


Article

Conservation of the Traditional Grain Mills in Dakhla Oasis, Egypt: Study of Mechanical Systems and Restoration

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Received: 11 September 2018; Accepted: 10 October 2018; Published: 17 October 2018



Abstract: This paper is the first study of traditional grain mills in Dakhla Oasis, Egypt, to ensure the sustainability of these traditional production systems while retaining their original function. In this sense, the aim of this study was to analyze the mechanical systems of the animal-powered traditional mills in Dakhla Oasis, which remain the key to figuring out the puzzle of how these mills work and produce flour. This is an original study that examines a sample animal-powered mill to be conserved; this sample old mill was selected from seven potential grain mills, after investigating each mill. This study provides the technical background and description of the selected grain mill in Dakhla Oasis, and describes its working and mechanical movement. In addition, the physical properties of the historic grain mill wood were measured (e.g., density, shrinkage, and hardness), using scientific techniques, to get some information about their properties. In this study, the methodology for grain mill conservation was based on a combination of the traditional experience of the old craftsmen and modern technology applications in the restoration and rehabilitation of animal-powered mills, in addition to the use of software programs in data analysis. Our results proved that the ancient traditional expertise of the old craftsmen and scientific techniques are the most appropriate methods for restoring and preserving animal-powered mills, which include the determination and rework of the mechanical movement between the wooden gear wheel and millstones. Finally, this study gives an in-depth look into the practical scientific restoration of animal-powered mills in Egypt and other countries.

Keywords: Dakhla Oasis; grain mills; mechanical systems; animal-powered; traditional expertise

1. Introduction

The milling of grain has been done since the dawn of history. Grinding was mostly women's work and only the amount of meal needed each day was prepared. They fought tedium by singing chants such as "May the gods give my master strength and health" [1]. The history of the ancient grain mills in Dakhla Oasis is closely related to that of the bread industry. Wheat, barley, corn, and other grains have been milled there for the purpose of baking; they are the main source of food in Dakhla Oasis, as it is a purely agricultural environment. Egyptian oases house various known milling machines, including the primitive form and the grain mill. The grain mill is based on the mechanical movement between a wooden gear and millstones and is animal-powered.

Dakhla Oasis lies in the New Valley Governorate in Egypt, 950 km from Cairo, and between the oases of Farafra and Kharga, as seen in Figure 1. There are several cultural heritage sites made of mud brick in Dakhla Oasis, such as Al-Qasr [2], as well as charming mud-brick housing in the fortified town and the city of Balat. Moreover, there are seven similar animal-powered historical mills in Dakhla Oasis that we need to know about, and what to do with each one.

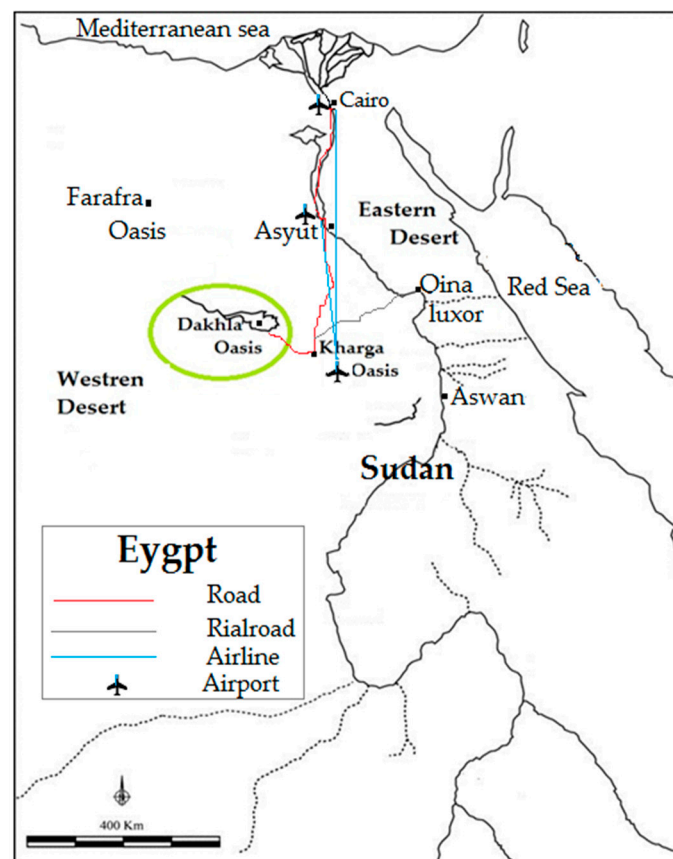


Figure 1. Map of Egypt which shows Dakhla Oasis: Located 189 km west of Kharga Oasis, Egypt (by author).

Historical Background of Grain Mills in Egypt

Grain mills in Egypt, and the old towns in which they sit, have long been a part of Egyptian heritage. However, the mill which was found in the archaeological area of al-Tarqah, in Upper Egypt, and used in grain milling for more than three thousand years, is one of the oldest and most famous mills. The length is 48 cm, and there is a gap at the top, which is used to grind the grain. There are a few animal-powered mills used to grind grain, including the Abu Shahin mill, which was established by Osman Agha al-Tobji in the twelfth century AH, in Rashid City, north of Cairo, in addition to animal-powered mills in Dakhla Oasis..

Grinding grain into flour began early in mud-brick houses in Dakhla Oasis, Egypt, whereby women used a stone bowl (mortar) made of a native palm trunk and a long stone (pestle) made of acacia wood to make flour for bread, as those shown in Figure 2.

Then began the use of the handmill (see Figure 3). The handmill is one of the most primitive utensils found in the world. As we have learnt from wooden models found in Egyptian tombs, now preserved in the Museum of Gizeh in Egypt, the way these utensils worked was by placing one round flat stone on another stone of the same kind using the power of the human hand—that is to say, the handmill [3]. Luckily, there are still a few of the old hand-powered mills for grinding grain available in Dakhla Oasis. Made during the Mamaluke and Turkish eras, this mill generally consisted of a couple of hard stones, the upper stone convex from the sides, 98 cm diameter, 20 cm thickness with a 11 cm hole in the center, and a lower fixed stone with a wooden peg at the center (see Figure 4).



Figure 2. Ancient mortar and pestle.



Figure 3. Showing what a handmill is and how it could be used in making flour. (Alia Hussein 1965). (DH/Alia Hussein, 1965) [4].



Figure 4. Old handmill in Dakhla Oasis.

A mechanism of the grinding process in Dakhla Oasis has evolved into the type of animal-powered mill since the Ottoman era. Consequently, the Abu Ishmael mill, one of the landmarks of the town of Al-Qasr, was built during the Turkish era in 1198 AH to be used to grind grain for all the people, according to the wooden lintel over the entrance. In addition, we have the Sheikh Ahmed mill (see Figure 5) and El-Prince Mill (Figure 6), which is one of the largest mills in the village of Balat. The millstone in this mill is one of the biggest millstones in Dakhla Oasis, with more than alternatives for a millstone, as seen in Figure 6. It had a presence in the production of flour and was built during the 4th century AH, according to the wooden lintel over the entrance.

