

Date Palm Pruning Residues as Key Elements in the Evolution of the Vernacular Architecture in Dakhla Oases, Egypt

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Abstract The community of Dakhla oases represents a unique experience in sustaining and developing its rich technical heritage to be implemented in contemporary architecture. They have inherited a rich technical heritage in utilizing date palm pruning residues in traditional handicrafts, and they have always employed this heritage in their architecture. This paper represents the first detailed investigation of the manifestations of the technical heritage of utilizing date palm pruning residues in shaping vernacular architecture and tracks its evolution to be implemented into contemporary architectural applications to predict the potential of further growth. It examines the basic heritage and analyses its consistency and influence on current applications, in order to identify the factors shaping this evolution to take its current form and nominate the techniques that can effectively fit into contemporary architecture. The grounded theory methodology is adopted to explain the evolution of this technical heritage, as shaped by the community and the market demands, from traditional, eco-tourism projects to contemporary architectural applications. Achieving versatility and sophistication were the main catalysts of this evolution. The prefabricated date palm midribs panels were found to be the most commonly used technique in contemporary applications which are direct decedents of traditional fences, roofs and furniture. Their dependence on inherent skills are still used nowadays, and their versatility and sophistication are the main factors that ensure their

existence. Prefabricated midribs panels could sustainably substitute conventional construction materials in a variety of forms and functions, for their ability for mass-production, cost-efficiency and depending on available handicrafts techniques. Further exploitation of prefabricated midribs panels unlocks the potential of pruning residues for a wider spectrum of sustainable construction applications.

Keywords Traditional Building Materials, Eco-tourism, Handicrafts, Date Palm Pruning Residues, Sustainable Construction, Prefabrication

1. Introduction

1.1. Date Palm in Ancient Egypt

Date palm (*Phoenix Dactylifera*) is a monocot flowering member of the palm plant family (*Arecaceae*) cultivated for dates [1]. Date palms are cultivated in the Middle East, North Africa and South Asia [2,3]. Currently, Egypt is the highest producer of dates globally, with over 15 million date palms distributed over Nile Delta, Nile Valley and western oases [4]. Date palm (Figure 1) has been interwoven into Egyptian culture since the ancient Egyptian era. Dates, as one of the most important sources

of food, spirits and pharmaceuticals since then, granted the date palm its high status both symbolically and practically [1,5]. The fast renewability rate of date palms was directly translated into the engravings on the walls of ancient Egyptian temples and tombs as a symbol of permanent youthful life [6]. To ancient Egyptian builders, the verticality and tallness of date palms mirrored the stability of the columns of their temples and the mightiness of the deities they represented [7]. The columns crowned with the date palm leaves capital column represented the dwelling of the goddess Nut who supports the sky. Furthermore, the date palm leaves capital itself represented the dwelling of the goddess Hathor, the ancient Egyptian goddess of fertility [7]. In addition, date palm pruning, necessary to stimulate the growth of the fruit bunches and flowering needed for pollination [8], provided Ancient Egyptian craftsmen with the raw materials used in making household applicants. Surviving artifacts dating back to the old kingdom indicate that date palm midribs were used in making doors, furniture and decorations [4]. Date palm leaflets were also used in making bags and mats using the weaving technique in the ancient Egyptian period. Later in the Greco-Roman period, lattices made from date palm midribs were used to create sturdy baskets [9], crates and cages that are still produced to the present day using the same lattice technique. Such techniques of utilizing the date palm pruning residues (DPPRs); midribs, leaflets, coir and spadix stems in handicrafts still support over 1 million families in Egypt to the present day. Furthermore, DPPRs have a technical heritage of being used in construction. Excavations dating to the ancient Egyptian period indicated the use of whole date palm leaves mats as reinforcement within mud brick walls and in roofing over beams made from halved date palm trunks.



Figure 1. Date palm. (a) A date palm. (b) Components of a leaf (1) Trunk. (2) Petiole. (3) Leaflets. (4) A green leaf. (5) A cleaned midrib. (6) Leaflets extracted from a leaf

1.2. Date Palm in Modern Egypt

Since then, DPPRs have been integrated into

architecture in rural regions rich with date palms with various degrees of complexity and sophistication, ranging from simple light huts to multi-storey houses [13]. More mature DPPRs utilizations in traditional construction were usually found in the regions where the communities enjoyed a strong technical heritage of utilizing DPPRs in handicrafts [14]. This advanced technical heritage of DPPRs in handicrafts has been concentrated in Giza, Fayoum, Nubia and Dakhla oases, which are still considered as the major DPPRs handicrafts centers in Egypt [15], in spite of the availability of date palms in Delta, along the Nile Valley, Sinai, Nubia and the western oases [5]. Nowadays, the vast majority of traditional construction in Egypt is replaced with conventional construction such as reinforced concrete and fired brick structural systems [14,16]. Abandoning traditional construction and roofing methods led eventually to the decline of the technical heritage of utilizing DPPRs into construction even in most of the major DPPRs handicrafts centers [17]. However, the conservative nature of some of the rural communities in regions rich with date palms helped establish and save their specific set of techniques of utilizing DPPRs in construction that passed through the generations of each community without external influences. This case can be found especially in the settlements outside of the Nile Valley such as Nubia and the western oases, where cultural and economic exchange with the Nile Valley is minimal because of their remote placement [1,14,17]. As a result, this technical heritage, although used in fewer applications nowadays, remains to depend mainly on local materials and local skills, manifesting a distinct character that adapts to the culture and environment of each community [15,18]. For instance, date palm midribs huts are still built cost-efficiently inside houses in various sizes and shapes as a part of common architectural applications in Dakhla oases, in the western oases region [17].

1.3. Date Palm and Western Oases

The western oases have been historically the main supplier of dates in Egypt [19]. Currently, 5 million date palms, of the total number of 15 million date palms in Egypt [20], are distributed over the western oases [15]. The western oases consist of 5 main settlements from North to South; Siwa, Bahareya, Farafra, Dakhla and Kharga. Date palm midribs, leaves and trunks have been among the basic building materials in the traditional architecture of the western oases, with different levels of development and with diverse techniques [21,22]. However, the technical heritage of utilizing DPPRs in construction had declined in the majority of the western oases since the launching of modern housing projects by The National Desert Reconstruction Authority in the 1960s [15]. Fortunately, the emergence of the ecotourism concept in the 2000s helped this technical heritage regain its popularity [23]. Ecotourism projects exploited the unique architectural

heritage of the western oases to execute projects with minimal environmental impact and to provide tourists and hosts with unique cultural experiences that remain sincere to the customs and beliefs of these communities [24,25]. In Adrere Amellal ecolodge in Siwa oasis, the first project launched by Siwa Sustainable Development Initiative, traditional construction techniques such as roofing using date palm trunks and kershef bricks, as well as traditional handicrafts techniques for interior design and decoration, were taught to local youth who participated in the construction of the ecolodge [24,26,27]. This project encouraged other ecotourism projects in the western oases to depend on DPPRs and traditional construction techniques in order to revive the cultural heritage of the western oases communities through utilizing their own local materials and skills [24]. Currently, eco-tourism projects represent the main field of utilizing DPPRs in construction in the western oases [28].

