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WATERMILLS: THE ORIGIN OF THE USE OF RENEWABLE HYDRAULIC ENERGY IN SPAIN

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ABSTRACT

The use of renewable hydraulic energy sources by mankind most likely has its origins in the development of the watermills. To understand the functioning of these mills, this article first reviews, through the analysis of different bibliographical sources, the technical evolution of the machinery used since the appearance of the first watermills to grind cereal grain in the 1st century BC.

Secondly, a particular area of the southwest of Spain, Alcalá de Guadaíra, has been selected for study, whose strategic location as well as its hydrological characteristics, gave rise, firstly, to an intensive milling industry, and, later, a famed baking industry,, from the late Middle Ages until recent decades. The huge development of these two industrial activities has made Alcalá de Guadaíra an exceptional example in Spain, with 40 watermills in the early 18th century.

Extensive work on site allowed the analysis of the state and types of watermills that still exist in this area, identifying their similarities and differences. Unfortunately, after they fell into disuse, only 28 of these mills remain today, 12 of them are in a relative good state of preservation, seven in an alarming state of ruin and, of the other nine, only some unrecognisable vestiges remain. Some of these mill buildings have been restored recently, although their machinery is missing. Only from old photographs or by visiting mills restored in other areas is it possible to determine how these watermills worked.

Due to the lack of financial resources to carry out physical restoration of the industrial heritage missing in these flour mills, a virtual model of one of them has been developed. This work provides, at least virtually, a reconstruction of the traditional mills which helps promote technological studies and shows how they worked, as part of virtual exhibitions. In addition, a computer application of augmented reality has been developed that any visitor can install on a mobile device to display the virtual reality of the machinery, generated by 3D models, so they can visualise the physical reality that they would have found in the mill.

KEYWORDS: Watermill; Hydraulic power; Industrial heritage; Computer-aided design; Computer animation; Augmented Reality; Alcalá de Guadaíra

INTRODUCTION

Since ancient times, when man wanted to break or crush any plant product for easier ingestion, they used to beat it with stones found in their habitat. Although the oldest hand mills date back to the Palaeolithic period, and were used to grind tuberous roots, the expansion in their use occurred during the Neolithic period, when the change from nomadic lifestyle to sedentary habits triggered the expansion of agriculture. Although seeds, acorns and chestnuts continued being harvested, cereals became the main product. Thus, wheat cultivation developed in the Middle East between 10th and 8th millennia BC. This new type of sedentary lifestyle required, for each harvest, that sufficient quantity of grain was collected for storing, in order to survive until the next harvest.[1]

To facilitate the ingestion of cereal grains, it was necessary to grind them into flour. It is likely that the grinding of wheat to make flour was originally carried out with mortars, or by crushing it between two stones; a flat block would be used as a table on which the grains and other smaller hand-held stones were placed. Later, this process was displaced by the use of curved stones called 'saddle stones', by rocking or rolling the handstone using parallel motions, pushing and pulling the handstone. The handstone is also referred as a 'rubber' or '*mouler*'. But in the same way the saddle stone replaced the mortar, this system was also superseded by the rotary quern, with the discovery and technical application of the rotary movement. It consisted of two circular stones: grain was poured into a central hole in the top stone, which was then turned with a wooden handle. The grain would be crushed by friction between the two circular stones as the upper stone was turned.

Initially, this type of mill was for domestic purposes and each family milled their own grain. However, the shift from nomadic to sedentary lifestyle, mainly along rivers and springs, was attracting more people and, likewise, the demand for all kinds of products, like flour, was growing. Therefore, the small hand mills with scarce production were not sufficient to meet the needs. In order to meet these new needs, improvements were made to the grinding process, which resulted in an increase of the quantity and quality of the produced flour, consequently prompting the use of larger rotary stones that required greater effort. Therefore, rotary mills of a greater size and production are usually shown operated by slaves or animals (Figure 1).

