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# Developing a Novel Prefabricated Enclosure Wall Panel based on the Traditional Technical Heritage in Egypt

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Prefabrication is a modern construction method where building components are manufactured offsite in order to maintain quality control and save construction duration and cost. This method has been adopted as a part of the traditional technical heritage in Egypt, especially in traditional date palm midribs furniture, light huts and partitions which are assembled using midribs lattices. However, there is a lack of research about the employing prefabrication in traditional midribs-based construction and handicrafts, which endangers this technical heritage in favor of modern imported alternatives. This paper aims to sustain this heritage through analyzing and building upon the traditional uses of prefabrication to reintroduce midribs as versatile cost-efficient contemporary building materials. A qualitative investigation on prefabrication uses in traditional midribs construction and handicrafts was conducted as the base upon which a novel date palm midribs enclosure wall panel was developed to serve as a versatile building element depending on predetermined detailing and prefabrication sequences, to maintain quality control and time-efficiency. Finite Element Model analysis of the developed panel, using validated mechanical properties, indicated that it was safe under own weight and wind. The developed panel can serve various architectural applications, which helps preserve this technical heritage that is capable of providing local modern competitors to imported products.

## 1. Introduction

Prefabrication, also known as off-site manufacturing, is a modern construction method that depends on using building components and systems which are previously prepared in an offsite controlled environment, where these components are transported to the construction site for assembly [1]. Degrees of prefabrication vary according to the size and complexity of the prefabricated components, from simple structural components (such as pre-cast concrete members and trusses), panelized construction systems (such as cladding panels and enclosure wall panels and partitions), semi-volumetric construction systems( such as services units), and fully volumetric construction systems (such as pods and modular systems) [2]. Production of these building components using standardized procedures inside a factory setting guarantees a steady level of quality needed for efficient mass production [3], and reduces the total onsite construction duration [3], and enhances the overall costs of construction [4]. Furthermore, prefabrication successfully contributes to meeting the sustainability goals in construction through maintaining the circularity of building components[5], which along with the rest of the advantages of prefabrication has led to the increasing interest of employing this method in Europe[6]. On contrary, and in spite of these advantages, employment of prefabrication in Egypt is mainly limited to Gypsum Reinforced Concrete (GRC) decorative elements, Adapted Shipping Containers (ASC) portable cabins and Light Gaged Concrete (LGC) caravans, as well as precast concrete housing, which constitute a minority among the general dependence on in-situ concrete construction [7].

Interestingly, the prefabrication concept is naturally embedded in several traditional practices in Egypt that are still used to this day. Date palm midribs are among the main materials associated with prefabrication, specifically in the production of date palm midribs furniture and light partitions and huts. While the main challenge opposing wide adoption of prefabrication in construction is the shortage of modular units manufacturers, specialized labors and trained management [8]; skilled craftsmen still preserve their unique technical heritage, which includes the concept of preparing standard units prior to assembly in creating furniture and partitions [9].

## 2. Research Significance

Employing prefabrication into the processes of producing some of traditional date palm midribs-based handicrafts and partitions has granted these products the sophistication, versatility and quality consistency, which led to their success in the local markets among the source communities, as in the case of major midribs handicrafts centers in Egypt such as Fayoum, Giza, Dakhla and Aswan [9,10]. This article aims to sustain and enhance this unique technical heritage through tracking and promoting the employment of prefabrication as an approach to reintroduce date palm midribs-based traditional products as innovative contemporary alternatives in the Egyptian market that are capable of serving a wide spectrums of uses. Exploiting the examples of adopting prefabrication to produce such

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sophisticated and versatile products can help open the door for further innovations that can save the unique technical heritage from declining under the pressure of modernization and replacement by imported plastic counterparts [12]. However, the majority existing body of literature has not yet addressed the main characteristics of employing prefabrication through traditional and modern date palm midribs products. This paper fulfills this knowledge gap through the investigation and analysis of various manifestations of prefabrication in traditional and modern date palm midribs-based products, in order to develop a new date palm midribs prefabricated building element that can encourage craftsmen to adhere to and pass on their heritage to future generations and expand their market.

