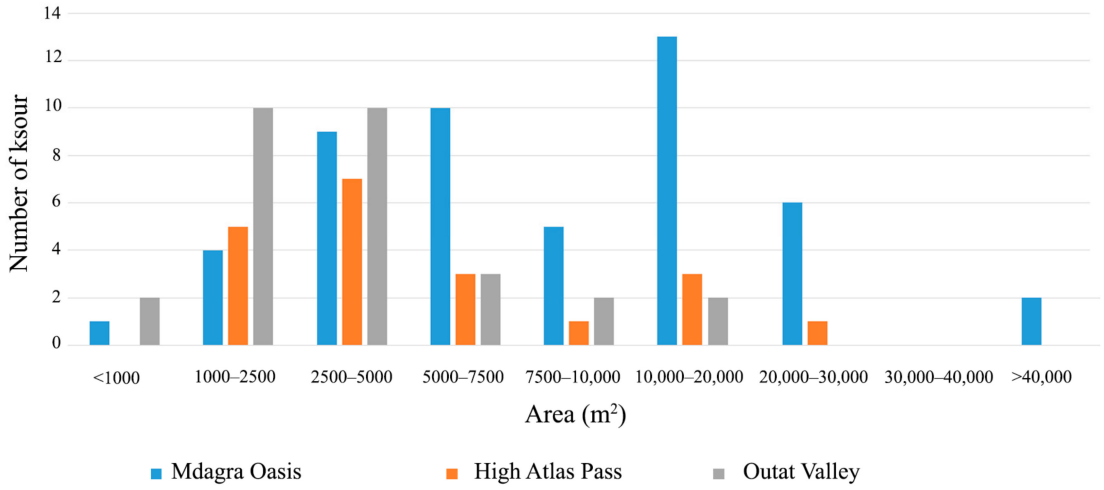


Figure 11. Relationship between the surface of the ksar and the number of ksour which are representative of the interval.

4.3. Defensive and Social Characteristics

Until the beginning of the 20th century, southern Morocco was marked by great social and political instability, which incited constant clashes between neighboring tribes [28]. Thus, the main function of the *ksar* was to provide shelter and protection to its inhabitants; therefore, all of them are enclosed by a wall. During the last century, the cessation of tribal struggles and the increase in political stability in the country has made the population seek out new models of existence, abandoning life in society to live in isolated houses. In a first phase, the population moved to houses built using traditional techniques, reusing the material from the *ksar* in the new construction. At present, "modern" materials are being implemented, while traditional techniques are being replaced by poorly executed current construction systems.

From a sociological point of view, the *ksar*'s population is divided into clans and classes, which are governed by the rules of the assembly of notables (*jamaâ*) [29]. In addition, the *jamaâ* is in charge of other matters, such as the control of water consumption, prescribing the maintenance of the irrigation canals, or the authorization of new constructions, among others. In general, during the day, the lives of the inhabitants of the *ksar* go on outdoors, performing tasks related to the land cultivation and to animal farming, so social relations within the *ksar* are scarce. These are limited to the *jamaâ* meetings, the celebration of some social acts and for prayer [30]. The spaces that accommodate these activities are:

- The entrance: the *ksar's* entrance is a space where different social activities took place. That is where the assembly of notables met and the most important decisions of the *ksar* were agreed. At night, this space was closed and served as a refuge for travelers passing through the area.
- Plaza: it was the meeting place of the inhabitants of the *ksar* and where all social events were held. It was located next to the entrance in such a way that marks a clear difference between the outer space of the *ksar* and the private area reserved for its residents. In the case of large *ksour*, the market was housed in the plaza.
- Mosque: most of the *ksour* visited have a mosque inside which is accessed through a distributor, which in turn gives access to the prayer room, an ablution room, a room acting as a warehouse, and a space with a boiling pot and a water well. Inside the *ksar*, the mosque stands next to the entrance. Only in one case have we found a *hamman* independent of the mosque. Today, traditional mosques have been replaced by large concrete block mosques built outside the *ksar*, following imported models quite different from the autochthonous ones grouping the inhabitants of several *ksour*.

4.4. Functional and Productive Characteristics

Despite the climatic conditions of its surroundings, with temperatures ranging in some areas between 0 °C in the winter and slightly more than 40 °C in the summer, the shape of the *ksar*, the thickness of its exterior walls and the construction materials, ensure minimum conditions of comfort inside [31]. In addition, the design characteristics dictating its internal organization favor better thermal and air renewal conditions, necessary to guarantee an enhanced quality of life for its inhabitants and more suitable than those found in the houses built outside the *ksar* [31].