During the Roman Empire, even with the abundance of slaves and convicts and the introduction of animals for this task, mills were limited in their production and began to fall short of meeting the demands of large concentrations of people in the cities, which were growing rapidly. It was necessary, therefore, to consider the use of other energy sources that would allow an increase of flour production capacity. These energy sources were found in the natural forces, such as wind and water, initiating the use of wind and water power.[2]

WATERMILLS

The date of invention of hydro-powered mills is uncertain, but it was around the year 85 BC, when the Greek epigrammatist Antipater of Thessalonica made the first reference to a mill driven by water, replacing animal or human force:

> Hold back your hand from the mill, you grinding girls; even if the cockcrow heralds the dawn, sleep on. For Demeter has imposed the labors of your hands on the nymphs, who leaping down upon the topmost part of the wheel, rotate its axle; with encircling cogs, it turns the hollow weight of the Nisyrian millstones. If we learn to feast toil-free on the fruits of the earth, we taste again the golden age.[3]

All researchers interested in the history of mills agree that the use of water power, which uses water flow to grind cereal, emerges in the ancient world almost simultaneously with two types of watermills: the 'Greek Mill', with a horizontal waterwheel (Figure 2), and the 'Roman Mill', with a vertical waterwheel (Figure 3).[4] Both of these watermills used similar mechanisms, the process involved grinding grain between two horizontal circular stones: the upper one or 'runner stone', turning over; and the lower one or 'bedstone', which is static.[5] Because of their lesser technical complexity, horizontal-wheeled mills were more common than mills with a vertical waterwheel, a much superior contrivance which required the vertical rotation to be converted into horizontal rotation by means of toothed gearing. While the technology used in horizontal-wheeled mills is simpler than in vertical-wheeled mills, their buildings were more complex because the waterwheel was at a lower level than the mill, in a room called a 'hell' – owing to it being in the basement and the deafening noise produced by the water as it passed through it – where the flow of water came with the force required to turn the wheel.

This wooden or metal wheel, with straight vanes or with curved blades, was pivoted on a block of wood fixed above the stream. A little way above the pivot, a vertical spindle was fixed on the horizontal waterwheel, but passing loosely through the lower stone and the stream playing down on the vanes of the water, it turned, with the latter, both the spindle and the upper stone. The grain was placed in a hopper and fell into a hole in the upper stone, and as the latter revolved, it gradually trickled through the top stone and was drawn between the upper and lower millstones. As it became reduced into foodstuff it was automatically forced towards the circumference of the stones and expelled (Figure 2).

However, in Ancient Rome, due to the abundance of labour and animal traction, as well as the costs of the necessary waterworks, watermills were not normally installed in the rivers until the 4th century AD, during the reigns of Honorius and Arcadius, when human and cattle labour were abolished, and water power was adopted instead of milling grain. The fall of the Roman Empire preceded a dark period with profound instability which extended from the 5th century until the end of the 10th. It was, however, a fruitful period for the quiet but effective spread of small watermills.

It was not until the Middle Ages, though, when the usefulness of the waterwheel diversified; numerous tasks which had been carried out by hand or by animals were to be carried out mechanically by devices driven by the force of the water and their use massively helped develop the most popular trades. So, it was not only mills, but also other hydraulic devices, such as those used for the fulling of wool cloth, the forging of iron and the manufacture of paper, sawmills, extraction of juice, etc. For this reason, specialists in the history of engineering have described the Middle Ages as 'the hydraulic machinery era'.[6] In Europe, with the emergence of the intellectual movement of Renaissance humanism, watermills were not considered simple mechanical devices but were the subject of scientific study. Thus, leading Italian researchers such as Taccola, Francisco de Giogio, Leonardo da Vinci or Cardano, studied the mills in the 15th and 16th centuries.