## 3. Structure and Methodology

Firstly, the paper explains the geometry and microscopic structure of date palm midribs that enabled them to be suitable for prefabrication in traditional practices. The, various examples of employing the prefabrication method in traditional handicrafts and construction are analyzed through a qualitative descriptive research approach. Qualitative research is more suitable to define concepts and describe characteristics related to the individual and group perception of culture, environment or material [13]. Recent implementations of prefabrication in date palm midribs-based products are also examined to determine the differences between them and traditional concepts. Studying the characteristics of the analyzed examples provides a base upon which the design of a new prefabricated date palm midribs panel can be developed. The design of the panel is developed through two simultaneous phases: 1) The conceptual design that must be able to match the microscopic structure of the midribs and 2) The Production Sequence that must adhere to traditional skills and techniques in order to facilitate practical implementation and validate its workability. Finally, a Finite Element Method FEM structural analysis is conducted to determine the structural performance of the developed panel in order to safely act as a versatile enclosure panels for partition and light shaded structures. The structure of the paper is illustrated in Figure 1.

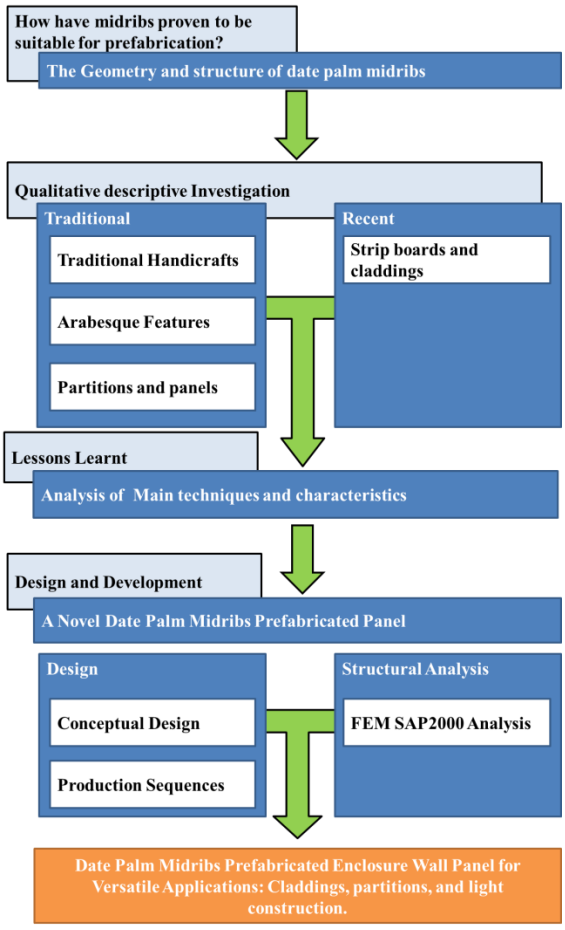


*Figure 1 Structure of the paper.*

## 4. Uses of Prefabrication in Date Palm Midribs-Based Products

The date palm, as depicted in Figure 2, is an elementary component of the Egyptian culture since the time of the Ancient Egyptians. 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 [10,11]. In addition, date palm pruning, necessary to stimulate the growth of the fruit bunches and flowering needed for pollination [16], provided Ancient Egyptian craftsmen with various pruning residues; midribs, leaflets, coir and spadix stems, used in making household applicants.

*Figure 2 A Date palm*

Surviving artifacts dating back to the old kingdom indicate that date palm midribs were used in making doors, furniture and decorations[9]. 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 trays, sturdy baskets[17], 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 in handicrafts still support over 1 million families in Egypt to the present day [14,15,18].

Furthermore, midribs especially have a technical heritage of being used in construction[14]. Excavations dating to the ancient Egyptian period indicated the use of date palm midribs as reinforcement within mud brick walls [19], and in roofing over beams made from halved date palm trunks [15,16].