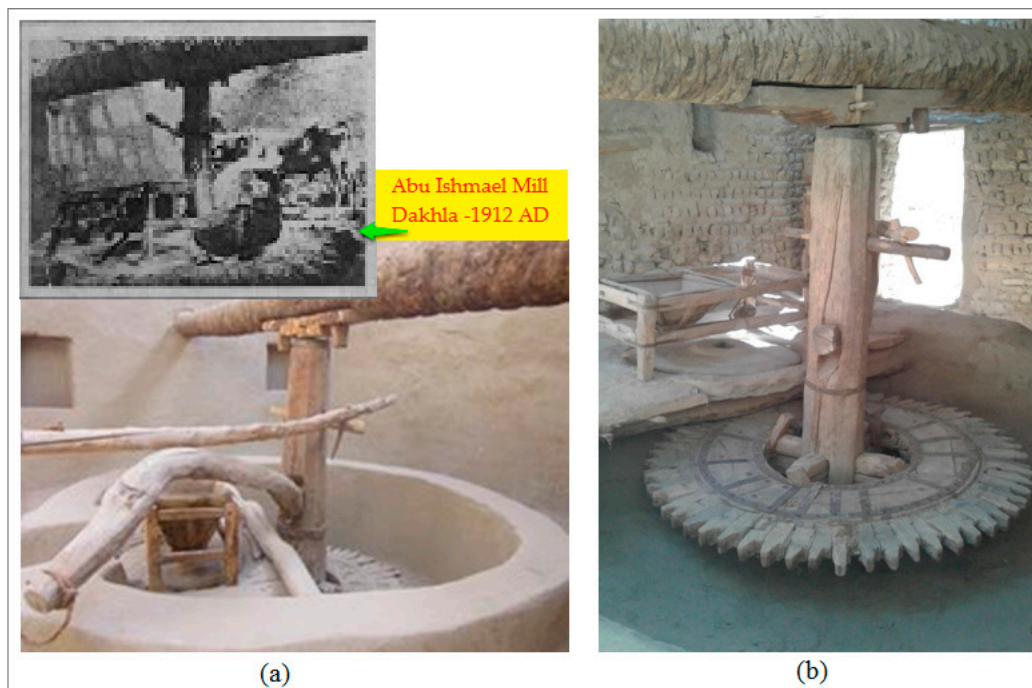


Figure 5. (a) Abu Ishmael mill. (b) El-Sheikh Ahmed mill.



Figure 6. El-Prince grain mill.

2. Materials and Methodology

2.1. Description and Technical Background

The simplest type of animal-powered mill is the gearless stone mill, known in antiquity as the “hourglass mill” [5]. The animal-powered mill in Dakhla Oasis is a machine for converting the energy of animal-powered into useful forms of mechanical movement, usually in a grain mill. A grain mill consists of a wooden gear wheel (Perimeter = 6.20 m; Radius = 95 cm) (usually constructed from acacia wood), with sixty wooden sprockets (Length = 31 cm; Width = 4 cm). The wheel is actually based on a wooden cross and mounted horizontally on a vertical shaft (a drive shaft) (Length = 2.35 m; Width = 27 cm), with a wooden finger at the hole under the center of a large hollow wheel, with its base pivoting on a wooden concave base set in the middle of a stone base. A drive shaft is rotated in a hole inside a “wooden balance” (Length = 91 cm; Width = 0.22 cm) between the drive shaft and the wooden palm trunk which bears all the parts of the mill (Length = 6.10 cm). In the middle of the drive shaft, there is a wooden rod varying in length from 3 to 4 m, with a wooden stick placed on the bull’s necks, rotating in a circular track of mud-brick (Radius = 1.5 m; Height = 70 cm).

The wheel is attached to one vertical driven gear, with 4 wooden teeth under the millstones; it consists of two circular stone, the upper stone “runner”, with a 43 cm perimeter, usually a little smaller than the lower stone, with Radius = 55 cm. The upper one has a slightly convex upper surface and rotates, while the lower one is normally fixed and attached to the vertical gear (pinion) by an ax. The vertical gear is based on a “nether balance” in its concave gap and jointed to the upper stone with a sword.

The grains pour into the millstones wooden box (*Hopper*), which is fixed above them; it comes down to the millstone for grinding. Finally, flour comes down to a pot of pottery in a hole spanning a total depth of 35.50 cm (9.8 inches) called “Flour Home”.

2.2. Methodology

The protection of cultural heritage is one of the most significant issues in the world. One of the most important issues in protecting cultural heritage is the difficulty in providing financial support. In fact, the preservation of the cultural heritage of the Oasis, including its traditional architecture and local structures, is the responsibility of international organizations interested in cultural heritage and workers in the field of cultural heritage protection. Moreover, the methodology of the research paper is based on the extent of compatibility between modern theories in the field of energy production

and the laws of gearing with the traditional experience of the old mill manufacturers in Dakhla Oasis, in addition to different scientific methods in restoration and rehabilitation. Furthermore, the study is based on the documentation of the human skills of the old craftsmen; most of these were no longer alive, except master craftsmen. Mr Mebarz Madani Mansour Issa Allam Al-Najjar, ninety-eight years old, is the last descendent of the Allam Al-Najjar family in Dakhla Oasis; this family made the grain mills and the wooden lintels in the towns of Dakhla Oasis. In addition, we adopted this traditional experience as a scientific and practical reference in the field of the grain mills restoration.

2.3. Mechanical Systems of Traditional Animal-Powered Mills

Most visitors of old grain mills do not know the exact process of the millstones. There are several mechanical movements related to starting and stopping the old millstones [6].

A brief visual summary of the mechanical system of traditional animal-powered mills is provided in Figure 7. Mechanical systems in the grinding process depend on the main mechanical movements of the traditional grain mills in Dakhla Oasis, from one part to another. A mechanical system in Dakhla Oasis grain mills uses animal power to accomplish a task that involves forces and movement in symmetry relationships between the hollow wheel (5) and the pinion jointed to the millstone, to achieve the desired forces and movement. In the beginning, the “miller” would open a bowl of grain and pour it into the millstone hopper (1). As a matter of fact, the first mechanical movement is based on the main drive shaft (3), a massive acacia pole, thus turning animal power into a main mechanical movement on its long axis attached to the wooden wheel, the drive shaft rotating freely with a wooden rod (4); this rod, placed on the bull’s neck, rotates in a circular track (2). The second mechanical movement is based on striking the pinion (12) under the millstone with a wooden wheel; such a wooden wheel would create great torque stresses for the pinion and the upper stone. The third mechanical movement is based on the upper millstone (6); the upper stone is rotating at 15 rpm, under steady steps, average for the bull, at a rate of 1 rpm of the wooden wheel in an anticlockwise direction. Finally, the last mechanical movement is based on the sword (9) attached to a “nether balance” (10) and the upper stone, in order to control the upper stone up and down. Such a process is needed in the production of flour for the desired grind grade.

