Aesthetic tradition and ancient technology: a case study of the water-wheel

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Abstract

The water-wheel is one of the oldest typologies of water architecture in the Mediterranean countries. Its technology has remained intact for centuries and has not changed despite the 20th century progress. This typology has been able to combine the functional with the aesthetic and spectacular aspects. This paper reports the considerations derived from the study of the typological formation and evolution of the water-wheel and from the relation between hydraulic work and natural morphology in the Mediterranean lands where water, although seemingly in contrast with the arid nature, has always been the object of deep reflection that has led to transformations of entire landscapes.
Keywords: craftsmanship, hydraulic works, noria, sāqiya, water architecture, water-wheel.

1 Introduction

Water-wheels have played a leading role in a centuries old tradition, up to the present day, in solving the main problem of supplying and carrying water for irrigation in many places in the Mediterranean. The water-wheels which exist now are the sophisticated results of a technology that has remained intact and whose achievement arouses admiration. In Syria, for example, the larger wheels lift the water to about twenty metres above the river-level and yield up to fifty litres per second. Such wheels can irrigate up to seventy-five hectares of land. The water-wheels are divided into three main types: machines which raise water through the power of animals, men or water itself. In addition, for every group, there are sub-classifications to indicate the different typologies of wheels.

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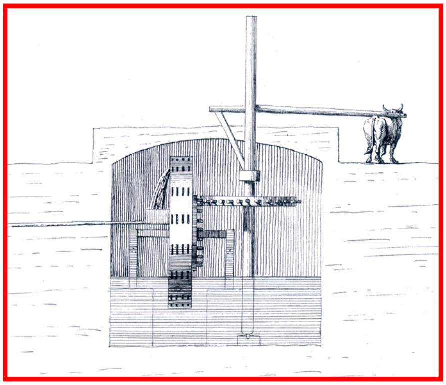
2 The types of water-wheels

2.1 Sāqiya and noria

Wheels moved by the power of animals are known by the Arabic names of "sāqiya" and "noria" (Fig.1). These wheels indicate the installation which raises water from streams or from underground to irrigate fields or to supply water for small structures. They are composed of a machine moved by the power of animals which turn a horizontal cogged-wheel made of wood, which turns a vertical wheel with cogs. The latter transmits the rotation to a vertical wheel which has some compartments on the rim, that is boxes which fill up when they reach the water. Instead of compartments the wheel can have a chain with pots. The wheel with pots consists of two pairs of bars, perpendicular to each other. There is a gap between the pairs of bars where the horizontal axis passes through to connect this wheel with that with cogs. Small transversal bars are inserted on the ends of this structure in order to support a chain with pots which consists of two parallel cords on which pots are roped. The installation is called "noria" if the vertical cogged-wheel and the wheel with pots or compartments are situated in the same hollow, because they are connected to each other by a short axis. The installation is called "sāqiya" if the vertical cogged-wheel and the wheel with pots or compartments are situated in two different hollows because they are connected to each other by a long axis. In both cases water raised is poured into a channel which irrigates fields and gardens.



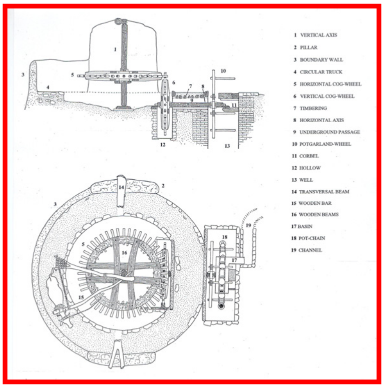


Figure 1: *Noria* with compartments (left) and *sāqiya* with pots (right).

The masonry works of both *sāqiya* and *noria* include a well (when water is underground) and one or two hollows (Fig. 2). All of the installations can raise water from a depth of 10 metres. Masonry works are built before the construction of the wheels. The cylinder well for containing water becomes parallelepiped in shape in the upper part. This upper part corresponds to a rectangular hollow, where there is the wheel which raises water. In this hollow is built a basin where water is poured. To ensure their impermeability, hollows and well are lined with of brick.

Sāqiya and *noria* were widespread in the whole Mediterranean basin. Now there are still some examples in Egypt, Spain, Portugal, Morocco, Syria and Iraq.