In Spain, during the reigns of Carlos V and Felipe II in the 16th century, researchers, like Francisco Lobato, Pedro Juan de Lastanosa, Juan de Herrera, Francisco de Mora and Juanelo Turriano, began to study the mechanisms of mills. The most important piece of work during this time is the manuscript *Twenty-one Books of Devices and Machines*', initially incorrectly attributed to Juanelo Turriano (Cremona, Milan, 1501 - Toledo, Spain, June 13, 1585), a copy of which is kept by the National Library of Madrid, and which is presently considered worldwide as the first textbook on hydraulics.[7] Book XI of this work is devoted to the study of mills; it describes a wide variety of mills and shows interesting drawings of them. The most common type of mill, 'although it does not grind much', is called an 'open channel mill'; it operates with the flow of water fed to a vertical wheel with flat, open paddles. This manuscript researches the proper inclination of the channel, as well as its distance from the wheel to the current of water directed on it to get maximum efficiency (Figure 3). Secondly, it describes another type of watermill called a 'bomb mill' which ground much more efficiently than the previous mills. This had an open channel and a wheel placed in a horizontal position, with inner curved blades to the wheel (Figure 4). In this case, the channel had to be more horizontal than in open channel mills and narrowed along the way.

Page 293 v of this work states that it is important to deal with some questions 'very necessary and yet very important' relating to mills where only a small flow of water was available; in such cases the mill was started by increasing the head of water to compensate for the low water flow. In order to achieve sufficient speed, a small vertical tank known as a 'penstock' (*cubo* in Spanish) was used, from which the water exited the bottom, hitting the wheel (Figure 5). Theoretical analyses of horizontal waterwheels conclude that they may reach maximum hydraulic efficiencies as much as 50%.[8] In contrast, vertical waterwheels may reach 65% for undershot types, whereas this increases up to 71% for more complex overshot types.[9] However, due to their simplicity, watermills using horizontal waterwheels were extremely common.

From the 16th century, a new type of channel mill, called *regolfo* mills, was introduced, which represented a significant advance in the Iberian Peninsular. They were based on a system of closed vessel in which the water spins, causing a vortex, which caused the rotation of an impeller (*rodete*), as a forerunner of modern turbines. Compared with open wheel horizontal mills (*molinos de rodezno*), this design improved performance when provided with a constant and abundant water supply, as explained in the *Twenty-one Books of Devices and Machines* (Figure 6).[10]

Until the mid-20th century, some watermills continued to function simultaneously with the large mechanised flour mills operated by large steam engines. Later, mills located in city centres powered by gas engines or electric motors operated with great success, leading to the disappearance of the vast majority of watermills driven by classic horizontal waterwheels.[11] However, traditional watermills have survived on a small scale in isolated communities in rural regions elsewhere in the world, like the Himalayas, which are serving mountain inhabitants to this day.[12]

FLOUR MILLS OF ALCALÁ DE GUADAÍRA

This article focuses on an area of the southwest of Spain with a singular set of these mills. In the case of Alcalá de Guadaíra (located in the province of Seville, Andalusia), the abundance of flour mills installed in its river, as well as those located on its numerous springs and streams, made this cluster of watermills unique in Andalusia and, probably, in all the Iberian Peninsula, becoming a true hallmark of the area and forming part of its landscape, as evidenced by the large number of paintings and other art objects that decorate many of its houses and art galleries, like the oil *Castle of Alcala Guadaira* painting by Scottish painter David Roberts, which can be seen in the Prado Museum (Madrid).

In the early 18th century, this old town, also referred to as 'Alcalá of bakers', had 40 watermills and 150 animal-powered mills*,* grinding 65,000 kg of wheat every day, thus making of Alcalá de Guadaíra the Andalusian city with the highest number of mills powered by water.[13] The origin of watermills in Alcalá de Guadaíra began during the Islamic period, but there are no references before the 13th century.[14] The etymology of some of their names and the fact that they were part of the division of property after the Christian conquest in Seville, indicate that many of these mills have an unquestionable Islamic origin. During this period, mills represented an important economic resource, due to the substantial incomes they generated. For this reason, as a part of this *distribution,* King Alfonso X bestowed many of these mills on the Seville Council, various military and religious orders, as well as on members of the Royal family and individuals connected to the Court, or noblemen who had helped him during the process of conquest.[15]