Within the *ksar*, the space is distributed in an orderly manner, its arrangement being defined by the wall boundaries. Depending on the size of the *ksar*, we find some in which the entrance gives access to a large plaza from which a main street leads to the secondary streets. In the rest of *ksour* of medium or small dimensions, the entrance leads directly to the main street, lacking an inner plaza. In this case, the community services are reduced to the construction of a mosque inside. In general, streets are narrow, covered mostly by the extension of houses on both sides; they only remain open to the outside at the crossroads, giving rise to light entry wells allowing the air renewal inside the *ksar* (Figure 12). This fact, together with the construction system used in its execution, with exterior walls of considerable thickness, favors the habitability inside, protecting the population from external atmospheric agents.

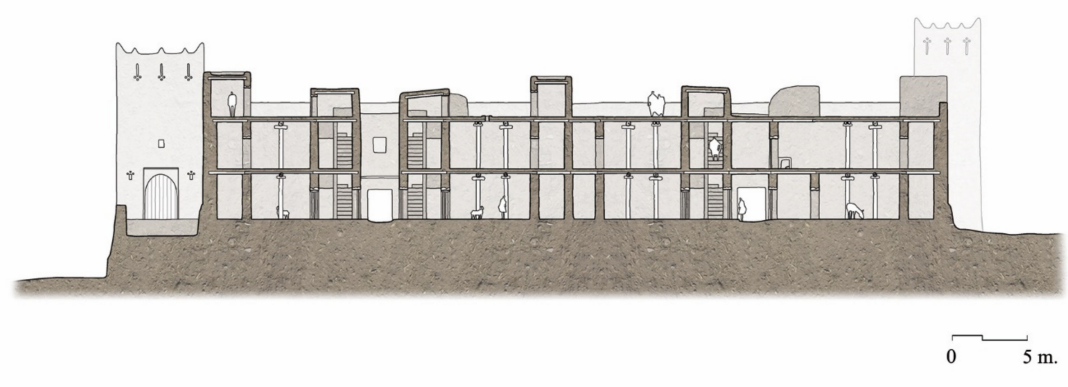


Figure 12. Section of the Tabenaâtout *ksar*.

At the productive level, some spaces arise to collect these activities. In the Outat valley, for example, there are several flour mills close to the riverbed, which are used for the community's milling of wheat. They are small constructions, independent from the *ksar*, whose grinding wheel turns by the force of the water coming from the river or from man-made ditches to serve this purpose. In the Mdagra oasis, the productive activity is based on the cultivation of olive trees and date palms. The production of oil is very common in the oasis, which is why many *ksour* have an outer annex space used as an oil mill. In this case, the grinding is done by means of an animal traction system, then going through the pressing and decantation phases. The only exception is Sidi Bou Abdellah, where the oil mill, equipped with a large warehouse, is located inside [18].

4.5. Domestic Characteristics

Given the state of ruin in which most of the *ksour* studied are found, we have only been able to document a limited number of houses, accessible because they were abandoned or because the homeowners allowed us in [32].

The dwellings in this area basically follow a single closed housing scheme with hardly any openings to the outside, avoiding the entry of heat, sunlight, and dust brought by the wind and sandstorms [33]. If the house has access to the roof, a kind of rooftop hut allows the installation of a door through which the household can be ventilated, generating an inner air current once the door on the ground floor is opened (Figure 13). In cases where

there is no direct access, a hole in the roof completes this function, favoring the interior air renewal.