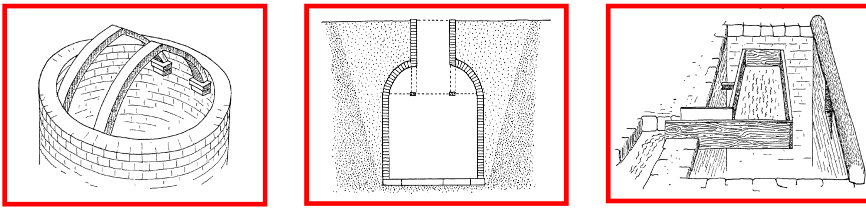


Figure 2: Well (left), section of the well (centre) and rectangular hollow (right) with the basin for receiving water from compartments or pots.

2.2 Treadwheel

The second type of water-wheel is moved by man power. It is known as a "treadwheel". This type can raise the greatest quantity of water. This wheel, which derives from the Vitruvian *tympanum*, is cylindrical in shape, with eight internal sectors opened on the periphery to allow water to enter the wheel. These containers fill with water at the bottom and empty at the top during the circular motion. Through internal channels, water arrives at the middle of the wheel, and flows out to an external channel through a hole. Instead of hollow segments, the treadwheel can have square buckets on the rim. Treadwheels can be turned by treading on steps inside the wheel, or from above (Fig. 3).

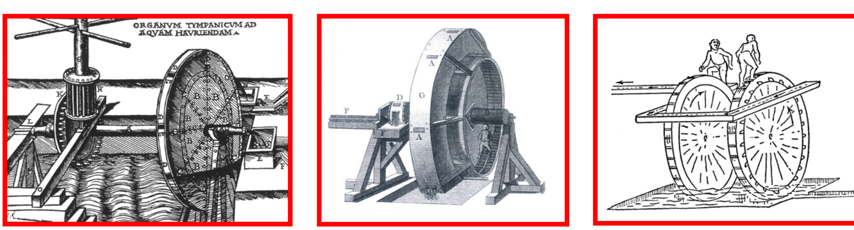


Figure 3: Vitruvian *tympanum* (left) and the two types of treadwheel.

Remains of treadwheels have been found at Riotinto in Spain, at Santo Domingo in Portugal, at Ostia Antica in Italy and at Dolaucothi in Wales.

2.3 Hydraulic noria

The third type is that of the "hydraulic *noria*" which raises water using the power of the river and has been used to irrigate fields or to supply water for bigger structures, owing to the great power provided by the river (Fig. 4). This is the typology widespread in Syria on the Oronte river (Fig. 5), but is still in use today in other parts of the Mediterranean basin, like Iraq, Spain, Morocco, Portugal, where its technology has not changed (Figs 6 and 7).

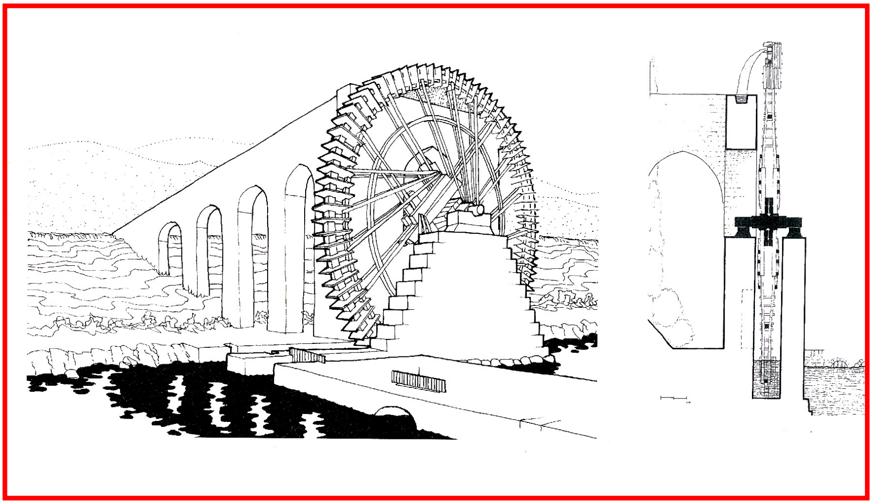


Figure 4: Perspective and cross section of a hydraulic *noria*.