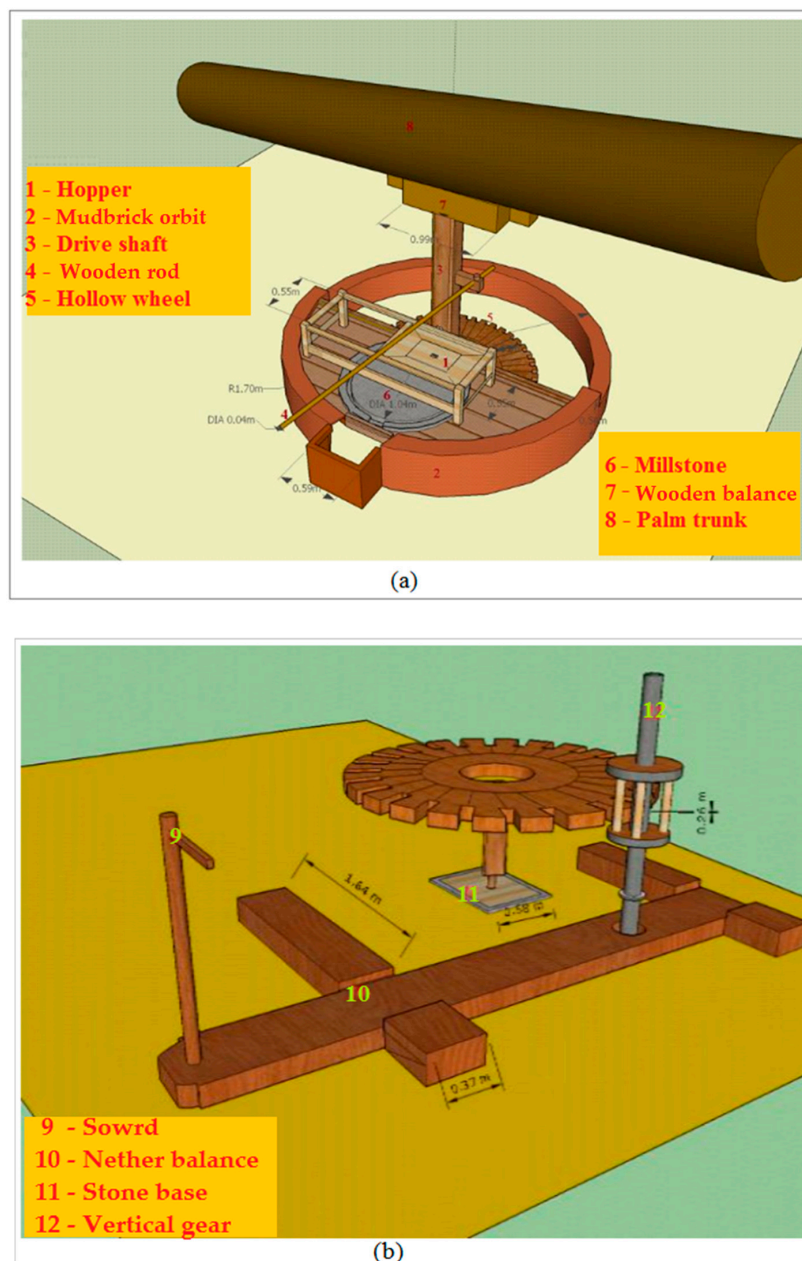


Figure 7. (a) The major mechanisms of the grain mill. (b) Schematic of the elements of the working system.

2.4. A Case Study of the Current Status and Deterioration Factors of Grain Mills in Dakhla Oasis

The study examined the current status of 7 grain mills (see Figure 8) in Dakhla Oasis. Particularly, 6 of them are located in archaeological cities and registered as Islamic monuments at the Egyptian Ministry of Antiquities. In addition, 1 grain mill is located within the ruins of the ancient historical village in Dakhla Oasis, but not registered in the Islamic monuments at the Egyptian ministry of antiquities.

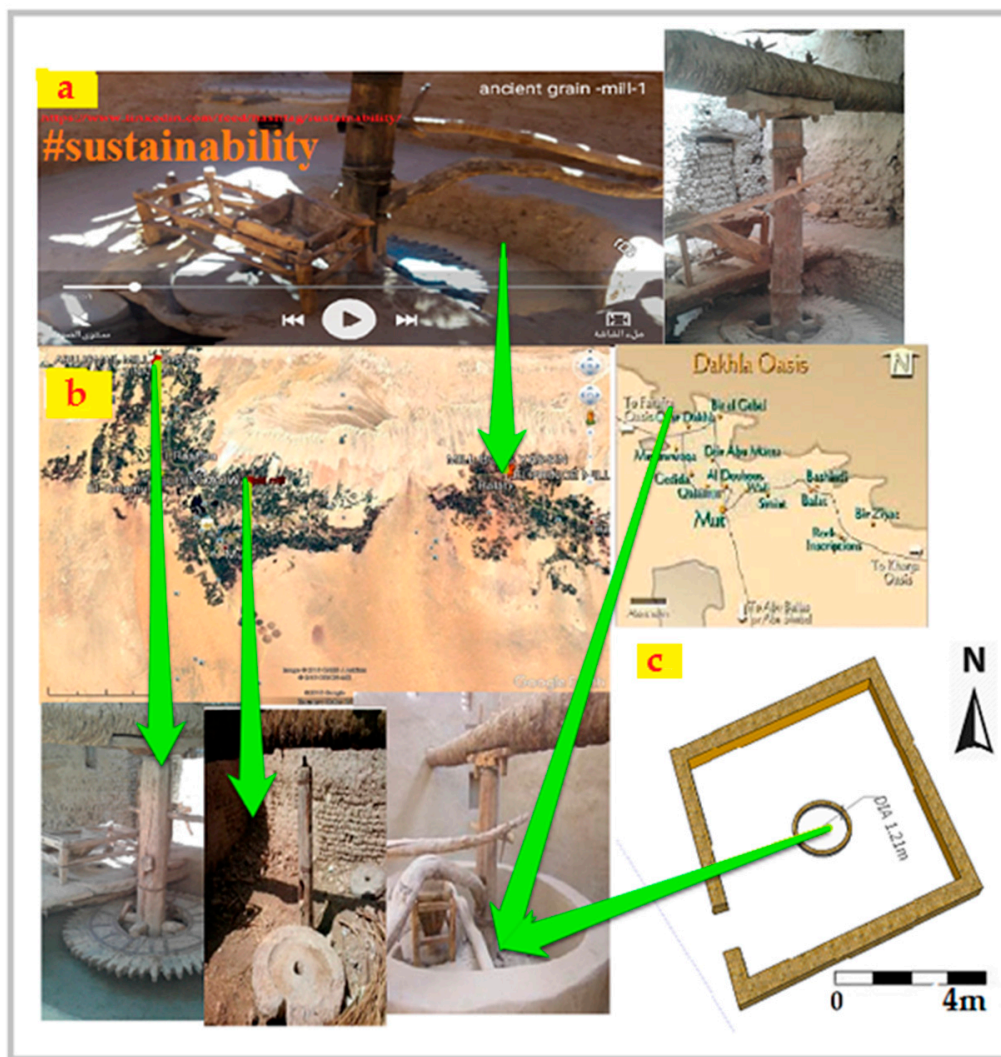


Figure 8. (a) Photos of a short movie show on Yasser Ali's profile on LinkedIn (b) Location of the grain mills in Dakhla Oasis on the map of Dakhla Oasis on the Google Earth website. (c) Ground plan of Abu Ishmael's grain mill.