On the other hand, the Dakhla community, as one of the major DPPRs handicrafts centers, enjoys a strong ongoing handicrafts DPPRs technical heritage which ensures the continuous flow of skills and techniques more significantly than in other western oases [15]. Craftsmen and builders in Dakhla are fully aware of DPPRs' structural strength, cost efficiency and unique aesthetic quality that can be used in versatile geometrical shapes and formations [22]. As a result, the present utilization of DPPRs in construction in Dakhla surpasses ecotourism to be integrated in various handicrafts and architectural applications as a part of the common practice [5,15].

2. The Unique Heritage of Date Palm in Dakhla Oases

Dakhla ranks second in the number of date palms among the five oases, after Bahareya, with a total of 1.25 million date palms. Date palm cultivation and maintenance are among the most profitable agricultural activities in Dakhla, feeding the growing demand for dates and pruning residues-based industries [15].

Efficient resource management strategies are undertaken in Dakhla community where pruning residues are utilized by local craftsmen in handicrafts and construction depending on a unique well-established DPPRs technical heritage. The rest of the western oases get rid of the pruning residues by burning [15]. The main DPPRs utilized in the local handicrafts industry in Dakhla are midribs and leaflets, in addition to coir and spadix stems as secondary elements [17]. Baskets, bags, and midribs furniture are the main products of this industry. Main techniques employed in traditional DPPRs handicrafts include latticing, paneling and piercing used in midribs furniture and crates [4,9]. Plaiting involves interweaving three date palm leaflets strands and sewing the strands with coir threads to create pleats used to create hats and bags. Coiling depends on leaflets strands wrapped and interwoven around a coil

made from stiff materials such as spadix stems to create sturdy baskets. In latticing, midribs are arranged in two sets, rectilinearly or diagonally, tied together using thin flax ropes to create the panels of the backrests and arm rests in midribs furniture where paneling is crucial for fast mass production. Piercing is done by hammering hollow steel pipes through a group of midribs to push a perpendicular group of midribs through these perforations. Hence, these techniques depend completely on manual skills which are easily educated and transferred among craftsmen in Dakhla [1,4].

This thriving technical heritage of using DPPRs in handicrafts naturally accompanied a distinctive technical heritage of utilizing DPPRs in construction. Builders and midrib carpenters in Dakhla acquire their thriving unique set of techniques of using date palm midribs and leaves in construction that is unmatched in other major DPPRs handicrafts centres in Egypt such as Fayoum and Giza. The technical heritage of utilizing DPPRs in construction is more advanced in Dakhla than in the rest of Egypt due to the following factors [14,15]:

1. Dakhla hosts the majority of builders and midrib carpenters in the western oases [14,15].
2. DPPRs-based products in Dakhla are still used domestically besides touristic marketing, while the domestic use of these products declined in Fayoum and Giza. Accordingly, Dakhla community is more accustomed to DPPRs as basic building elements of their houses [14,15].
3. Professions related to DPPRs based handicrafts and construction are highly in demand in common practice and not limited to Eco-tourism projects [16,26]. Accordingly, techniques are still successfully transferred across generations ensuring its survival and growth.
4. The relatively long distances between wells and agricultural fields, and urban settlements required a unique construction technique to build fast movable huts [15]. Accordingly, prefabricated garages and huts provide versatile and reliable solutions unique to Dakhla.
5. Traditional uses of DPPRs in construction naturally adapt to the Dakhla community needs and environment. Modern construction systems in the national housing projects introduced by the National Desert Development Authority in the 1960s did not solve the need for light shaded areas for stockbreeding. Therefore, traditional Shari'a roofs remained to be actively in use in the middle of modern reinforced concrete structures [15,21].

Therefore, Dakhla community is loyal to its unique technical heritage of utilizing DPPRs which adapts to their inherited skills and environment. This is evident as DPPRs in construction never ceased to be a major characteristic of the architecture of Dakhla, especially in roof construction, light shaded structures and ornaments in spite of

introducing modern construction systems in the national housing projects in the 1960s by the National Desert Development Authority [15,21]. Moreover, tenants in the new villages of West Mawhoub region, built by the government using Nubian mud brick vaults and domes in 1965, replaced the domes with date palm midribs roofing. This substitution occurred because the community in Dakhla was used to domed roofing exclusively in cemeteries, leading to its spontaneous rejection to be used in their houses. Traditional date palm midribs roofs provided the community with flat surfaces that would host additional floors and multi-use roofs [15,21]. All these incidents prove the confidence and loyalty that the community of Dakhla has towards their technical heritage of utilizing DPPRs in construction. This confidence guarantees that these techniques are still used, yet with different levels of complexity, in various regions in Dakhla. DPPRs are still being actively used in Dakhla in the light shed structures in ecotourism projects, roofing for mud brick houses and shading for the top roofs of modern reinforced concrete buildings depending on traditional techniques [15,29,30], as well as more developed uses such as prefabricated panels for huts, garages and fences [15].

However, the majority of the existing body of research regarding the construction practice in Dakhla is more focused on the characteristics of the traditional mud-brick architecture and the attempts to revive mud-brick construction. Dabaieh [31] focused on the procedures of manufacturing mud-bricks and traditional mud-brick bearing wall construction in Dakhla. Seif et al. [23] emphasized on the difference between the traditional compact urban fabric using local skills and materials, and the modernized urban fabric that consists of rectilinear planning regardless of the environmental conditions, climate requirements or social aspects.

De Flippi [30] analyzed the influence of the Islamic desert defensive architecture and the hot arid climate on shaping the architecture of Dakhla. Light shade structures utilized light building materials such as date palm trunks, leaves, midribs and acacia logs, as alternatives to heavy mud-brick construction. Reintroducing this architectural heritage requires the establishment of a database of traditional construction methods and analyzing their compatibility with contemporary applications [23].