The system is composed of two main parts, the wheel and the aqueduct. In addition, there are secondary works which include a dam, one or more derivation channels, a main channel and a triangular wall (Fig. 8). The base of the wheel is submerged in the river and turns because of the current. Water flows up the wheel, through compartments or pots placed on the periphery of the rim, and is carried into the channel on the top of the aqueduct, and is directed to irrigate fields and gardens.

To move the wheel continuously, it is necessary that the river flows at a constant speed.

The dam, which is made of masonry, bars the river to maintain an initial sufficient level of water. One or more derivation channels regulate the level of the water during periods of plenty or scarcity. The channel which conveys water to the wheel, because of its particular profile and small width, increases the flow of water under the wheel. The barrages allow the flow to be regulated in every channel. The so called "triangle" is a brick structure, triangular in shape, which supports one of the ends of the shaft. On the sides of the "triangle" there are same steps to allow access for maintenance. The other end of the shaft is placed on the sill of the aperture of the aqueduct tower. At the bottom the wheel rotates between the triangle and the façade of the tower. The wheel is mobile and is placed beside the aqueduct, on the bank of a stream, in a vertical position. The wheel is made of wood and is built by local craftsmen and can reach a diameter of more than 20 metres, like the wheel *al-Bišriyya al Kubrā* at Hāma (Fig. 5). Wood used has to be durable and flexible, like mulberry, poplar or apricot.

Although they look rustic, they show a sophisticated construction, characterized by a simple assembly and maintenance. The main structure of these water-wheels consists of two pairs of continuous parallel beams perpendicular to each other.

Figure 5: Hydraulic *noria*-s on the Oronte river at Hāma (Syria): *Al-Biširiyya al Kubrā* (left) and the group called "The four *noria*-s"(right).

Figure 6: Hydraulic *noria* at Cordoba in Spain.

Figure 7: Hydraulic *noria* at Ana (Iraq).

They are the main spokes of the structure and are pivoted around a central axis supported at each end by stone walls. The secondary beams stabilise the structure. They can be radial, or perpendicular to the main beams or oblique (Fig. 9). The size of the aqueduct is proportional to the wheel. In fact, decreasing the diameter of the wheel, the height of the aqueduct also decreases, while the submerged part increases. The number of pots or compartments under water, increases in smaller wheels. For this reason big and small wheels raise and transport the same amount of water in the same time (Fig. 10).

On the circumference hydraulic *noria*-s can have pots or compartments. Hydraulic *noria-s* with pots characterized the banks of the Euphrates (Fig. 7) where today there are 9 examples, but only 3 are still in use. It is composed of a wooden cross-braced rim. A large number of pots are lashed to the outer rim. The main three elements are the same in the compartmented wheels (the stone supports, the wheel and the irrigation channels). Hydraulic *noria*-s with compartments are characteristic and numerous in Syria on the Oronte river (Fig. 5), where there are around 90 example; 24 are in working order. This type is similar to the pot-wheels, but in place of the pots there are compartments and in place of the cross-braces there are several radial spokes.