Some additional information for the following centuries is available from the general response to the survey of the Marquis of the Ensenada (1751), describing, in question No. 17 the existence of 32 mills driven by water in Alcalá de Guadaíra, 19 of them property of lay people and with a total of 47 stones, producing an annual income of 110.,83 *reales* and 24 *maravedís*. The 13 remaining mills were owned by churchmen, with 45 stones, and an annual income of 138,763 *reales*. A deeper investigation would allow access to the specific responses (*respuestas particulares)*, in which the dimensions of buildings, quantity of stones, location, production and owner of each of the mills are detailed in the same year, 1751. (The documents will be in the Provincial historical archive of Seville.)

Throughout the following centuries, these mills changed hands on several occasions, as a result of grant, sale or inheritance, usually between wealthy people or entities, because their high value and income-generation capacity, whether by exploiting them with employees or by renting them to miller families, who managed them for a percentage of the grain produced. At the end of the 19th century, the decline began for this type of mills, culminating in the mid-20th century, when almost all of them stopped production as a result of the strong competition from mills operating with new energy sources, primarily electricity. Thus, a study carried out in 1934 by the chief engineer for hydraulic services of the Guadalquivir river, Rafael de la Escosura, shows that, even then, there were only 15 mills in operation. These last mills were being abandoned until the decommissioning of the last of them, the *Pelay Correa* mill, in 1971, led to a gradual process of ruin or, in some cases, total destruction.[16]

Today, fieldwork for this study, shows that only 28 of these watermills remain, in various states of preservation, but unfortunately none of them has retained their grinding machinery. Names like *Cerrajas*, *Pelay Correa*, *Realaje*, *Algarrobo*, *La Tapada*, *Eras*, San *Juan, Benarosa, Aceña, Pared Blanca, Granadillo* and *Pared Alta*, some of them with a clear Islamic origin, are a small sample of the group of interesting buildings that housed milling machinery,and which can still be visited near Alcalá, on the banks of Guadaíra river or its tributaries, called Marchenilla and Gandul, or in some of its numerous springs. The findings of this fieldwork has been integrated in a Geographical Information System which records the exact location of these sites, (Figure 7). All the watermills found in this fieldwork (Table 1) used a horizontal wheel and can be divided into two types: channel mill and penstock mill*;* the difference is only in the water supply system to the mill, there is no difference with respect to the grinding machinery.

Channel mills are installed in river banks (Figures 6 and 9), where the water flow is continuous and abundant, and have as a common feature the construction of a dam or *azuda* - from the Arabic *as-sudda* - that traverses the entire width of the river at an angle and directs water into channels that flow into the waterwheels. These dams are finished on the top with a paved level surface, constructed using recycled fragments of old grindstones, that serves as access to the mill from the opposite bank. Today, vestiges can be seen of at least, nine out of the ten mills of this kind that existed, but only five of them remain in good condition after the improvements in their buildings carried out by the City Council in recent years. Unfortunately, one of them is in an unrecognisable state with few remains, but there are another three in an alarming state of ruin that could still be restored if action was taken soon.

Mills located on springs or streams with limited and seasonally-variable water supply, are penstock mills. This kind of mill, also with a horizontal waterwheel, has one or more penstocks to increase the speed of the water that strikes the waterwheel, thus supplementing its low flow. The penstock is a tank adjacent to the grinding room, having enough height and usually a cylindrical shape, with a considerable drop to dispose of a significant source of potential energy, achieving water power similar to that of the channel mills using lower flow rates. This kind of mill requires the construction of a system of collection and conveyance of water to the penstocks through an artificial water channel, either a ditch or leat, (known as *atarjea* in Spain) with a minimum slope, at the end of which water splits into branches or goes through a delta-shaped widening, in order to distribute the water to the different penstocks (Figure 8).