Schijns et al. [32] focused on analyzing traditional mud-brick construction techniques from three example houses from Islamic Qasr, Qalamoon and Balat villages to build an archaeological working and training centre in Dakhla. Dabaieh [16] applied a Participatory Action Research (PAR) model to help sustain the traditional know-how among local inhabitants through involvement in actual construction. A room of a model house designed by locals during a participatory seminar was built using traditional techniques. Mud-brick bearing walls and midribs roofing were used in building the room. Although the model house was never finished, this model proved that techniques involved in this traditional construction could

be easily transferred to new generations.

Elders admitted that mud-brick houses provided better indoor thermal quality, while youth favored modern neat RC structures free from the threats of underground water and floods, and the social stigma associated with living in old mud-brick houses [29]. Accordingly, common construction practices nowadays in Dakhla utilize two main forms of construction: fired mud-brick load-bearing wall construction and RC skeleton structures. Interestingly, traditional midribs roofs are still used along with RC slabs in load-bearing wall construction [8,16,18]. Hence, although most of the previous attempts of reviving traditional construction methods in Dakhla remain limited to eco-tourism projects and research studies, several techniques taken from DPPRs-construction technical heritage continue to be used to produce local and cost-efficient alternatives to conventional construction methods to serve the community need [15]. When a new garage is needed, a barn for livestock, or a shaded extension for a house, owners do not automatically hire workers to build light steel pipe frames covered with corrugated sheets. Instead, owners fulfill their needs using date palm leaves and midribs depending on shared expertise inherited from accumulated technical heritage [15].

3. Knowledge Gap and Research Significance

Most of the existing literature regarding the architecture in the western oases in Egypt focused on mud brick construction, its decline in the newer regions, and the attempts that aimed to restore traditional mud brick construction. However, there is a clear knowledge gap: the specific role of DPPRs in traditional and current architecture in the western oases. Furthermore, the techniques and details of implementing the technical heritage of DDPRs into contemporary architectural applications are yet to be investigated.

This paper aims to provide a valuable contribution to the field of studying the vernacular architecture of the western oases in Egypt, by emphasizing mainly Dakhla oases, where the technical heritage of DPPRs plays a major role in its architecture [14,15,30]. The paper presents the first in-depth analysis of the technical details of utilizing DDPRs in traditional architecture of Dakhla, as well as eco-tourism projects and contemporary architectural applications that people build for themselves based on their inherent experiences. The basic objective of this analysis is to define the main factors that saved several forms of the traditional uses of DPPRs to be still employed in contemporary architectural applications while other forms declined along with the decline of traditional mud brick architecture. Understanding the rationale by which the Dakhla community deemed some specific uses worthy of saving can help nominate which techniques can be further

developed to be used in a wider and more sophisticated spectrum of purposes.

4. Methodology and Data Analysis

The paper investigates the technical heritage of utilizing DPPRs in construction and its manifestation in current architectural practice. Subsequently, the paper raises the following question: What is the extent of the technical heritage of utilizing DPPRs throughout the architecture of Dakhla? In order to approach this question, the paper adopts qualitative research using the grounded theory approach. Qualitative research is more suitable to define concepts and describe characteristics related to the individual and group perception of the environment [33]. Site documentation is among the basic qualitative data sources in architectural research [34]. In addition, grounded theory is used to generate a theory that is “grounded in data systemically gathered and analyzed” [35]. Collection of artifacts and texts is one of the common methods used in grounded theory to learn about group by collecting data and materials used by the members of this group [35]. Artifacts include records, documentation, photographs, educational materials, books, and materials produced by the members of the setting [36]. The paper learns about the extent of this technical heritage and its relationship with the culture in Dakhla by collecting artifacts, texts, site documentation and literature produced by members of the community historically and in the present in order to generate a theory that examines and predicts the continuity of this technical heritage in contemporary architectural applications.

The main characteristic of the grounded theory approach is constant comparative analysis. This involves continuous shifting between data collection and data analysis simultaneously [37]. Each shift is known as an iteration. To launch the research, the first question directs the first iteration of the theoretical sampling. After collecting and analyzing the first general data, researchers begin to create an initial theory, which directs researchers where to move to gather the next samples of data. Deeper iterations continue until saturation is achieved, where the researcher finds strong repetitions in the new data which cease to generate new insights to theory [35].

In the case of using collection of artifacts and texts as the major method of data collection in this paper, the first iteration began by scanning general accounts of utilizing DPPRs in various construction forms in Dakhla. Preliminary site documentations confirm DPPRs implementation in traditional and contemporary construction. Preliminary categories of DPPRs construction applications were analyzed to define differences necessary to create more categories. Cross comparisons and additional diverse categories were added, such as using DPPRs in Eco-tourism projects, until collected data was repeated and saturation was achieved.

Categories were organized into clusters according to the pruning residue used, techniques employed and function. Finally, categories were integrated to recognize uses and techniques accumulative patterns to explain the characteristics of evolution of DPPRs-construction technical heritage towards implementation in common contemporary construction practices and suggest the DPPRs based-building elements that can be developed further in order to sustain the unique technical heritage and promote its investment in contemporary architecture.

5. Results: DPPRs-Construction Technical Heritage in Dakhla

DPPRs-construction technical heritage in Dakhla manifests through three forms: traditional construction of the old region where the basic technical heritage originated, environmental construction of the Eco-tourism projects where this technical heritage is accentuated as a part of the architectural heritage revival concept, and common construction practices where this technical heritage is employed by people in common applications they need and build for themselves. This classification of Dakhla architecture into traditional architecture and contemporary architecture, also classified into environmental architecture and common practice architecture, aligns with the previous classification suggested by [23].

5.1. DPPRs in Traditional Construction

First settlements in Dakhla were situated above the eastern plateau between Dakhla and Kharga oases, to protect mud-brick houses from rain streams and floods and defend the inhabitants from bedouin attacks [38]. Gradually, settlements began to descend towards the fertile valleys below the plateau. The old settlements, founded above the plateau, have managed to overcome floods and outsider attacks, preserving their architectural heritage for centuries [15,38]. The constricted buildable area above the plateau, the availability of date palm leaves and acacia logs needed for multi-storey housing, and the need for narrow alleys to obstruct outsider attacks shaped the traditional architecture of the old region [14,38]. The dense compact planning of villages and towns in the old region above the plateau consists of contiguous blocks of mud-brick houses interspersed with narrow sinuous alleys [30]. These settlements include Mut, Balat, the Islamic Qasr village, and Qalamoon [15,38]. Traditional building techniques in these settlements remain unchanged due to the prohibition issued by the Supreme Council of Antiquities against any unsupervised modifications [30]. Therefore, inspecting the architecture of the villages in the old region provides a faithful image of the DPPRs applications in the traditional construction of Dakhla [14,15,30].