The “Best” grain mills are grain mill No. 1, named: “Abu Ishmael's grain mill” in the ancient city of Al-Qasr, after restoration by the Egyptian Ministry of Antiquities and Social Fund for Development in 2015. Grain mill No. 2 is named: “El-Prince grain mill” in the ancient city of Balat after restoration by the Egyptian Ministry of Antiquities in February 2017.

The “damaged” grain mills are grain mill No. 3, named: “El-Zinni grain mill” in Qasr, and grain mill No. 4, named: “Sheikh Ahmed grain mill”, also in Qasr.

Finally, the “ruined” grain mills are grain mill No. 5, “without name”, in the village of Al-Hindaow, grain mill No. 6, named: “Abu Yassin grain mill” in Balat, and grain mill No. 7, “without name”, in Qasr.

The evaluation criteria of grain mills in Dakhla Oasis that were identified by visual and scientific methods are based on the mechanical system that was damaged or not, restoration and conservation works, various degrees of damage, etc.

Fluctuating temperature, biological deterioration, and human activities are the main deterioration factors of grain mills in Dakhla Oasis.

Temperature in Dakhla Oasis can rise up to 50 °C during the day. At night, temperature can drop to below 15 °C; there is great variation in temperature during the day and night. In conservation science,

temperatures certainly play a large role in the damage to the grain mills' wood. High temperatures produce a thermal energy; this leads to dimensional changes in physical properties, such as flexibility, rigidity, and the development of biological pests.

With regard to the biological causes of wood deterioration, the main wood-destroying organisms in Dakhla Oasis are termites.

Termites are soft-bodied social insects which feed on cellulose, although the gastric juices of most species do not contain celluloses. The presence of cellulose-digesting protozoa in their hindgut enables them to utilize wood as food. Because these one-celled animals play such an important role, termites are indirectly vulnerable to high temperatures and oxygen pressures [7].

In the opinion of the author, the relationship between human activities or man-made damages and local structures is mutually beneficial; more attention to the importance of local structures is given when a person derives a direct personal benefit. Therefore, the interests of citizens with grain mills in Dakhla Oasis remained conditional on their production of flour.

As a final point, lack of cultural awareness causes severe damage to grain mills in Dakhla Oasis; grain mill structures for grinding grain are exposed to mechanical deterioration due to loads and stresses resulting from the wrong use of the mill, as well as using the wooden structures for other purposes.

2.5. The Scientific Method in the Restoration of Animal-Powered Mills in Dakhla Oasis

There is no doubt that most countries around the world and the international organizations interested in preserving cultural heritage seek to restore traditional mills. Furthermore, once a mill has been restored wrong or incorrectly, it may be almost impossible to have it restored right. There are a great number of mills that have been restored incorrectly. These mills were just not that way originally [8].

The basic procedure for the restoration of old animal-powered mills starts with an in-depth look at its mechanical system philosophy, which lies behind all the difficult decisions. This is followed by an outline of the management of such a project and a description of all the other aspects and activities that are necessary for the successful outcome of any restoration project [9].

The society for the preservation of old mills (SPOOM) [10] shares common interests with the International Molinological Society (TIMS) [11] in promoting interest in old mills.

David H. Jones is a Senior Lecturer in TIMS, who says: "What is the right way to preserve a mill? If we are taking this literally, we need not discuss it at all, because it does not exist. While there are plenty of wrong ways of treating mills, there is no single 'right' way, every preservation must be seen as a special case to be decided on its merits" [12].

To begin with, it is relatively easy to say there were animal-powered mills in Europe, Australia, the United States, and other countries during the nineteenth century. Sometimes, people interested in old animal-powered mills forget the formal documentation methods entirely; sometimes they don't look at the writing about their experiences. At the same time, restoration experiences may not always be interchangeable. Based on these assumptions, sharing of practical experience and scientific expertise may be limited. However, to this end, the restoration project of the Volckerinckove horse mill in France [13] (see Figure 9) is probably the closest model to other restoration experiences. Alongside all this tangible evidence, the mechanical movement is the basis of the restoration process in each animal-powered mill.

Based on the foregoing observations, the restoration project of El-Prince Mill in Dakhla Oasis could be considered a scientific-practical reference for the restoration process of animal-powered mills and their mechanical systems in Egypt and other countries (Table 1).

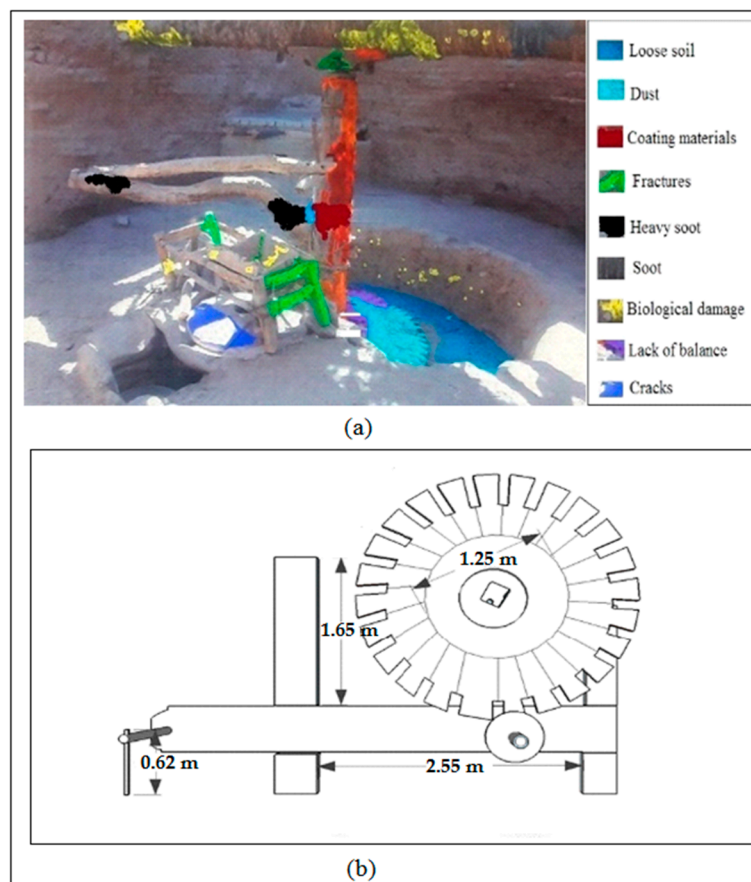
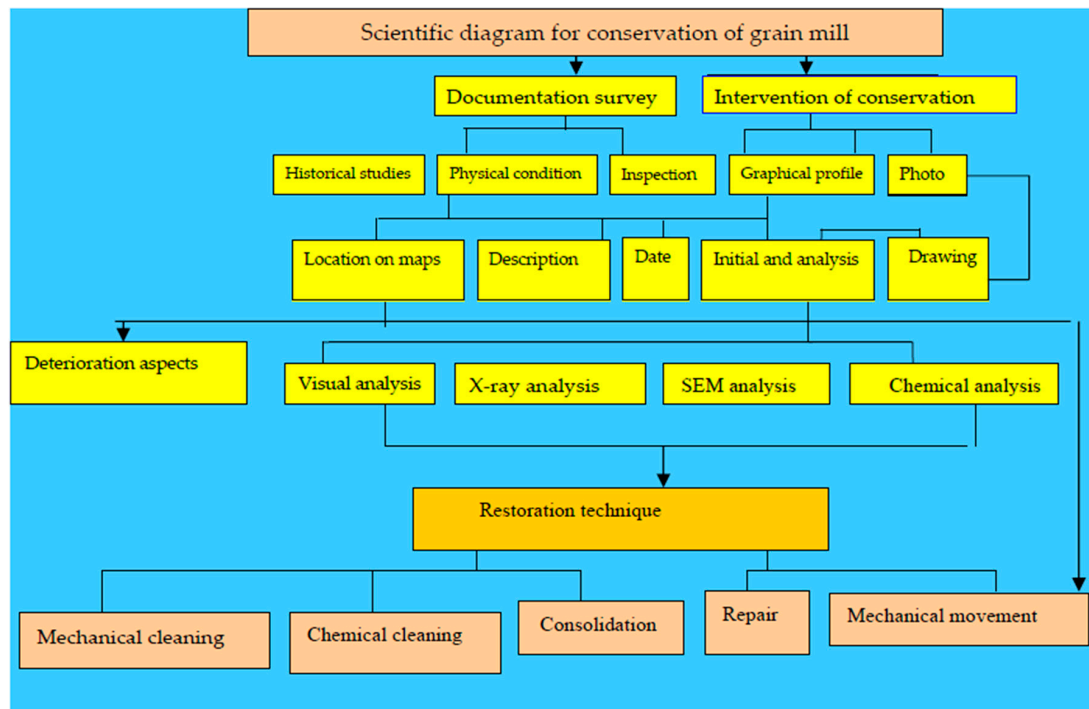