### *4.1. The Geometry and Microscopic Structure of Date Palm Midribs*

The average of 54kg of pruning residues are produced by each date palm annually. 20 midribs with the total weight of 15 kg are collected per palm, while the rest of the collected amounts vary between leaflets, coir and spadix stems [22]. A midrib is the longitudinal base of the leaflets extending along a leaf, as illustrated in Figure 3. The length of the midribs can reach up to 5-7m according to the date palm species, with the thickness ranging from 0.5cm to2.5cm [9]. A midrib consists of longitudinal bundles of fibers, as illustrated in Figure 4. The density of these bundles is the highest at the peripheral area of the midrib which makes this area the strongest portion of a midrib [23]. The lean shape of a midrib allows it to be used in a variety of traditional skeletal-based products that sometimes depend on prefabricated components assembled together.

*Figure 3 A date palm leaf*

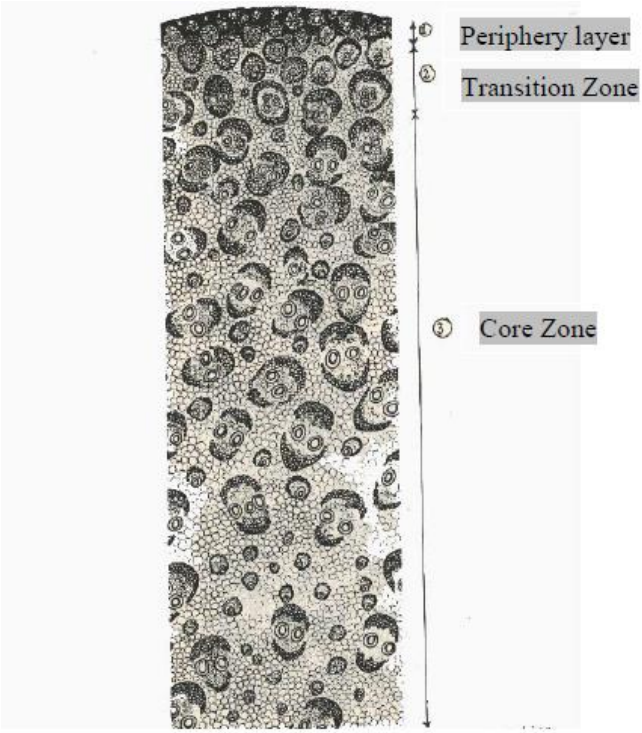


*Figure 4The fibers along the parts of the cross section of a date palm midrib [23]*

### *4.2. Date Palm Midribs Furniture*

Date palm midribs crates and furniture are the most prominent uses of midribs in Egypt [11,18]. Both crates and furniture depend mainly on the latticing technique, where a number of midribs are perforated at specific locations in order to be perpendicularly penetrated by another set of midribs [9,17]. However, the main difference between both products is the production process. While date palm midribs crates are typically built from the base and towards the top of the crate, as shown in Figure 5, furniture are assembled from separate lattice panels that are prefabricated prior to assembly. In chairs, beds and tables, the lattices of the armrests, seats, and backs are prefabricated individually with predesigned joinery necessary for assembly with nails over a skeleton made from thick date palm midribs, as shown in Figure 6. These lattices are made according to the needed dimensions, using stiff dry midribs for the straight members that are to be perforated, or using green midribs for the members that are to be bent or driven through perforations to

preserve their natural flexibility. The reliefs and details of the prefabricated lattices differ according to the expertise of the workers. Prefabrication of the lattices of a chair takes the average of 3 days while the process of assembly takes less than a day [11]. Small makerspaces prepare the lattices on demand, while bigger makerspaces store groups of identical prefabricated lattices ready for assembly. Thus, time of assembly is considerably shortened while in the same time the quality level of production is efficiently maintained.

*Figure 5 The making of a traditional date palm midribs crate.*


*Figure 6 Prefabrication of a traditional date palm midrib chair. (a) Creating a lattice for the back of the chair. (b) The structure of the chair. (c) A completed chair.*

### *4.3. Date Palm Midribs Arabesque Features*

Arabesque elements made from date palm midribs were introduced by the government firstly in the 1980s in New Valley governorate in Dakhla oasis [10]. Pealed midribs are mounted onto the lathe machine where a worker applies a pressure on the midrib using specific blades in order to carve the needed form. In addition, special tenon mortise and screwed joinery is carved into the endings of the midribs by which the carved members are then assembled together, as shown in Figure 7a. The finished arabesque lattices are usually bordered by a wooden frame to be used as a table or a partition, as shown in Figure 7b.