5.1.1. Traditional Procedures of DPPRs Collection and Treatment

The main DPPRs used in construction in Dakhla are leaves and midribs [15]. The average weight of produced leaves is 29.6kg per palm accounting for 50% of the total residues. This weight consists of 15kg of midribs and 14.6kg of leaflets [4]. A date palm midrib is a rib extending through the axis of a leaf from which the leaflets branch. Its length and thickness range from 5-7m and 0.5-3cm, respectively, according to the palm species. Date palm leaves are collected after the annual pruning process in February and March. According to their inherited experience, midribs carpenters affirmed that leaves collected in February have significantly higher resistance to pests. Each palm produces a yearly average of 8-15 midribs [39]. Leaflets are removed from the leaves and the midribs are cleaned thoroughly [17]. Leaflets are given to handicrafts workers and the midribs are ready for treatment. The midribs are sun-dried for 2 days before smoking, where midribs are laid horizontally in racks above blazing petioles that produce thick hot smoke for 12 hours terminating pests' eggs inside the midribs [15]. Thus, smoked midribs can be used in unventilated applications such as roofing without the danger of internal decay.

5.1.2. Traditional Date Palm Midribs Habk Roofs (DPPRs Techniques used: Habk, Rak)

A traditional house in the western oases would consist initially of 2 floors. More floors were added as the family grew. In Dakhla, the height of traditional houses used to reach 5 floors in Dakhla [14]. The traditional midribs roof, seen in Figure 2, has proved its structural integrity to be used in multi-storey housing through centuries of practice by employing the traditional Habk technique. Acacia logs were traditionally used as main beams for roofing and Saqifas along with trunks columns in the old region in Dakhla [15,29]. Acacia trees (*A. raddiana*, *A. ehrenbergiana* and *A. tortilis*) are among the most available trees in the South of the Eastern and Western deserts in Egypt [40]. Acacia logs have been used in construction since Ancient Egyptian period due to their high rigidity [14].



Figure 2. Traditional Date Palm Midribs and Thick Acacia Logs Using Habk Technique in Balat village. (1) Date palm midribs. (2) A thick date palm midrib as Hommar. A date palm leaflets ropes, Shalaq, is used in tying Hommar to the midribs. (3) An acacia log beam

In Habk technique, beams are laid parallel to the span [29] on the top course of the grooved mud-brick wall to accommodate beams endings [14]. The typical height of mud-brick walls is 2-2.5m, and thickness is 40-45cm on the ground floor decreasing gradually until 20cm on last floors [41]. The maximum spacing between beams was 60cm. Secondly, thick midribs, known as Hommars, are tied and laid parallel to the main beams, where a Hommar is laid between every 2 beams. Thirdly, midribs are tied in perpendicularly to Hommars. Each worker specializes in tying midribs to only one specific Hommar simultaneously with the other workers [15]. Traditional ties used in tying the midribs to Hommars were made from date palm leaflets ropes known as Shalaq [29].

Leaflets layer and mud-brick layers are used over roof midribs to enhance the stiffness of the roof and protect from water erosion [29]. A thick layer of clay-based plaster is added to finish the surface of the roof to be used in different activities. This finishing technique is called Rak [15]. Nowadays, midribs roofs are still used as a cost effective method by which people can build extensions for their houses or additional rooms above top roofs.

Also, the same Habk and Rak techniques were employed in Saqifa roofs, which were roofs built above portions of narrow alleys. These roofs could carry extensions of the first floors of adjacent houses. Saqifas were 1.5-2m wide, the street width, and 6-15m deep [14]. Builders used to build Saqifas to help reduce the air current temperature and extend the area of the first floors [14,30]. Saqifas were supported by mud-brick columns protruding from the walls of the adjacent houses or palm trunks planted vertically as columns supporting acacia logs beams and Hommars along the alleys width [15]. Final finishing depended on Rak technique. Nowadays, streets width has increased to 3-5m to accommodate transportation [14]. Accordingly, Saqifas can only be found over the narrow alleys in the old regions.



Figure 3. Date Palm Leaves in a traditional Shari'a roof in the Islamic Qasr Village

5.1.3. Date Palm Leaves Shari'as (DPPRs Techniques Used: Binding)

A Shari'a (Figure 3) is the local name of a space roofed by leaves mats bound by ropes at the tips, also known as Seddas, laid over acacia logs [15]. Seddas are made using the Binding technique which depends on using belts of leaves to bind leaves to create coherent mats. Shari'a

spaces were situated in the back area of the house which included the kitchen and the poultry barn. No plaster was used over the Shari'a roof as ventilation is crucial for these spaces. Shari'a roofs are still used in barns, grain silos and garages units supported by wooden planks beams [14].

5.1.4. Date Palm Leaves Fence (DPPRs Techniques Used: Binding, Latticing)

The majority of fences in Dakhla are constructed from dense whole leaves. Whole leaf fences are built using the binding technique [4,9]. Construction of a fence (Figure 4) is divided into 3-4m long segments. To build a fence, the soil is dampened to dig holes with a depth of 30cm with 10-20cm spacing. Vertical leaves are planted successively in the holes. Vertical acacia logs posts are planted with 3-5m spacing to ensure fence verticality. Two horizontal belts of leaves are tied on both faces to bind the vertical leaves to the acacia posts to enhance firmness. Fence gates are made from midribs lattices, using latticing techniques, which are fixed on special hinges to act as revolving doors. Leaves fences have proven their integrity to be used as light walls and barriers beside conventional steel fences and brick walls.



Figure 4. A traditional whole date palm leaves fence in Islamic Qasr Village. (1) A belt made from a whole date palm leaves. (2) Vertical whole date palm leaves. (3) An intermediate acacia logs post

5.1.5. Date Palm Leaves Roof Parapets (DPPRs Techniques Used: Mud-brick Reinforcement)

Roofs in Dakhla are used for sun-drying the rice crops over beds of date palm leaves, sun-drying dates, or for sleeping in warm Summer nights. Accordingly, roofs in Dakhla require high parapets to protect them from falling. Traditional parapets, 150-170cm high, consisted of mud-brick walls reinforced by vertically protruding leaves [15,16]. Currently, high RC parapets replaced traditional parapets.