Figure 9. Comparison between the Horse-drawn mill of Volckerinckove in France and other animal powered mills in our Oasis. There are some copies in Belgium. Association Yser Houck rebuilt it in 2009–2010.

2.5.1. Scientific Documentation for El-Prince Mill

Quebec declaration pointed out that modern digital technology can be used efficiently and effectively in cultural heritage documentation [14].

In addition to artistic archaeological documentation, photographs were taken with a digital camera connected to a computer and video recorder. A “deterioration graphical profile” was designed by ArcGIS visualization software program in data analysis to evaluate the relationship between deterioration factors and deterioration patterns, as well as to choose the suitable conservation and interventions that should be applied. Additionally, an architectural documentation drawing was produced using SketchUp Pro 2016, to give an accurate visualization of the mill, including the details (see Figure 10).

Table 1. The Restoration Diagram of the traditional animal-powered mills.**Figure 10.** (a) Showing the front view of the El-Prince Mill after drawing a graphical profile by ArcGIS visualization, data analysis. (b) Top view of the lower parts under the millstone, by SketchUp Pro 2016.

2.5.2. Physical and Mechanical Properties of Selected Wood Species in El-Prince Mill

Acacia is a native wood in the El-Prince Mill. Three samples of damaged wood were examined in order to determine the physical and mechanical properties, and to choose the suitable conservation technique that should be applied. Consequently, the sizes of the samples are 3 cm × 3 cm × 3 cm, 2.05 cm × 2.05 × 2.05 cm, and 1.80 cm × 1.80 cm × 1.80 cm, respectively.

In Table 2, analytical results referring to the acacia wood are dark brown, hardwood, moderately dense, and fine-grained. At the same time, there is low moisture content, specific gravity, and volumetric shrinkage. Finally, Acacia wood has generally been considered suitable for restoration and conservation.

Table 2. Average values of physical and mechanical properties.

Sample Properties	No. of Samples		
	1	2	3
Density (g/cm ³)	2.05	1.08	1.05
Porosity (%)	0.21	0.15	0.12
Moisture content (%)	4.02	3.07	2.09
Shrinkage (tangential) %	0.32	0.15	0.07
Shrinkage (radial) %	0.22	0.12	0.01
Hardness (kg)	17.04	15.03	12.34
Stress (kg/cm ²)	15.0	431.8	12.45

2.5.3. Mechanical and Chemical Cleaning

For the purposes of mechanical cleaning, we used brushes, scalpels, and soft abrasives to remove the dirt, dust, and other surface deposits accumulated on wood species without any reach to the wood surface and without eroding parts of the cell walls. However, chemical cleaning with Ethyl alcohol (95%) to remove coating material achieved satisfying results, and this may need to be taken into account for the chemical compounds used in the invisible part. According to the result of several studies, Ethyl alcohol had the least influence on the surface of archaeological wood [15] (see Figure 11).



Figure 11. Cont.



Figure 11. (a) Mechanical cleaning. (b) Chemical cleaning. (c) After restoration.

2.5.4. Rehabilitation Wood Structures and Restoring a Mechanical Mill Movement by Local Milling Experts

As we see in Figure 12, the application of traditional expertise in rehabilitation and restoring the mechanical mill movement by local mills expert Mebarz Madani Mansour Issa Allam Al-Najjar could be summarized as follows:

- (a) The local expert adjusts the perimeter of the addendum circle. In fact, the addendum circle is a circle touching the outermost points of the sprockets of the wooden gear wheel (pitch circle). The local expert uses a wooden tool from a palm branch. The wooden tool end remains fixed at the circular track of the grain mill, and in front of a fixed point at the other end, the wooden gear rotates to determine the addendum circle from the correct perimeter [$P = 6.20$ m].
- (b) Next, use an awl to punch a wooden scantling in the center between every two gear sprockets to adjust the proper spacing between the wooden gear sprockets. This spacing is a preset distance on the pitch circle. Nine centimeters is just the right spacing in every space between the wooden gear sprockets. As an illustration, the old craftsman used a wooden measuring instrument (closer to the Vernier caliper today), designed according to the proper spacing between the wooden gear sprockets and the beginning of the pinion tooth when it starts running.
- (c) Reinstall the pinion gear down on the surface of the millstone to 90° vertically and rotate 90° clockwise to transfer power to the upper millstone.
- (d) Reinstall the lower millstone (radius = 55 cm). In addition, reinstall the upper millstone and install it with the pinion gear by an ax.
- (e) Animal-powered mills in Dakhla Oasis are made almost entirely of wood; after a long while, these wooden parts can be worn down. Old Craftsman can often replace them with other parts in

a like-new condition with the same dimensions, or sometimes tweak the shape of the wooden gear sprockets. Old craftsmen are actually famous for offering a lifetime warranty on grain mills in Dakhla Oasis.