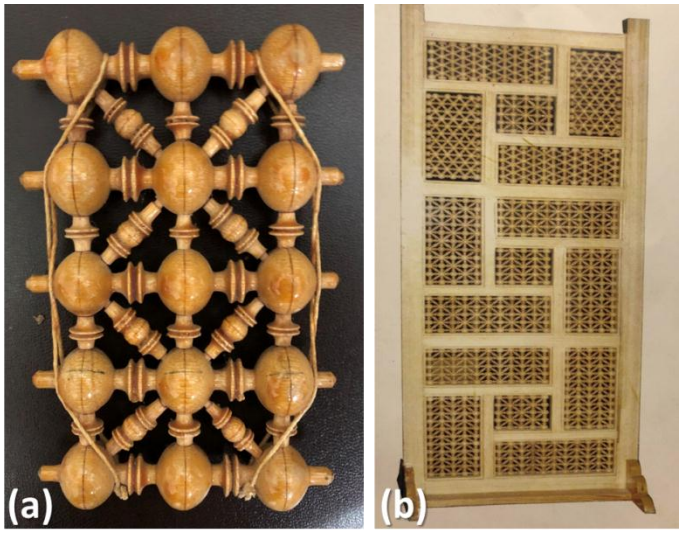


*Figure 7 Date palm midribs Arabesque. (a) Arabesque unit. (b) A decorative partition made from Arabesque units connected with wooden frame.*

### *4.4. Prefabricated Date Palm Midribs Partitions*

One of the more developed forms of employing prefabrication in date palm midribs products is partitions panels, which belong to the panelized construction systems category, according to the prefabrication categorization suggested by [2]. While most of the light huts and fences in rural areas in Egypt depend on whole date palm leaves planted vertically in the soil and tied horizontally to tree branches posts, as shown in Figure 8 [9], more developed garages can be found in the western oases, especially in Dakhla oasis which is considered as one of the major date palm related handicrafts centers in Egypt [10]. In such garages, movable panels are made using timber frames to which grids of date palm midribs are nailed down. These panels are prefabricated in makerspaces, with the addition of the needed openings and ornaments, and then the panels are moved to the construction site to be nailed down to a shallow brick foundation and to the simple timber post and beam structure of the garage. These movable panels can be partially prefabricated offsite and completed after installation or fully completed offsite. Partially prefabricated midribs panels as shown in Figure 9, consist of one sloped set of midribs that are nailed to a simple timber frame in the makerspace, upon which another set of midribs are fixed onsite with the opposite slope as well as horizontal belts of midribs.

*Figure 8 A traditional whole date palm leaves fence.*

*Figure 9 A garage made from prefabricated date palm midribs panels in Dakhla oasis.*

On the other hand, fully completed prefabricated panels are usually fixed to denser timber frames to produce more organized inclination and spacing between midribs, as shown in Figure 10. Movable date palm midribs prefabricated panels are unique to Dakhla oasis [10].

*Figure 10 A timber framed date palm midribs fence in Dakhla oasis*

Another example of light prefabricated partitions can be found in Aswan. It depends on date palm midribs mats that are bound together using steel wires to produce a sheet-like panel of date palm midribs that can be moved to site and fixed by steel wires to simple steel pipe frames, as shown in Figure 11.

*Figure 11 A steel wire-threaded date palm midribs partition in Aswan.*

### *4.5. Date Palm Midribs Strips Boards Cladding*

Recent innovations focused on producing industrial prefabricated cladding panels using date palm midribs [12]. In a project launched by the Egyptian Society for Endogenous Development of Local Communities (EGYCOM) in Al Qayat village in Minya, it was decided that standardizing the shape of the midribs and establishing basic production procedures would allow for a controlled quality mass-production that is required to introduce these products as substitute for imported conventional cladding materials [24]. Date palm midribs are skimmed and pealed using Simplex stripping machines in order to transform the midribs into a regular square cross-section strips, as shown in Figure 12a [24]. These strips are then bonded using resins in order to produce boards or blocks of regular cross-section. These boards are cut to create paneled units with the needed dimensions, as shown in Figure 12b. These paneled units are used usually as parquet panels or wall claddings [12]. Flooring and

parquet panels are usually coated with veneers to withstand friction, as shown in Figure 12c. On the other hand, the varied colors of the peeling strips enriches the aesthetical quality of the produced claddings where only transparent varnishes are applied over the claddings preserving the natural different tones of the midribs, as shown in Figure 12d. However, the final dimensions of the produced board are restrained by the available lengths of the strips, which limit the usage of the boards to be cladding fixed to a supporting frame system.