5.1.6. Date Palm Trunks Cross Beams (DPPRs Techniques Used: Carpentry)

Another extinct DPPRs application in traditional construction is cross palm trunk beams. Trunks were usually added during maintenance of old buildings to

support between opposite slanting walls. The oldest surviving trunk cross beams can be found in the old oil press in the Islamic Qasr Village, dating back to the Ayyubid period. However, this practice is no longer needed in modern construction that depends on RC structures. Also, modern treatments against pests are successful in extending the life of date palms, which led to less date palm cutting. Currently, using date palm trunks as columns and beams in Dakhla is now limited to Eco-tourism projects such as ecolodges.

5.2. DPPRs in Contemporary Construction

5.2.1. Eco-tourism Projects

Inspired by Adrere Amellal, the first ecolodge built by Siwa Sustainable Development Initiative [24], architectural design of Eco-tourism projects in the western oases proudly expose their natural materials without any refinement to illustrate depending on minimal machinery and avoiding negative impacts on the environment [26]. However, Adrere Amellal has a strong impact on the interior design of rooms in ecolodges of Dakhla. Traditional building techniques imported from Siwa are used in most of the roofing types in Desert Lodge and Tarfa Lodge hotels in Dakhla. Although roofs of the rooms can be built cost-efficiently using Habk technique, some of the roofs are built using stacked rows of halved trunks. Other roofs are built using acacia logs beams and leave bundles. Also, unique translucent roofs are built using Kershef blocks over trunk beams [27]. Thus, generating an exaggeratedly natural interior design that expresses wholesomeness is accorded a higher priority than utilizing original Dakhla roofing techniques [14]. Conversely, shade structures in Dawar El-Omda, a community club built by local builders, are clearly inspired by DPPRs-construction technical heritage merged with foreign elements. This merging indicates that local developers aimed to revive the architectural heritage of Dakhla through using the ability of this technical heritage to be altered to produce various formations and functions.

a. Date Palm Trunks and Leaves Structures (DPPRs Techniques used: Carpentry, Binding)



Figure 5. Date Palm Trunk and leaves gable roof. (a) The longer side (1)

The quartered date palm trunk ridge beam. (2) Casuarina purlin (3) A whole date palm Sedda (4) A Casuarina beam. (5) A date palm trunk wood side beam. (6) Shebaikah wall. (b) The gable end (1) A Casuarina purlin. (2) A date palm wood rafter (3) The quartered date palm trunk ridge beam. (4) A halved date palm trunk column

Light multi-purpose halls are covered by 8m span structures made from midribs and trunks (Figure 5). The roofing structure is inspired by Shari'as but with modifications taken from standard timber framing. Quartered trunks are planted vertically as columns along the space perimeter and along the middle of the span with 3-4m spacing. Quartered trunks are laid as rafter beams and ridge beams. Acacia logs are laid across the middle of the rafter beams. Finally, three layers of leaves Seddas are laid over the roof structure, parallel to the span and tied to Acacia logs using the binding technique. Leaves are left uncovered to flaunt their natural form.

b. Shebaikah Walls (DPPRs Techniques used: Binding)

Light walls are direct descendants of traditional leaf fences but with the addition of a diagonal lattice layer clearly inspired by Shebaikah technique. Shebaikah technique is used in traditional reed huts in Manzala Lake in North Egypt [42]. Walls of traditional reed huts in Manzala consist of reed bundles planted vertically along the boundary of the huts and braced by diagonal reed bundles to provide high resistance to wind and impact forces. Diagonal midribs are added to traditional leaf fences, in 5.1.4, to produce sturdier walls (Figure 5). After planting the vertical leaves and posts, 2 sets of oppositely inclined leaves bundles are planted alternatively with 60° inclination on both faces of the wall and tied to all of the vertical leave. Finally, whole leaf bundle belts are tied horizontally across the walls to increase the coherence between vertical leaves and the inclined midribs. Unlike the walls of the reed huts in Manzala which are covered by thick lime plaster, the walls here are left without external plaster to flaunt their color and ornate texture.

5.2.2. Common Practice

Traditional midribs roofs are still used commonly by Dakhla community with modifications. Other current applications utilizing midribs are specifically tailored to adapt to the needs of the market.

a. Date Palm Midribs Habk Roofs (Casuarina Beams) (DPPRs Techniques used: Habk, Rak)

Beams made from local Casuarina logs emerged as substitutes for the acacia logs to produce sturdier roofs with straighter beams rather than the crooked acacia log beams. Casuarina trees thrive in harsh environments that lack nutrients, such as dry climates and sandy soils [43]. Therefore, Casuarina was introduced in Egypt in the 1970s to maintain a source of local hardwood, planted in the western desert, eastern desert and Sinai [44]. Casuarina logs are commonly used for construction purposes, such as beams and poles [45]. Casuarina logs and midribs roofs are

built now using traditional Habk technique. These roofs are used in 4x3 m rooms and can be repeated up to three floors. In addition to acacia logs and Casuarina logs, welded hollow steel pipes frames are recently used as main beams in Habk technique roofs for faster and easier construction (Figure 6). Midribs are tied together to Hommars with flax ropes, jute ropes [29] or steel wires now instead of palm leaflets ropes. Current roof finishing layers are based on traditional Rak technique with few modifications. Leaflets are laid in a 5cm thick layer over the midribs, above which a layer of polyethylene water barrier is added to increase protection from water leakage during rain [29]. Above the water barrier, a 5-7cm thick layer of clay is added and mud-bricks are compacted into the clay by pressure. Above this thick layer, a mixture of crushed mud-bricks and clay is leveled to reach a thickness of 3-5cm [14]. The roof is left to dry for a week. Finally, a calcified soil mixture plaster is applied to provide fairness and hardness to the finishing surface [15]. Furthermore, a Dursban 6cm³/litre in kerosene solution is applied to midribs, Casuarina logs and leaflets as a treatment against termites [46]. Thus, Dakhla community has generated solutions to improve the overall performance of traditional midribs roofs. The enhanced resilience against rain and pests and facilitated construction procedures encourage youth to embrace this traditional roof as a part of contemporary construction.