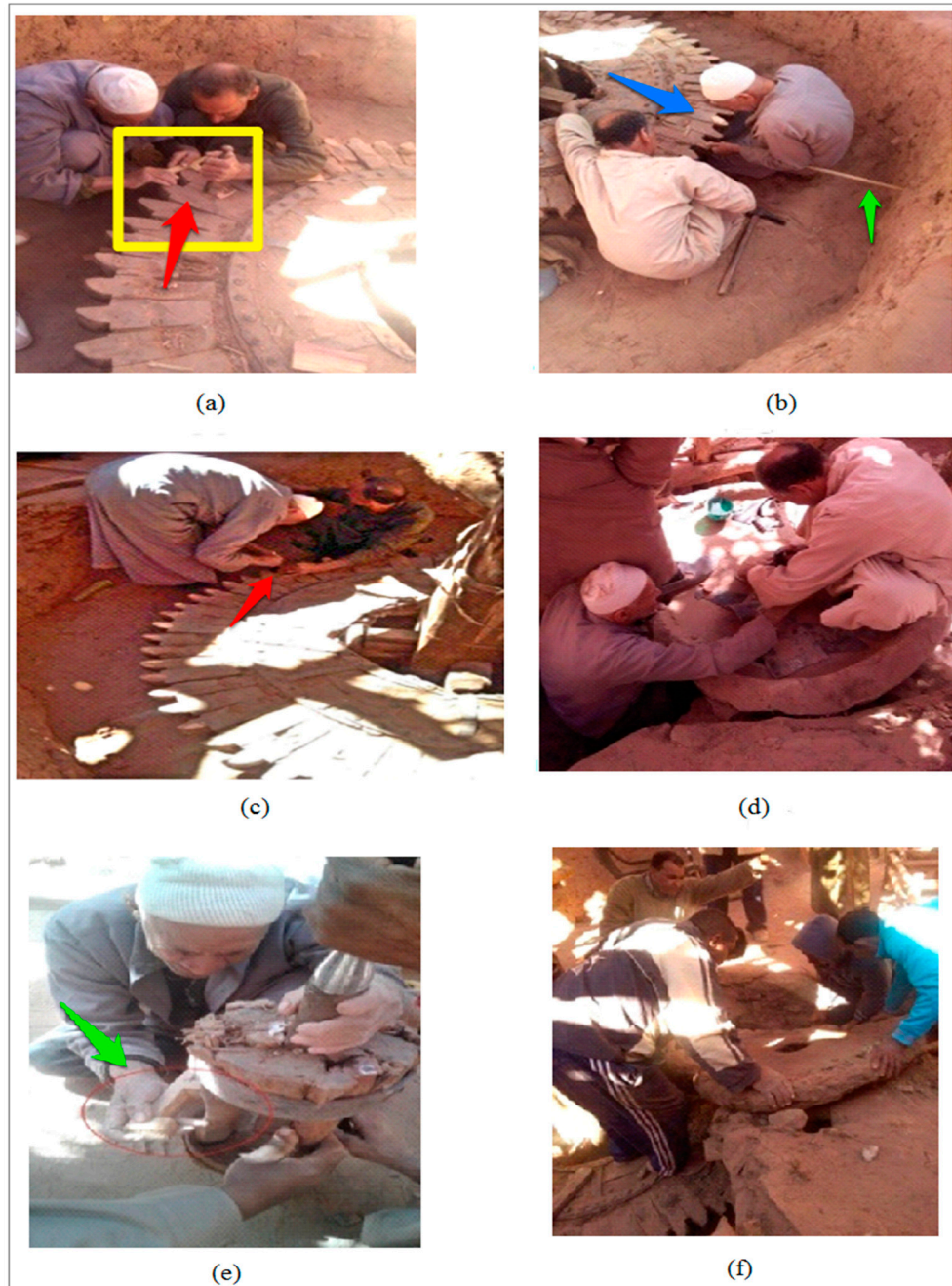


Figure 12. (a,b) Adjust the distances between the wooden Sprockets. (c) Adjust the perimeter of the Addendum circle. (d,e) Reinstall the vertical gear. (f) Reinstall the lower stone of the millstone.

3. Results and Discussion

Animal-powered mills in Dakhla oasis are an outstanding example for the beginnings of the old mill manufacturers' knowledge of mechanical engineering and gears. Indeed, in mechanical engineering, as shown in Figure 13, it is possible to say "these are the simple gears". Particularly, wooden gear wheel No. 1 is called the driver and vertical gear No. 2 is called the pinion.

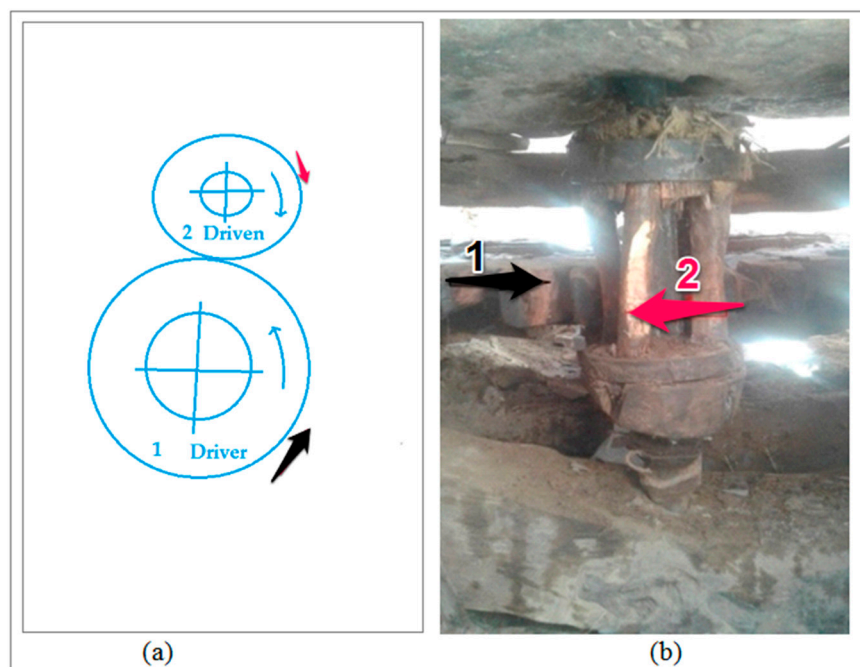


Figure 13. (a) The driver and the driven gear in mechanical engineering. (b) The driver and the driven gear in animal-powered mill.

Let N_1 = Speed of driver (rpm) [16].

N_2 = Speed of driven in (rpm)

T_1 = Number of teeth on gear 1

T_2 = Number of teeth on gear 2

Train Value = $\frac{N_2}{N_1} = \frac{T_1}{T_2}$ [17].

Train Value = $\frac{\text{speed of driven}}{\text{speed of driver}} = \frac{\text{No. of teeth on driver}}{\text{No. of teeth on driven}} = \frac{60}{4} = 15$

It should be noted that the ratio of the speed of the driven to the speed of the driver is known as the train value of the gear train.

The working speed for most draught animals is about 1 m/s (3.6 km/h, 2 mph) [18]. Therefore, calculations of revolution per minute (rpm) in the Al-Prince mill, according to Kent's Mechanical Engineers Handbook 12th Edition [19], are as follow:

Average of cow speed = 1 m/s, diameter of cow path = 9 m, diameter of millstone = 86 cm. When, in fact, the velocity of millstone: $W1 = V/R = 1/15 = (0.666 \text{ rps}/6.35 \text{ rpm})$

According to that, the Mechanical System in animal-powered mills in Dakhla Oasis is as follows:

Free "software" of any animal-powered mill is the mechanical mill movement that transfers animal power into motion that can be transmitted to the "Hardware" of the mill or the structures.