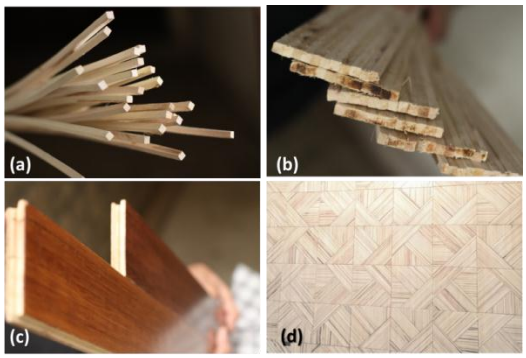


*Figure 12 Date palm midribs strips boards. (a) Date palm midribs strips. (b) Date palm midribs strip boards. (c) Veneer coated parquet panel. (d) Wall cladding panels.*

*4.6. Comprehensive Analysis*

Through scanning examples of prefabrication employments in traditional handicrafts and architecture, it can be noted that whenever the concept of prefabrication is adopted in a certain traditional practice, the final products tends to be more developed and sophisticated. As the production process takes place exclusively in specialized makerspaces by highly skilled workers, the quality of the production and the advancement of detailing can be achieved through the compilation and focusing of the ingenuity of the workers in each community. Thus, prefabrication reforms one of the different manifestations of the next step of the natural evolution of the technical heritage of date palm midribs utilizations.

In addition, the majority of the previous prefabrication-based date palm midribs applications are more inclined towards the production of a versatile panel. However, timber frames were almost necessary for the final assembly of the prefabricated units to enhance the sturdiness and fineness of a partition. On the other hand, using latticing technique in traditional date palm midribs crates and furniture sustained the stability and the orderly character of the prefabricated midribs units without the need for imported timber frames or backing systems. Depending on the perforations of the midribs grids preserved the peripheral layer of the midribs which are responsible for their overall strength. In addition, although standardizing the midribs into strips and bonding them with resins provided stiff boards [24], available dimensions are much smaller than to stand on their own without a dense supporting frame system. Therefore, latticing and preserving the natural peripheral area of the midribs, if well exploited, can help improve the structural and formalistic integrity of a prefabricated date palm midribs unit, while minimizing the use of timber framing and excessive machinery. The main challenge here is to design the lattice to fit the natural channels of stresses flowing through the fiber bundles along the midribs under external loads, as shown earlier in 4.1.

## 5. Prefabricated Date Palm Midribs Enclosure Wall Panel

*5.1. Conceptual Design*

This paper represents the first step to experiment the limitations and potentials of date palm midribs lattices in producing prefabricated enclosure wall panels via prefabrication, through the design of a single leaf non-loadbearing wall cladding panel, which does not require a supporting timber framing system. The developed panel must be capable of withstanding its own weight, lateral and wind forces. Accordingly, the design was based on lessons learnt from the previous examples as follows:

- If a lattice consists of a set of midribs driven through the perforations of a perpendicular set of midribs, then the imperforated set should be the vertical midribs in the lattice. That is because the wind driven stresses on the wall panel are to be transferred down only to the foundation and upper fixation to the structural system, as the panel must be structurally safe without the use of a supporting frame system behind the panel. Therefore, the fiber bundles channeling these stresses must be continuous and safe from perforations.
- The proposed dimensions, as shown in Figure 13, are selected according to the minimal distance between perforations where the internal structure of the midribs would remain intact. As reported from various crate makers, spacing between perforations should not be less than 15cm, otherwise, the internal fibers will begin to dismantle decreasing the coherence of the perforated midrib.
- In the back piece of a date palm midribs chair, side diagonal bracings are crucial in order to redistribute lateral forces parallel to the plane until they reach the chair legs. Similarly, the panel must have side bracings to transfer non-uniform loads to the vertical midribs.
- Depending on resins was crucial to bond the midribs together, as in the boards cladding in 4.5, to provide a stiff board. On the other hand, depending on the lattice joinery requires the addition of secondary horizontal binds between the verticals to resist against shear forces which can cause dismantling.