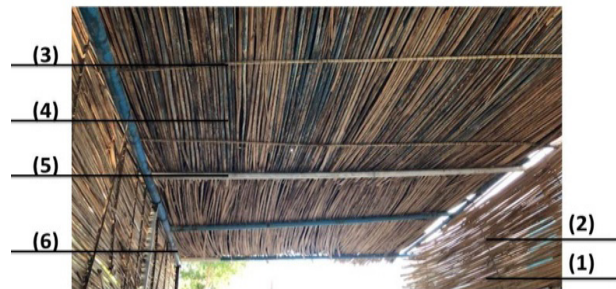


Figure 6. Hollow Steel Tubes Frame in a recent Habk date palm midribs hut in Mut. (1) A date palm midribs Sedda wall. (2) Steel wiring used in tying the midribs. (3) A date palm midribs Hommar. (4) Date palm midribs in the roof. (5) A hollow steel tube beam. (5) A hollow steel tube side beam

b. Date Palm Midribs Pergola Structures (DPPRs Techniques used: Habk, Piercing, Latticing)

Midribs pergolas (Figure 7) are commonly used in Dakhla due to their sophisticated forms which balance traditional techniques and modern designs. Midribs are integrated with fired-brick columns and wooden beams. Fired-brick columns are firstly built at the center and corners of the plans. Mid-height brick walls are built between brick columns. The rest of the wall height is completed using midribs lattices.

These lattices, made using piercing technique, consist of vertical thick midribs perforated to fix diagonal members and horizontal thick midribs. Horizontal members are also perforated to drive the diagonal members through the

perforations. In cases where midribs lattices are intended to work as clerestory windows, the lattice is designed as a rectilinear crate where a set of midribs are perforated through which a perpendicular set of midribs are driven by friction.

Casuarina logs are secondly laid horizontally as beams supported by the columns and the top horizontal thick midribs along the perimeter. Radial beams are arranged from the central columns towards the perimeter. Two thick midribs are fixed back-to-back as Hommars between each two radial beams, as inspired by Habk technique. Radial beams can be made from date palm trunks Casuarina logs according to the span. These radial beams must be prepared before fixation with the needed grooves to connect roofing midribs. Stacked roofing midribs are hammered to be fixed by friction between the radial beams grooves.

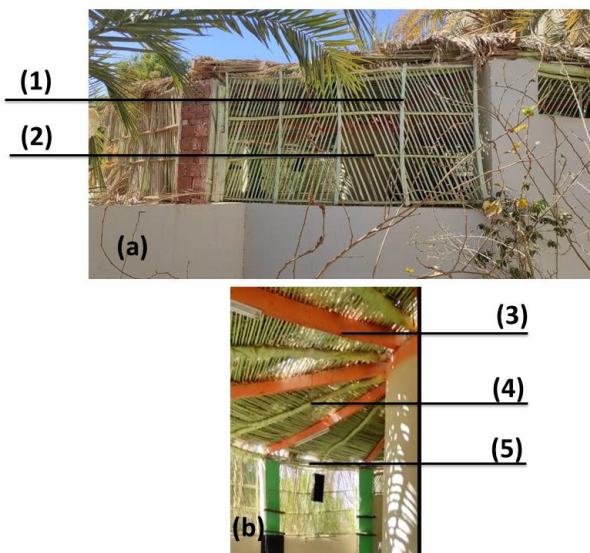


Figure 7. A midribs pergola in Mut. (a) The pergola from the outside. (b) The pergola from the inside. (1) A vertical date palm midrib. (2) A horizontal date palm midrib. (3) A painted Casuarina log laid radially from the center column. (4) Two radial Hommar midribs fixed back to back. (5) Top horizontal midribs to fix the radial beams

c. Date Palm Midribs Crate Sheds (DPPRs Techniques used: Piercing)

Hollow steel pipes are used as beams to support midribs lattices. Lattices are made using the piercing technique used in making bread crates [4,9], where a set of midribs is driven through a perpendicular set of perforated midribs. Fabrics or cardboard sheets are laid above the lattices as a fast shading option (Figure 8).

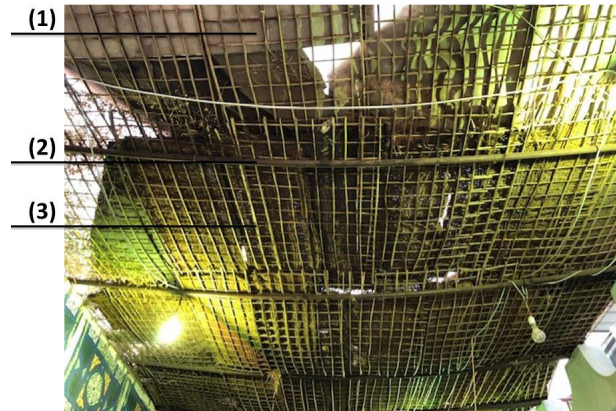


Figure 8. A date palm midribs crate shed in Mut. (1) Cardboard sheets. (2) A hollow steel pipe beam. (3) Date palm midribs crates

d. Date Palm Leaves Units (DPPRs Techniques used: Binding, Latticing)

Light private garages (Figures 9-10) are common in the villages in Dakhla [15]. Garage forms vary according to the expertise of the garage owner. One of the types used is the leaves wall garage. Vertical leaves are closely planted into 30cm deep holes to create outer layers of the garage walls. The vertical leaves are bound by ropes to 2 horizontal leaves belts on the outer face of the wall. Midribs are planted vertically into 30cm deep holes within a spacing of 10-20cm. Horizontal midribs are tied within the same spacing to create a backing lattice behind the leaves' outer face, similar to the lattice used in the gate in 5.1.4. In between, sheets of cardboard are connected by tapes to provide air tightness. The three layers of leaves wall, cardboard and midribs lattice constitute the structure of the garage wall, as well as the structure of the garage roof. This Shari'a-based roof can cover a 3-4m span between walls, as private garages can consist of a single parking lot or 2 parking lots. Deflection can be seen in the roof under the weight of cardboard and leaves layers. This structure type does not include any wooden elements.



Figure 9. A garage made from leaves and cardboard in new Qasr town from the inside. (1) leaves in the roof of the garage. (2) Cardboard sheets. (3) midribs lattice. (4) leaves outer wall



Figure 10. A garage made from leaves and cardboard in new Qasr town from the inside

e. Timber Frame and Date Palm Midribs Units (DPPRs Techniques used: Binding, Latticing, Paneling)

In contrast to the leaves units, a faster alternative emerged in the 2000s depending on the concept of prefabricated midribs panels (PMP) which is a unique concept only found in Dakhla, as shown in Figure 11. Paneling depends on using rectangular wooden frames made from wood planks. This frame is laid over the ground and 60 degrees inclined stacked midribs are nailed to the frame. A lighter midribs layer is nailed to the first layer with 120° inclination. Two belts of horizontal midribs are nailed to tighten both midribs layers to the wooden frame. Hence, the panel is ready to be moved to the site. On site, the soil is dampened and wall panels are planted vertically in 30cm deep linear grooves. The wall panel is backed by taped cardboard sheets and a lattice of midribs is planted and fixed with ropes to the outer wall panel to create the same triple layered walls used in 4.2.2.c Shari'a inspired roofing consists of Casuarina log beams parallel to the span supporting perpendicular midribs bound to Seddas using binding technique. An additional layer of cardboard is laid between the midribs and Seddas to enhance water tightness. Panelized units serve the need for fast easy cost-efficient versatile units.