When four sprockets of the wooden gear, which has sixty sprockets, are in its normal engaged position with pinion gear tooth (341.73 inches for everyone), they cause the wheel to revolve. This gives one turn of the upper millstone at the same time as the one turn of the wooden gear, which pushes the pinion gear. This gives a gear ratio of 15:1. For every one turn of the wooden gear, the pinion gear rotates 15 times.

Hence, the upper millstone would rotate at 0.66 revolutions per second (RPS) and at 95 to 100 revolutions per minute (RPM), as opposed to 6.35 revolutions per minute (RPM) for the wooden gear wheel.

Application of traditional expertise enhances the positive role of civil society in the protection of cultural heritage, with their experience in using mechanical engineering and mathematics. Adjusting the perimeter of the Addendum circle refers to the knowledge of the old mill manufacturers in Dakhla

Oasis on the tangent theory to a circle. A tangent to a circle is a line that intersects a circle in exactly one point (simply tangent), as explained in Figure 14 [20].

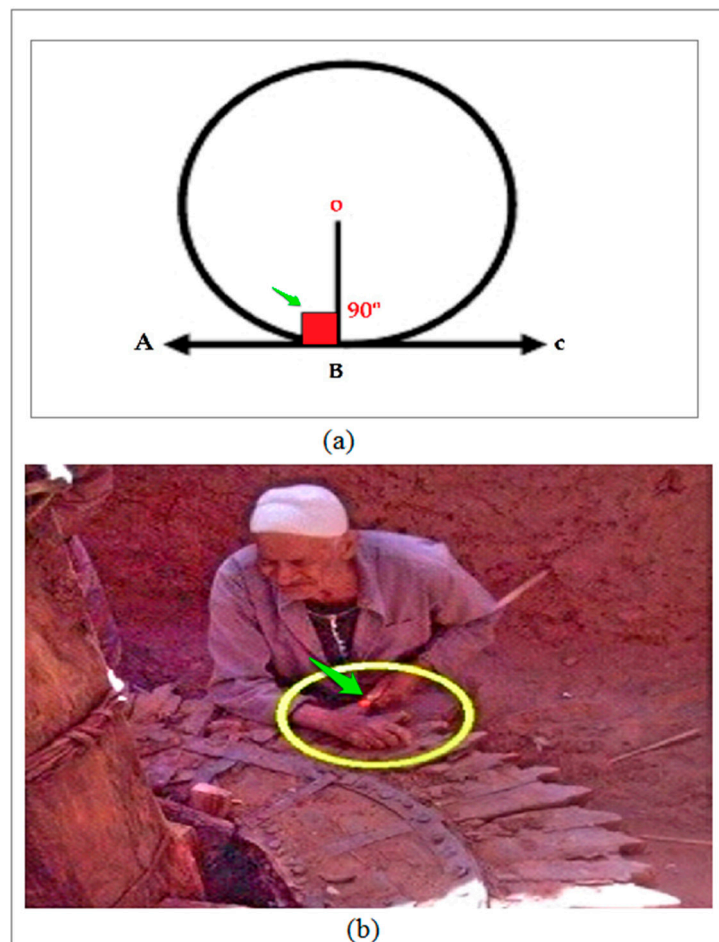


Figure 14. (a) Tangent theory to a circle. (b) The same tangent theory to a circle by local milling expert.

The old carpenters in Dakhla Oasis defined the culture of the reduction process of wheat flours, which express wheat flour particle size during the milling process and are composed of sizing, middling, and fine bran. That was before the knowledge of modern commercial mills, where the grain particles are being exposed to strong shear and pressure by the teeth of the cylinder surface towards a mill nip area. Thus, the old grain mill manufactures in Dakhla Oasis used the sword attached to the pinion and upper stone. It may be raised or lowered to alter the spacing between the millstones. Such a process is needed in the production of flour for the desired grind grade. According to this, recent scientific research has demonstrated the effectiveness of the reduction process on the biochemical and technological properties of wheat flours. It definitely affects dough properties and quality of bread [21].

The study of the mechanical systems of the traditional animal-powered mills in Dakhla Oasis adds background Information about the operating system of animal-powered mills in Egypt and other countries. Aside from these considerations, The target mechanism for this type of restoration ensures their survival as an integral part of the traditional cultural heritage and adding new quality of archaeological sites on the tourist map.

Restoration of the traditional grain mills in Dakhla Oasis played a dominant role in influencing society with regard to reinforcing social cohesion, strengthening the sense of identity. Moreover, grain mill restoration projects are committed to providing employment opportunities to all unemployed

youth. As a result, the conservation process trained local youths on techniques of rehabilitation of ancient grain mills, which were rehabilitated under the guidance of the Ministry of Antiquities and in cooperation with the New Valley Governorate (see Figure 15).

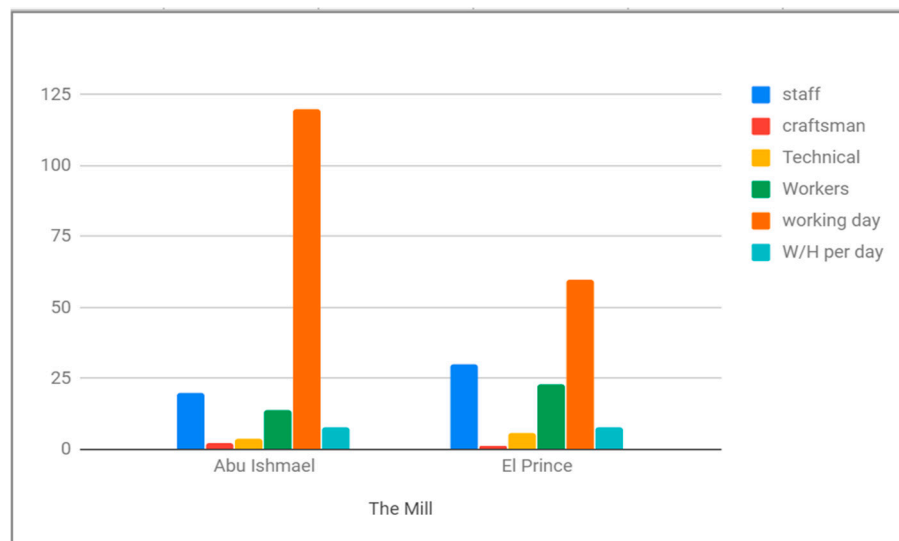


Figure 15. The diagram shows the number of participants in the restoration of the El-Prince Mill and Abu Ishmael Mill in Dakhla Oasis under the guidance of the Ministry of Antiquities and in cooperation with the New Valley Governorate.

In addition to these considerations, the grain mills in Dakhla Oasis and its traditional production structure attract local and foreign tourists in all stages of production, such as an olive mill built in the 1860s in Southern France and the water mill in the Antalya Province, Konyaalti County. Therefore, international organizations involved in heritage conservation must provide financial and moral support for the conservation of these rare mills.