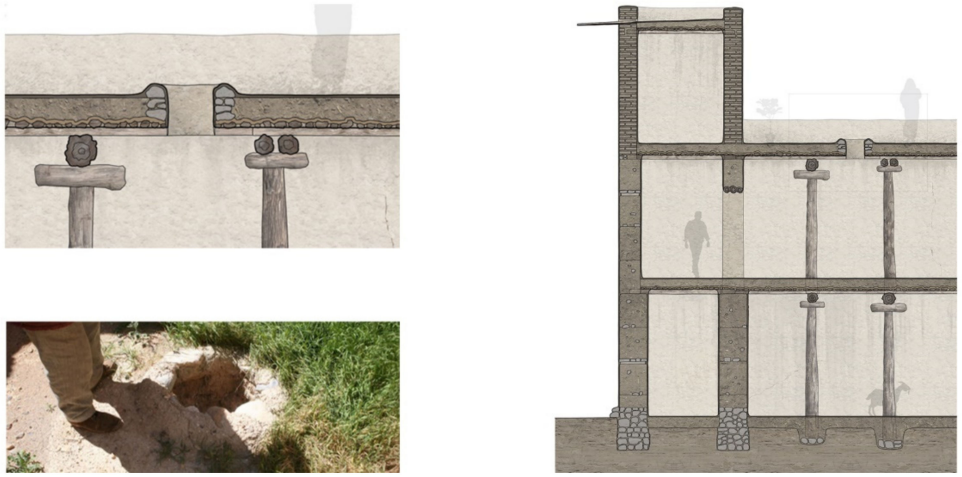
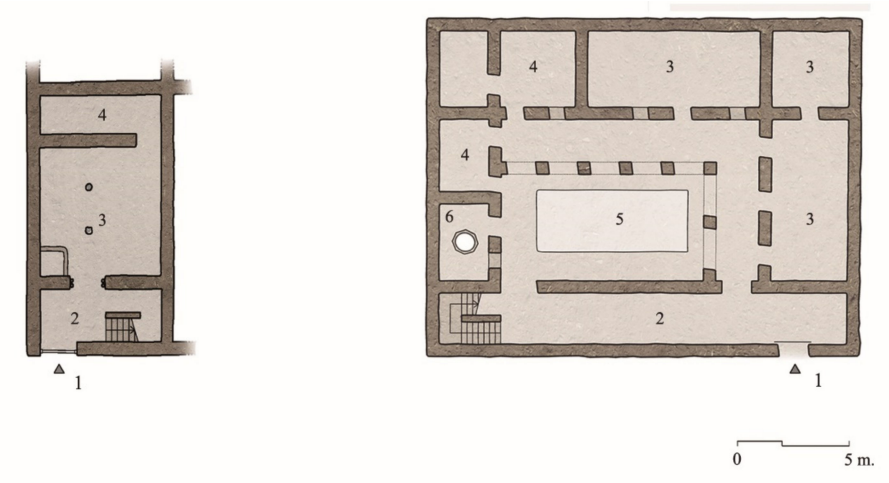


Figure 13. Detail of the ventilation opening in the roof. Ksar of the Outat valley.

In general, this type of housing consists of a two to three-story rectangular plan construction occupying an area that ranges between 60 m^2 and 100 m^2 per story (Figure 14a). Its structure is made up of rammed earth load-bearing walls on the ground and first floors, and adobe walls on the third floor. On each floor, perpendicular to its maximum length, we find two rammed earth walls, acting as partition walls to generate three interior spaces. The entrance gives access to a hall and to the staircase leading to the upper floors. The ground floor provides shelter to animals, which become a source of energy due to the heat they release towards the first floor. The rest of the floors are used as family rooms and for food storage. Their use is not defined, since it varies according to the season.



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

Figure 14. Schemes of a house without patio (**a**) and with patio (**b**). First floor: 1. Entrance, 2. Hall, 3. Room, 4. Store, 5. Courtyard and pool, 6. Waterhole.

In two *ksour*, however, we found a different housing model. They are the Sidi Bou Abdellah *ksar* and the Titaf *ksar*, located in the Mdagra oasis. These houses have a larger floor plan, although of lesser height. The Mdagra courtyard houses follow a markedly different plan from those found in other southern Morocco regions (Figure 14b). These are houses designed around large patios, to which the rooms joined by large openings decorated with moldings face. In general, this type of house has a water well, as well as

ponds guaranteeing the water supply to the house. Through these patios, the indoor air is renewed, improving its temperature.

4.6. Materials and Construction Techniques

The construction of the *ksar* is closely linked to the way of life and the social organization of the territory. Its layout and shape is planned from the beginning, constituting a hallmark of its population. In addition, the materials involved in its construction (stone, earth, wood, and plant matter) originate from its natural environment; hence, this architecture is part of the landscape.

The foundation of the *ksar* is generally composed of stones of different sizes that are placed on a trench of 0.50 to 1.00 m wide, in layers of 0.50 to 0.80 m in height joined by a mud layer, thus guaranteeing the stability of the wall [34]. The depth of the trench will depend on the resistance capacity of the soil, being built without foundations in the case of direct support on rocky surfaces. Sometimes this stone boot is prolonged above ground level, like a plinth, in order to protect the base from run-off and humidity by capillarity that favors its erosion reducing its bearing capacity.