Figure 11. A garage made from timber frame and date palm midrib in new Qasr town. (1) A Casuarina beam. (2) A Casuarina overhang. (3) A horizontal date palm midrib belt. (4) Timber frame. (5) Diagonal midribs nailed to the timber frame

f. Timber Frame and Date Palm Midribs Gates (DPPRs Techniques used: Paneling, Latticing)

Light artistic gates are widely used in Dakhla depending on paneling technique and PMP, as shown in Figure 12. 2-3m-wide rectilinear wood frames are made beforehand according to the intended design. The maximum spacing between the members of the frame, horizontally and vertically, is 60cm. The distribution of the members must consider the places of windows, doors and ornaments.

Firstly, midribs are refined to produce identical members complementing the engineered panel form. The first layer of midribs is arranged with 45° inclination and nailed only at the tips to frame members using steel nails. A second layer of midribs is arranged perpendicularly over the first layer and nailed using steel nails through the first layer to the frame. Arched midribs are fixed with nails to shape the openings of the panel. Endings of midribs are trimmed along edges and openings. After trimming, the panel is ready to be moved and installed on site over plain concrete footing. The panel is raised 5-10cm over ground, while the frame is nailed to wooden posts fixed to footings.



Figure 12. Gate made from PMP. (a) The panel before installation. (b) The panel after installation onsite. (c) Shaded pathway made from PMP. (1) Arched midribs ornaments. (2) Timber frames. (3) Diagonal midribs nailed to the timber frame

Moreover, panels are often decorated with ornaments made of arched midribs. Short straight midribs are arranged radially in between two layers of arched midribs by nails. This ornament unit is fixed to horizontal midribs at the top of the panels. Also, outdoor corridors in Dakhla are usually enveloped in midribs panelized walls nailed to wooden posts. Vertical midribs in the panelized walls are extended to be interwoven into the simple shaded roofs made of long thick midribs beams and purlins lattices, as shown in Figure 12c.

6. Discussion

Inspecting the map of DPPRs-construction technical heritage in Dakhla, illustrated in Figure 13, indicates that its evolution is moving towards the following aspects:

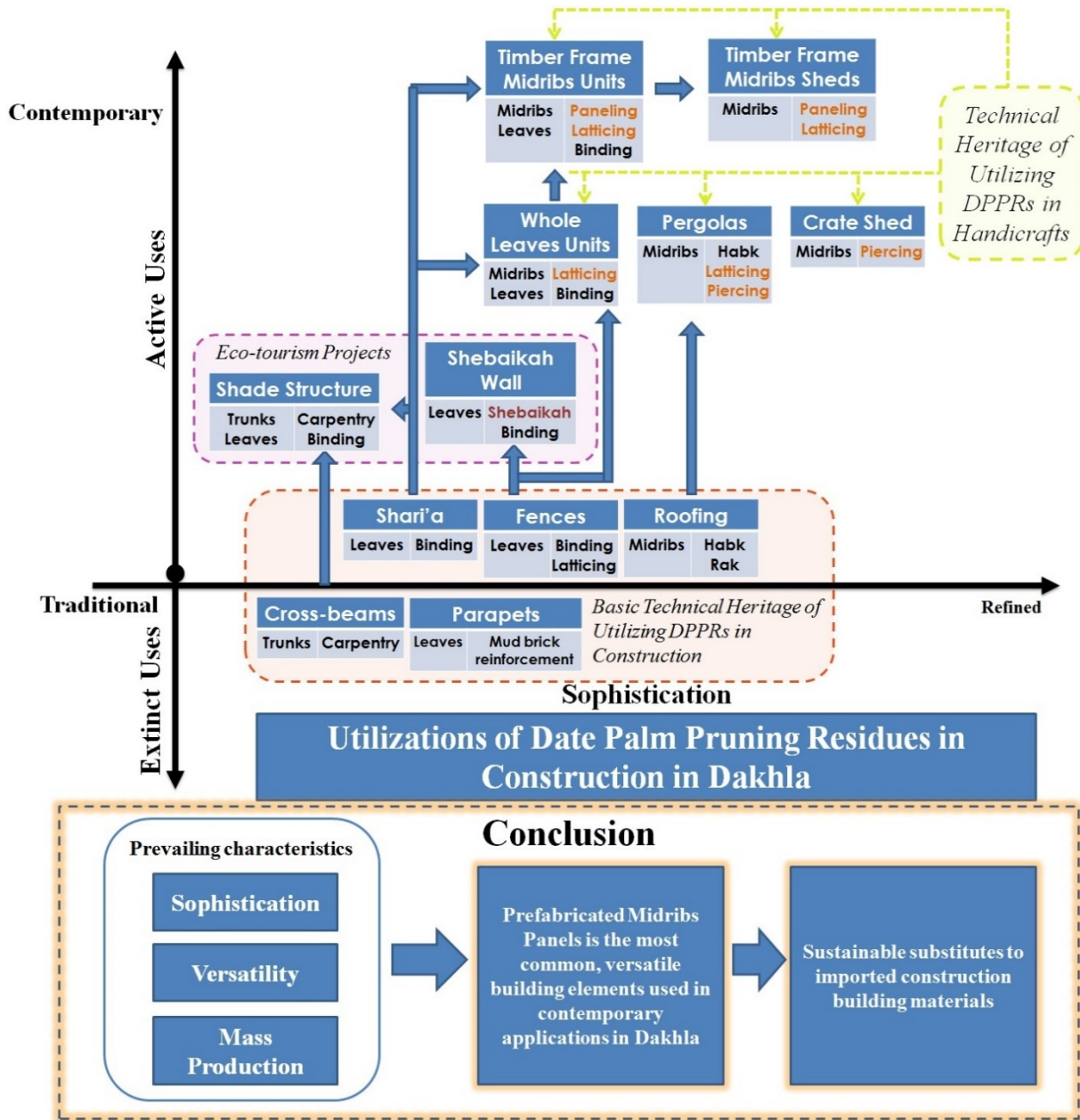


Figure 13. A Map of the evolution of DPPRs-construction technical heritage in Dakhla