Given these lessons learnt from the previous examples, the detailing of the design, shown in Figure 14, consists of main vertical midribs that pass through main perforated horizontal midribs, as a basic latticed grid. These main vertical midribs are the main structural elements that transfer the own weight of the panels and wind to the main structural frame to which the panels are fixed along the top and the bottom of the panel. Diagonal lattices are added to efficiently redistribute non-uniform wind loads, as shown in Figure 14a. Secondary horizontal midribs are

added to strengthen the resistance against shear forces. These secondary horizontal midribs are fixed through secondary vertical midribs, which are driven adjoining to the main imperforated vertical midribs through the perforations of the main horizontal midribs, as shown in Figure 14b.

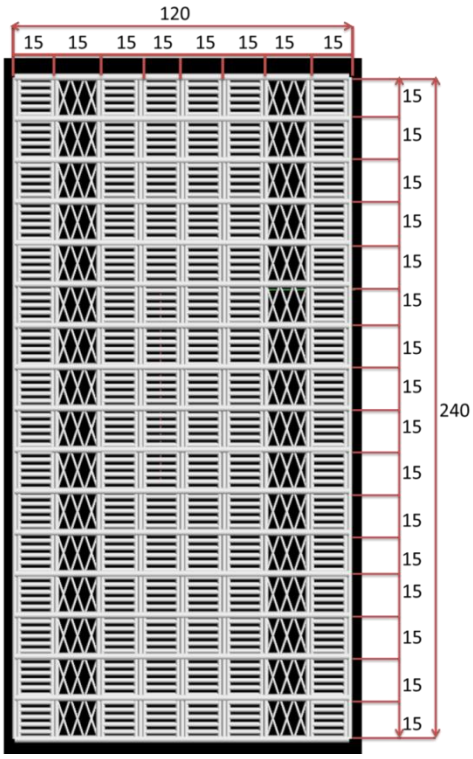


*Figure 13 The proposed prefabricated date palm midribs enclosure wall panel*

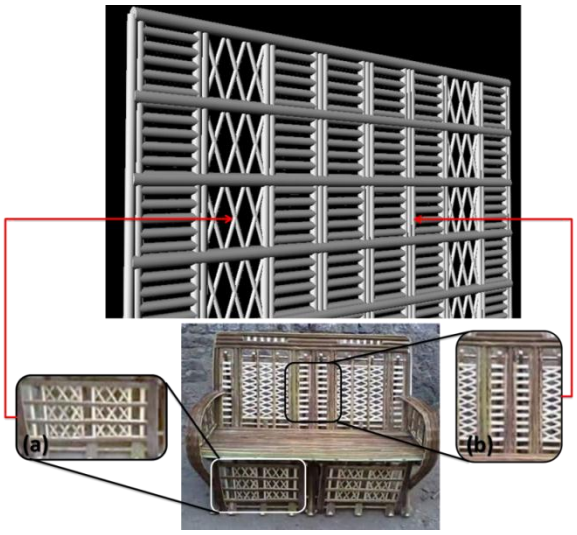


*Figure 14 The details of the prefabricated date palm midribs enclosure wall panel as inspired by a traditional date palm chair.(a) A diagonal bracing in the footing panel (b) The secondary horizontal midribs and the main vertical midribs in between 2 adjoining secondary vertical midribs.*

*5.2. Production Sequences*

The production sequences can begin from the middle and towards the sides as follows:

1. The set of the main perforated horizontal midribs are laid on the ground with the predetermined spacing.
2. The first main vertical midrib is driven through the middle of all the main horizontal midribs, followed by the 2 adjoining secondary vertical midribs.
3. The perforations in each secondary vertical midrib will host the secondary horizontal midribs from one ending, until the next secondary vertical midrib is driven through the main horizontal midribs.
4. The second main vertical midrib is driven through the main horizontal midribs, followed by the next adjoining secondary vertical midrib on the outer side, and the rest of the procedures are repeated and mirrored.