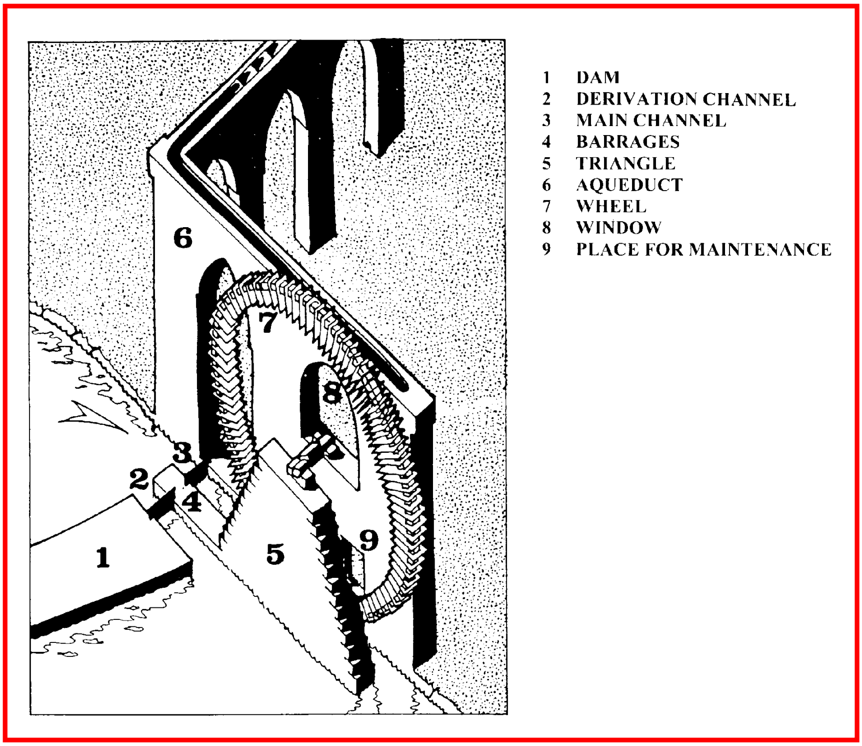


Figure 8: Axonometry of a hydraulic *noria.*

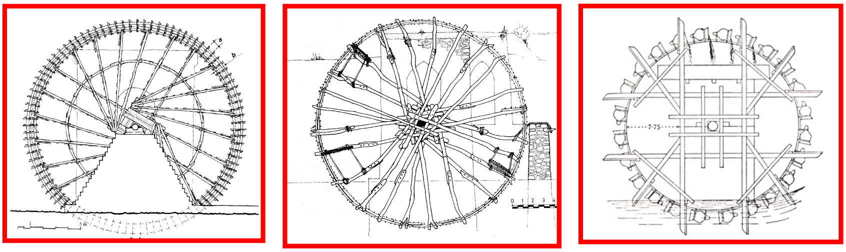


Figure 9: The main structure of a hydraulic *noria* is composed of two pairs of parallel beams perpendicular to each other. The secondary beams can be radial, perpendicular to the main beams or oblique.

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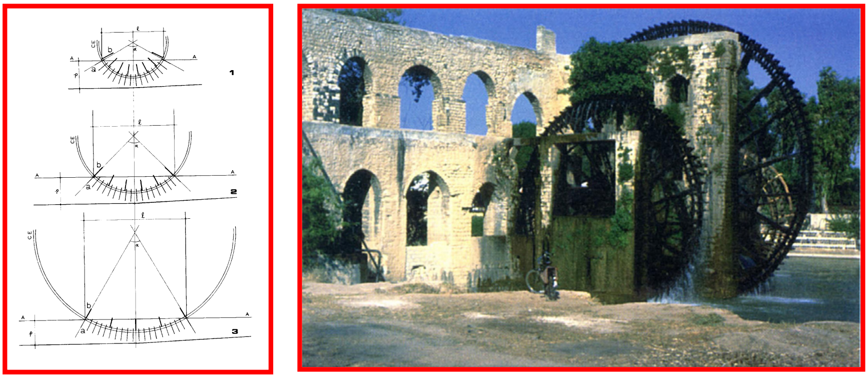

Figure 10: Scheme showing that, in proportion, the submerged areas tend to decrease in large wheels and to increase in small wheels (left). The group called “The four *noria*-s”(right) at Hāma (Syria).

The dimensions of the wheels are proportional to the diameter, while the distance between two compartments does not change, and it is always around 50 centimetres.

When it is necessary to supply a large amount of water on the Oronte river, it is common to find wheels arranged in groups. There are in fact four types of installation, depending on the number and the position of the wheels. The first is the simplest and includes one wheel. The second includes two wheels with the same diameter which are placed on both sides of one aqueduct. Another kind of installation is composed of two wheels with different diameters, which supply two aqueducts; in this case the installation enables irrigation at different levels. Finally there is the type of installation which includes two wheels placed at both ends of the same dam (Fig. 11).

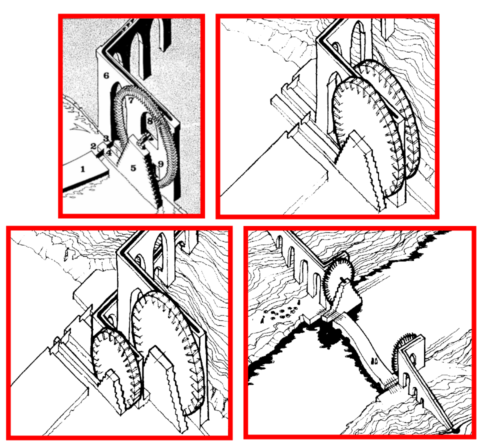

Figure 11: The four types of installation of hydraulic *noria*-s.