1. Most of the current DDPRs-based building elements depend mainly on midribs. Midribs are the final refined residues of the date palm pruning process after removing leaflets from leaves. Midribs can acquire more refinement by Tasdeeb process, where the peripheral layer of a midrib is removed to produce a standardized shape with a regular cross-section [47]. Leaflets are immediately employed into the continuously demanding handicrafts industry in Dakhla to produce baskets, mats and bags. Also, the diversity of the sizes of harvested midribs allows for using midribs as versatile members in the structures of pergolas and fences.
 2. The majority of techniques employed in contemporary DDPRs construction applications are directly descended from the techniques used in midribs furniture in Dakhla, such as latticing, piercing, and paneling. Walls of pergolas are built using latticing and piercing techniques taken from the technical heritage of utilizing DPPRs in handicrafts. The multi-layered walls of these units also depend on handicrafts techniques such as latticing. Paneling technique, used in midribs furniture, is now adopted to produce more sophisticated units depending on PMP for a faster and cheaper construction process. These techniques belong to the strong DPPRs-handicrafts technical heritage which is well preserved and invested in Dakhla as one of the major DPPRs –based handicrafts centers in Egypt. Accordingly, these uses are common because they depend on techniques at which skilled craftsmen are almost available in every family. Thus, these applications are widely common as people can build for themselves whatever light structures they need instead of depending on imported conventional building materials.
 3. Refined DDPRs-based building elements are more significantly common than raw-shaped elements. Refined and fine forms are necessary to compete with imported conventional industrialized building elements and fit into the modern urban style. As midribs are the main pruning residue of current DPPRs-based construction applications, the employed techniques taken from midribs furniture industry are naturally accurate to ensure the fine quality of the produced furniture which is one of the most important exports of Dakhla. On the other hand, utilizing date palm trunks as columns and beams in structural frames remains limited to Eco-touristic projects and ecolodges despite the previous presence of this method in traditional construction. Steel frames and timber frames can provide wider spans using a more common set of skills than the carpentry skills needed to build structures using trunks which receded with enhanced palm maintenance methods. Also, the raw final forms aimed by eco-tourism projects developers create a barrier between the public and their ambition to imitate modernization. Accordingly, the public is more willing to accept these wholesome designs in touristic projects than in their common daily uses, confirming what was reported earlier by [29,48].
 4. Contemporary DDPRs construction applications provide versatile architectural solutions. Pergolas in Dakhla employ the Habk technique using midribs and Casuarina beams to build modern shade structures with a variety of forms and spans, instead of depending entirely on imported timber framed structures. This traditional Habk roofing can be used with various structural systems, such as timber frames, Casuarina log beams and hollow steel pipes frames. Leaves units and timber frame midribs units can serve various uses such as light huts, garage units, sheds and partitions PMP substitute imported plywood panels in various uses, such as garages, gates and shade structures.
 5. Most of the common DDPRs construction application in Dakhla, such as timber frame and midribs units, gates and shade structures partitions, depend on prefabrication. PMP timber frames are prepared and assembled before shipment to site. These panels can be made by the owner of the structure or by professional midribs carpenters in their workshops according to the complexity of the intended design. These specialized workshops acquire lines of mass-production for this type of DPPRS-based construction.
- Accordingly, the sophistication, the ability for mass-production and versatility of DPPRs construction applications are crucial to be accepted by the market as viable cost-efficient sustainable alternatives to conventional methods. Thus, the paper suggests that PMP is the most versatile DPPRs-based building element which can efficiently compete with imported light construction panels such as imported plywood panels or corrugated sheet panels, as modern sustainable alternative panels that enjoy high aesthetic quality and economic value. Furthermore, combining traditional Habk midrib roofing and light Shari'a roofing with PMP units succeeded in maintaining and reintroducing these traditional construction methods as clever and versatile construction methods that are fit for the modern lifestyle the youth aspire to. Developing and expanding the uses of PMP can help stimulate better waste management strategies to benefit from DDPRs as a renewable resource for various modern construction applications that can compete with conventional construction methods and ensure the continuity of this unique sustainable technical heritage circulation among new generations.

7. Conclusions and Recommendation

Inherent skills and techniques are subject to natural selection, where some techniques are accepted by the next

generations and built upon, while other techniques are not as fortunate. The technical heritage of utilizing DPPRs in construction consists of the tangible resources; which are the pruning residues, and the intangible resources, which are the know-how among the community. And although the tangible resources are renewable and steady, the intangible resources of skills and know-how are highly subject to the social pressure of competition against modern conventional building materials and systems. However, the community of Dakhla oases represents a unique experience in sustaining and developing its rich technical heritage to be implemented in contemporary architectural applications. The techniques constituting this technical heritage are naturally sustainable, as they depend on manpower and local and renewable raw materials. However, attempts to reuse traditional building techniques to promote sustainable construction have proved to be limited to Eco-tourism projects, unable to be replicated among the community. On the other hand, the fact that this heritage has successfully evolved to be commonly employed by the community of Dakhla producing sustainable contemporary architectural applications serving its daily needs encouraged this paper to question the characteristics of these uses to determine the factors that led to this success. In order to replicate these modern utilizations in a wider base of rural communities as sustainable alternatives to conventional materials and methods, the advantages that industrialized building elements provide must be imitated. Versatility, cost efficiency and the ability for mass production enabled prefabricated date palm midribs panels to be one of the most common forms of utilizing DPPRs in Dakhla as major competitive to conventional imported paneling materials. Their dependence on inherent skills that are still used nowadays, their versatility and neat forms are the main factors that ensure their existence, yet limits their production, to the talented midribs carpenters in Dakhla oases.

The paper recommends that future researchers, engineers and designers who aim to develop successful new architectural applications using DPPRs must base their work on handicrafts details and techniques as they are more reproducible and functional than replicating the exact traditional trends which are exclusively used now in exotic eco-tourism projects. In addition, further research is needed to determine the engineering and structural aspects of prefabricated date palm midribs panels in order to develop their design for a wider base of architectural applications. On a practical level, the paper recommends that prefabricated date palm midribs panels must be offered enough publicity and branding to order to extend their market to become a viable sustainable and cost-efficient alternative to conventional prefabricated panels which are highly in demand in the Egyptian market.

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