After completion, the panel can be transported to the construction site, where it can fixed along the top and the bottom side to the structural system of the intended building.

*5.3. Structural Analysis*

Mechanical properties obtained from [25], were defined into SAP2000, a Finite Element Method (FEM) software to determine the structural performance under own weight and wind loads according to the Egyptian code, as shown in Figure 15a. The developed panel was restrained at the top and the bottom, as it was proposed that in real life the panel would be fixed at the top to a structural beam, and at the bottom to the structural footing. The results showed that the deformations were recoverable, as shown in Figure 15b, and the design of the cross-sections was safe, as shown in Figure 15c.

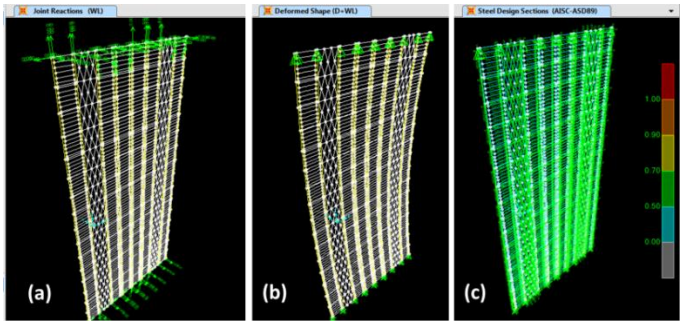


*Figure 15 Digital analysis of the prefabricated date palm midribs enclosure wall panel under own weight and wind loads. (a) The applied wind loads. (b) The deformed shape. (c) The design of the cross-sections is safe.*

## 6. Conclusions & Recommendations

Prefabrication is the new construction trend of the modern age. Incorporating technology is crucial now to guarantee a stable level of quality in mass-production[26]. The paper argues that strengthening the adoption of prefabrication into local materials craftsmanship can help secure the passage of their precious technical heritage to the future, especially with the presence of evidences that confirm that the idea of prefabrication has been already adopted in several traditional date palm midribs

handicrafts and architectural applications. Accordingly, the paper introduces a novel non-loadbearing enclosure cladding wall panel depending completely on date palm midribs. The panel developed in this paper is a valuable contribution to sustainable and natural building materials research field due to the following factors:

1. The need for timber supporting frame system behind the panels is reduced than in the case of the traditional prefabricated partitions discussed previously in 4.4, where timber frames are necessary to hold the midribs together. The usage of timber framing is minimized to act as the main structural system by which the panel is supported only at the top and the bottom. This aspect is highly critical in countries where local timber is not widely available.
2. The dependence on the traditional latticing technique provides a new field at which crate makers and furniture craftsmen can invest their skills and expand their market by producing wide-range versatile panels and partitions.
3. This panel represents the first trial at establishing a standard set of production sequences for a midribs-based panel. This standard set can help maintain a steady level of quality, instead of the differentiated quality levels that can be realized in the panels, fences and partitions in 4.4. Hence, the concept of this panel can be taught, reproduced and rebuilt within an adequate consistency among craftsmen with varied skills.
4. Details and production sequences of this panel were mainly inspired by traditional date palm midribs chairs, which provide a direct proof of the structural integrity and the efficient workability of the design, as judged by experienced craftsmen who inherited this know-how for thousands of years.
5. Structural analysis of the design was undertaken using FEM software. The analysis indicated that the panel was safe under its own weight and wind loads with recoverable deformations.
6. The integrity and workability, validated by being directly derived from practical expertise, and structural stability, proven using FEM structural analysis, promote the panel to be used in various architectural applications, such claddings, partitions and light construction.

The full potential of this panel will be investigated in further research, where expanding the utilization fields of this panel can help regain the trust in traditional materials and enrich the market with local, cost-efficient and versatile alternatives to conventional imported claddings and enclosure wall panels.

## Conflict of Interest

The authors declare no conflict of interest.

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