Walls are built with mud according to the rammed earth technique, using adobe on the top floors to lighten the weight. Normally, the soil used is collected in the surroundings, although it is also very common to use the soil coming from demolished buildings, as a clear example of sustainability. The only preparation to which the soil is sometimes subjected to is screening, which allows for the removal of foreign materials and possible coarse gravel. The soil in this region has low clay content, so shrinkage during the drying process is relatively low; on the contrary, it favors the water permeability of the walls and roofs, which will require auxiliary waterproofing [35]. The nature of the wall, with a thickness varying between 45 cm and 90 cm, allows its adaptation to the climate and provides it with adequate thermal inertia [36].

In general, the roof structure is made up of wooden beams, joists and slabs, esparto grass, and a small layer of soil, which is placed slightly damp to facilitate compaction (Figure 15). Regarding the wood, cedar is the most used in the Outat valley and the Atlas pass and, to a lesser extent, thuja and juniper are also employed. Cedar wood is used in slabs, supports and pillars, and as beam material. In the Mdagra oasis, palm wood and reeds are mainly used for the construction of the slabs. Finally, the esparto grass and palm leaves are placed over the wooden structure of the slab to retain the soil from the upper layer.

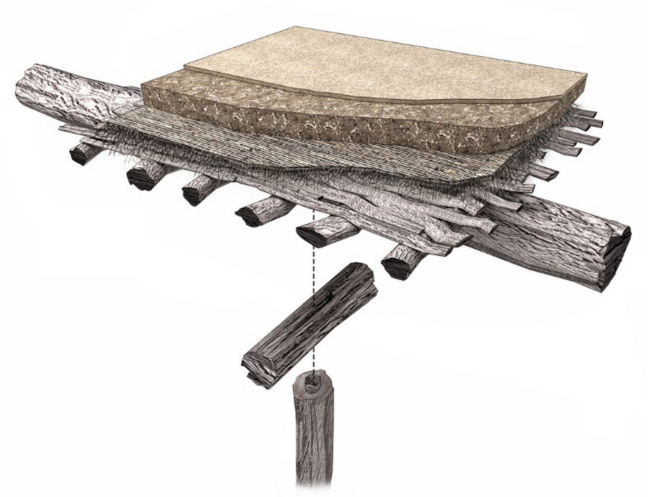


Figure 15. Deck detail. *Ksar* Tatiouine, Outat valley.

In the case of the roofing slab, this is finished with a new layer of mud kneaded with straw, which provides greater insulation. Straw is also used as an additive in the external

cladding of the walls and adobe construction to improve their consistency and prevent shrinkage while improving their insulation.

5. Conclusions

Throughout this research, we have analyzed the earthen architecture in the southeastern area of Morocco, addressing its study along three different geographical areas, all of them located in the natural axis connecting the cities of Midelt and Er-Rachidia.

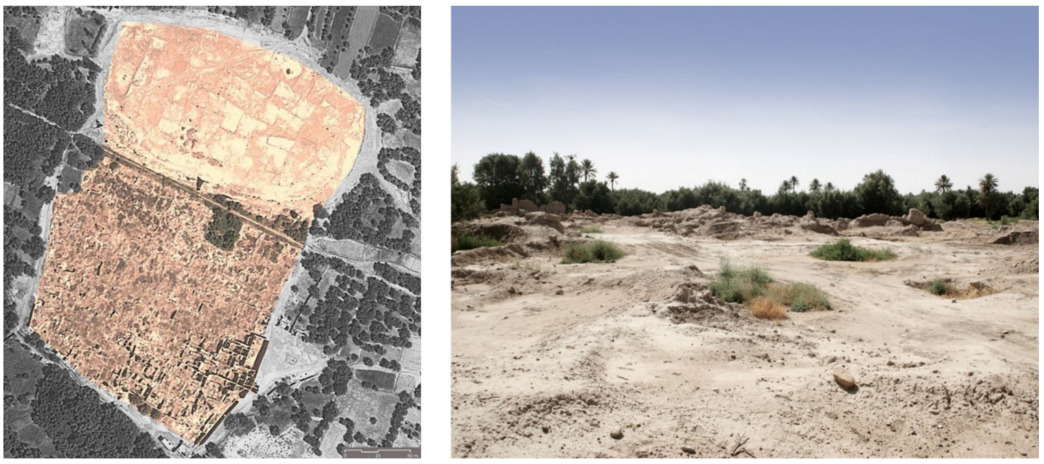
Through the analysis of the data, we have been able to characterize this traditional heritage so representative of the local culture at the time we have defined some of the parameters that make this heritage an example of sustainable architecture. In addition, the implantation of the *ksour* in the territory has been analyzed through their location with respect to the riverbed and the cultivable area. From the point of view of traditional architecture, a classification of *ksour* models based on their shape and surface has also been provided. From this analysis, we can state that despite the different geographical and climatic conditions of the three study areas, the most commonly used *ksar* model in this region is characterized by having a square plan, being located at the limit of the fertile area, at a level similar to that of the river. It is also defined by having a defensive structure enclosed by a wall, flanked by towers at the corners, and equipped with a monumental elbow shaped or direct entrance. At the productive level, we see how, depending on the area, the *ksour* have flour mills or are equipped with an oil mill. Furthermore, we have analyzed their defensive, social, functional, and productive characteristics, from which we are able to determine that the construction of the *ksar* is linked to the way of life and culture of its inhabitants. Regarding the use of materials, it has been observed that only materials from the immediate environment intervene in the construction of the *ksar*, facilitating its integration into the landscape. Finally, concerning construction techniques, they follow the local building construction tradition by adapting the needs, when necessary, to the materials available in the area.