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3 The question of the origin

It is difficult to assert for certain when the water-wheel originated, and which was the first typology to be constructed. Although different hypotheses have been advanced, they are not supported by convincing enough evidence.

Sources analyzed have shown that most probably the earliest water-wheel was a *sāqiya*, for which there is much archaeological evidence of *sāqiya*-s found at Fayyum in Egypt dating from the 3rd century B.C. Also in the *Peri Alexandreias* by Callixenus, there is the first mention of the existence of a wheel which corresponds to a *sāqiya* used at Alexandria during the reign of Ptolemy IVth (221-205 B.C.). Subsequently a fresco from the 2nd century B.C. representing a compartmented *sāqiya* has been found in Alexandria.

The treadwheel could have appeared in Egypt dating from the 1st century B.C. when it is mentioned in Roman literary texts. In fact in 48 B.C. Hirtius, in *De Bello Alessandrino,* mentions a treadwheel used by Caesar to raise water from the sea, when the Roman army was passing through Alexandria. In 18 B.C. Strabo, in *Geographica,* mentions a treadwheel as a means of torture for prisoners who “had to work to bring water up from the Nile”. Use of the treadwheel as a means of torture for men is also mentioned in *Tiberius* by Suetonius in the 1st century A.D. and in *Oneirocritica* by Artemidorus in the 2nd century A.D., where he mentions a man who dreamt of being condemned to move a wheel for raising water. But the first remains of treadwheels date to from the 2nd century A.D. and refer to widespread findings of treadwheels found in Italy, Wales, Romania, Spain and Portugal.

Hydraulic *noria* also appeared in the 1st century B.C.. In fact in the 1st century B.C. Lucretius mentions “compartmented wheels moved by the river by scoops” in *De Rerum Natura* and compares their rotation with the perpetual motion of the celestial spheres. Although the place where this wheel originated is still uncertain, it is possible to hypothesize that the first hydraulic *noria*-s were born in Syria, due to a mosaic dating from 496 A.D. which decorated one of the porches which crossed Apamea North to South and which represents a hydraulic *noria* with compartments of the same type of those actually existing on the banks of the Oronte. It is the oldest evidence which represents a hydraulic *noria*.

The first technical treatise which deals with water-wheels is *Pneumatica* by Philo of Byzantium from the 3rd century B.C.. He first mentions a bucket-chain, but a clear description of it will be made only by Vitruvius in *De Architectura* in the 1st century B.C. Vitruvius in the Xth book of *De Architectura* was the first to give a detailed description of all vertical wheels, that is treadwheels (which he calls *tympanum*), *hydraulic noria*, and bucket-wheels. Only the *sāqiya* will be analyzed in terms of technical aspect in the early 13th century by Al Jazari. He produced detailed partially three-dimensional drawings describing the function of the sāqiya, enabling the future craftsmen to construct the machine.

4 Nature and technology

Many water-wheels are still in use, although some examples are reconstructions of the original or were built recently. The most widespread typology of water-wheel is the hydraulic *noria* with compartments. In particular in some places in the Mediterranean, like Syria, Portugal and Spain the constant speed of the river, the gradual slope of the ground and the absence of floods have allowed their utilization and provided perfect conditions for the construction and use of hydraulic *noria*-s. In Syria, the country with the greatest number of water-wheels, there is another important factor which has enabled their construction and function, that is the permeable ground of the nearby mountains. In fact, in summer, the weather changes suddenly from a dry climate in the East to a Mediterranean climate, with heavy rains on the mountains in the West. The permeable mountains of Lebanon, Anti-Lebanon, Djebels Ansariyé and Zaouiyé supply water to natural underground reservoirs. In Iraq, on the Euphrates river, the typology still in use is that of hydraulic noria with pots, because the quantity of water to raise is minor and inconstant. In fact the period of maximum water supply does not correspond to the period of maximum demand. In summer, when water is vital, the river is at its lowest, while late winter, when the water is not needed, is the period of maximum efficiency.

The water-wheel, in particular the hydraulic *noria*, has always been able not only to utilise the power of nature, but also to integrate itself with nature, becoming part of it. In particular, the Syrian wheels were objects of admiration to many travellers in the 19th and 20th centuries, who, impressed by the sight of the wheels in their natural setting, wrote of their amazement.

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