4. Conclusions

The grain mills located in Dakhla Oasis in Egypt's New Valley are one-of-a-kind models, which were, at one time, used for the production of flour, one of mankind's staple nourishments. This study investigated the strategies used to rehabilitate these mills. The investigation was based on the hypothesis that the restoration of the mills should combine logical, cutting-edge conservation and preservation strategies with the traditional experience of old craftsmen. The research also examined the significance of promoting the undocumented experience of these craftsmen, as well as the utilization of modern technology in the restoration and conservation of cultural heritage.

The study presented a logical strategy for the conservation and protection of animal-powered mills and included an investigation of their mechanical systems, per the international charters governing restoration interventions. Additionally, all the scientific methods that could facilitate the examination and conservation of cultural heritage, as stipulated by the Venice Charter of 1964, were utilized.

The examples provided in this study delineated the significance of the grain mills as a feature of the cultural heritage of the Egyptian Oasis, which is portrayed as in shortage and unique. Financial assistance is needed from associations worldwide that focus on social legacy, as this would facilitate the reclamation of the grain mills in Dakhla Oasis.

The traditional technique of using animal power to transfer mechanical movement into millstones to grind wheat into flour can help us to understand the developments in the milling process to flour mills and industrial mills.

In regard to the economic and social dimensions, reclamation would promote internal and external tourism, increase employment opportunities for young people, and improve the sustainability of traditional experience in the restoration of traditional heritage.

On the whole, further research is needed to strengthen the mechanisms for the preservation of the grain mills in Dakhla Oasis, and this is expected to reinforce the instruments used in their conservation.

If we take a last look back at a mill story, we can see the “miller” was feeding the grain slowly into the millstones and could weigh 100 kg or more, then begin a wooden wheel powered by animal power striking the driven gear at the point from one to two, the height of the pinion, causing the “runner” to revolve in a direction opposite to grinding 300 pounds or more of wheat in an hour. Time to try out the traditional mills in Dakhla Oasis!

Funding: This research received no external funding.

Acknowledgments: We want to thank the protectors of civilization in Dakhla Oasis. In either case, a tribute to these men who are working in silence. Thanks to Mr. Haj Mebarz Madani Mansour Issa Allam Al-Najjar.

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

References and Notes

1. Montet, P. La vie quotidienne en Egypte au temps des Ramsès, Hachette 1946 Delwen Samuel, Bread making and social interactions at the Amarna Workmen’s village. *Egypt World Archaeol.* **1999**, *31*, 3.
2. Ali, Y.S.; Massoud, M.M. Modern Technology Applications in the Restoration of an Ancient Mud Brick Houses in Dakhla Oasis, Egypt. *Int. J. Archaeol.* **2016**, *4*, 87–94.
3. Dalman, G. Grinding in Ancient and Modern Palestine. In *The Biblical World*; The University of Chicago Press: Chicago, IL, USA, 1902; Volume 19, pp. 9–18.
4. Ethnographic Museum, Museum in Al Qasr. Occupying Sheriff Ahmed’s house, which itself dates back to 1785; the museum’s everyday objects try to give life to the empty buildings around them, constructed by Prof. Dr. Alia Hussein. Hall No. 2. Available online: <https://www.lonelyplanet.com/egypt/al-qasr/attractions/ethnographic-museum/a/poi-sig/1005243/355275> (accessed on 1 February 2018).
5. Lowe, P. Animal-Powered Mills. *Animal Powered Systems: An Alternative Approach to Agricultural Mechanization (German Edition)*. (German). 1986. Available online: <http://www.nzdl.org/gsdldmod?e=d-00000-00---off-0hdl--00-0---0-10-0---0---0direct-10---4-----0-11--11-en-50---20-about---00-0-1-00-0--4---0-0-11-10-OutfZz-8-00&cl=CL1.1&d=HASH9a40519cc8e7f5ef526fdf.3>=2> (accessed on 11 December 2017).
6. Flory, P. Old Millstones. *J. Lanc. Cty. Hist. Soc.* **1951**, *55*, 73–86.
7. Kollmann, F.F.P.; Cote, W.A., Jr. *Principles of Wood Science and Technology*; Springer-Verlag: Berlin/Heidelberg, Germany, 1968; p. 112.
8. Hazen, T.R. Introduction to Old Mills and Mill Restorations. Available online: <http://www.angelfire.com/journal/millrestoration/intro.html> (accessed on 14 December 2017).
9. Metz, D. *BM22—Pine Creek Grist Mill, Its History, Description and Restoration*; The international Molinological Society, 2015. Available online: https://www.molinology.org/index.php?option=com_content&view=article&id=222&Itemid=605 (accessed on 10 May 2018).
10. SPOOM, The Society for the Preservation Old Mills. Available online: http://www.spoom.org/content.aspx?page_id=22&club_id=664666&module_id=288270 (accessed on 19 August 2018).
11. TIMS, The International Molinological Society. Available online: https://www.molinology.org/index.php?option=com_content&view=article&id=72&Itemid=480 (accessed on 11 July 2018).
12. With the kind permission of “The International Molinological Society”, David Jones. A General Philosophy of Preservation [PDF].
13. Le moulin à cheval de Volckerinckove. LE MOULIN À CHEVAL, Je vous avais parlé ici de Volckerinckove et de l’Association Yser Houck. 24 September 2010. Available online: <http://uncoeuurenflandre.canalblog.com/archives/2010/09/24/19135448.html> (accessed on 23 September 2018).
14. (ICOMOS) International Council on Monuments and Sites 2008, the 17th Session of the General Assembly; (Quebec Declaration). Available online: <https://www.icomos.org/en/about-icomos/2016-11-17-13-14-08/minutes-of-the-general-assemblies> (accessed on 23 September 2018).

15. Hamed, S.A.M.; Ali, M.F.; El hadidi, N.M.N. Assessment of commonly used cleaning methods on the anatomical structure of archaeological wood. *Int. J. Conserv. Sci.* **2013**, *4*, 153–160.
16. Sawhney, G.S. *Mechanical Experiments and Workshop Practice*; I. K. International Publishing House Pvt. Ltd.: New Delhi, India; Bangalore, India, 2009; p. 72.
17. Gear Trains—MoodleLearn. Available online: <https://moodlelearn.ariel.ac.il/mod/resource/view.php?id=572701&redirect=1> (accessed on 3 February 2018).
18. WWF: Animal Power—WorldwideFlood.com, Animal Power. Copyright Tim Lovett Mar 2004, June 2007. Available online: http://worldwideflood.com/ark/technology/animal_power.htm (accessed on 31 February 2018).
19. Carmichael. Design and Production Volume Hardcover. In *Kent's Mechanical Engineers' Handbook*, 12th ed.; J. Wiley Chapman & Hall: Hoboken, NJ, USA, 1950; pp. 1–20.
20. Jefremova, O.; Radenkova, V.; Kunkulberga, D.; Klava, D. Technological properties of dough from wheat flour and fermented bran. *Cheminè Technologija* **2015**, *66*, 13. [[CrossRef](#)]
21. Katz, A.; Khim, J.; Wang, T. Tangent-Perpendicular to Radius; Brilliant Math & Science Wiki. Available online: <https://brilliant.org/wiki/tangent-perpendicular-to-radius/> (accessed on 11 March 2018).



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