Most importantly, throughout the investigation, we have been able to verify the vulnerability of the *ksour* (Figure 16). The fact of being executed using raw earth, without any additive conferring resistance (beyond the protective layer formed by earth and straw), makes them require constant maintenance. Natural threats as a consequence of heavy rains, wind, and snow in the high mountains are risk factors, but they are not the only ones endangering this traditional architecture. With the passage of time, we see how it has also been subjected to significant social risks and anthropic dangers. In essence, it is a sustainable traditional architecture requiring maintenance and conservation efforts if we wish to extend its life cycle.

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

Figure 16. Sidi Bou Abdellah *ksar*; 2003 (**a**), 2013 (**b**). Google Earth.

As political stability arrives in the area, we witness the beginning of this model's decline. The abandonment of the *ksar*'s dwellings, built as the rest of the *ksar* with rammed earth and vegetal matter, affects the durability of the complex, leading out to the first signs of decay. Once the lack of maintenance and conservation initiates the phase of ruin in one of its areas, the process becomes irreversible (Figure 17).



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

Figure 17. Satellite image of the Taznak L'akedim *ksar* (**a**); Ground level image of the Taznak L'akedim *ksar* (**b**).

Another important milestone is the independence of Morocco from the French Protectorate in 1956 [37], which entailed the beginning of a migration movement to the North, first to the cities abandoned by the French and then, from the 70s, directly to France. This movement, in addition to initially promoting the abandonment of the *ksar*, with the return of these emigrants in the last decade of the 20th century, brought as a consequence the importation of typologies, construction systems, and foreign materials. In turn, this led to the implementation of Arabized-style houses with great presence that, although improper, placed the returning emigrant in a higher social rank, as this external sign is considered to be a reflection of economic prosperity.

In some *ksour*, the abandoned houses were reoccupied by nomads who, although they tried to preserve them, were not familiarized with the maintenance techniques. Over the years, living in the *ksar* has become a sign of poverty, being increasingly related to the concept of substandard housing, identifying it with a life model of past epochs and equating the use of traditional materials to something unpopular and of low quality.

Today, most of the *ksour* presented in this article are abandoned (64%) and in an advanced state of ruin, only 3% of them being restored. Throughout the ten years that we have been working on this research, we have witnessed how some of these *ksour* have lost their monumental entrances, the structure of their streets, the crowning of their towers, the shape of their houses, their mosques, and even their inhabitants. For all these reasons, we ought to be aware of the importance of documenting this ancient architecture, a clear example of tradition and sustainability, a characteristic icon and a world reference in the cultural landscape of southern Morocco.

Author Contributions: T.G.-P. and P.R.-N. collected historical documents, analyzed research data, developed the original idea for this study, suggested appropriate methodologies for general analysis, and wrote the article. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the following projects: Arquitectura Habitacional de Tierra en el Alto Atlas Septentrional. Midelt (Marruecos). PAID 06-11; Estudio de la Arquitectura Habitacional de Tierra en el Alto Atlas Septentrional. Midelt (Marruecos). Categorización, Sostenibilidad y Puesta en Valor del Patrimonio Arquitectónico para Contribuir a la Descentralización y al Desarrollo

Sostenible, ADSIDEO-2011; and Arquitectura y Habitat: Investigación Para la Mejora Global de Espacios Habitacionales en la Región del Tafilalt, AD1409, under the program of Research Projects in Technology for Human of the Center for Development Cooperation of the Universitat Politècnica de València.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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