In the early 18th century, 30 penstock mills were installed on the streams and springs of Alcalá. Traces of 19 of them remain today, but unfortunately only seven are in a good state of preservation; five are in an alarming state of ruin while, of the other seven, only some almost unrecognisable vestiges remain. Among them, the mill called *La Mina* is especially interesting since its construction is completely underground; it is fed from ground waters that circulate under the city, the only example of underground mill that known in Spain.

Many of these mills have another small building used as the miller's residence, sometimes attached to the principal building and sometimes separated from it and built on higher ground to protect it from the river floods. Some mills of Alcalá have towers crowned with battlements (Figure 9), to which some researchers attribute a defensive character while others only give them an ostentatious and ornamental value. The millstones were the most important element of the mills, because it is between them that the milling of wheat took place. The number of stones, or rather pairs of stones used in the mills of Alcalá varies between one and five, the number being an indicator of the production level.

AVAILABLE HYDRAULIC POWER

The available power of an hydraulic machine is a function of the hydraulic head and rate of fluid flow. So, the available power from falling water can be calculated from the density of water, flow rate, local acceleration due to gravity and the height of water head. The available power is calculated as:

$$P = \eta \rho Q g h$$

where P is the available power, η is the efficiency coefficient of the waterwheel, ρ is the water density, Q is the volumetric flow rate, g is the gravity acceleration and h is the height difference between inlet and outlet point of the turbine. This expression was used to calculate the available power of the mills working in 1934 (see Table 2). Hydraulic head and flow rates have been obtained from the study carried out by Rafael de la Escosura.[17] An efficiency of 50% for the watermills has been considered. This is a usual hydraulic efficiency for waterwheels with curved iron blades.[18] The results shown in Table 2 demonstrate that penstock mills can reach similar hydraulic power to that of channel mills using lower flow rates. For that, penstock mills have to increase the water head. It can also be seen that the mills with higher available power used larger and, therefore, heavier stones. Mills with lower available power needed to use smaller stones, so they were less productive. An exceptional case is *Pelay Correa* mill, which reached almost 30kW thanks to a high available flow rate, allowing it to compete with modern mills driven by new energy sources until the 1970s.

VIRTUAL RECONSTRUCTION

Due to the lack of financial resources to carry out physical restoration of industrial heritage, some research groups are performing 3D virtual reconstructions.[19] The goal of this procedure is to bring these ancient devices back to life, making their design and operation accessible to researchers and the general public. With this objective in mind, the aim of this work has been to perform a graphical study of these mills, based on a review of information obtained from bibliographic archives and the data collected from the fieldwork. The graphical study has been made using advanced 3D CAD modelling tools for the virtual reconstruction, allowing the operation of the mill to be demonstrated through animations and virtual tours through the interior of the building.

The *Algarrobo* mill was chosen as a practical example of the virtual reconstruction techniques used for this heritage cluster because it is one of the most complete and architecturally complex, and in it, even today, the different construction stages that took place during its history can be appreciated. For this virtual reconstruction two CAD programs, *CATIA v5* and *Autodesk 3dsmax* were used, combined with other tools like *Vray 1.5*, *CrazyBump*, *Photoshop 2010*, *Autocad 2010* and *Global Mapper*. Figure 10 shows the results in the form of rendered images obtained from the model of the building, integrating the model of the grinding machinery. In order to shows their accuracy, they are accompanied by their real images. Once the virtual model has been defined, it is easy to obtain sections of the building to appreciate the layout of the machinery inside the building (Figure 11). With these instructive images, the operation details of the mill can be explained to the general public.

It is also possible to generate highly-detailed animations or videos through a sequence of rendered images, allowing the movement of all the mechanisms generated by the water flow, the wheat supply through the hopper and the production of flour between the stones to be demonstrated (Figure 12). Once the generation of virtual animations from the digital model has been completed, the next step is the virtual immersion of users who wish to interact with the industrial heritage, to allow visitors to the original remains of mill to interact with the virtual model. To make this possible, innovative techniques of 'augmented reality' have been used. Figure 13 a screenshot of the computer application running the augmented reality project of the *Algarrobo* mill. It shows a 3D virtual model of the machinery superimposed over the real image of an empty grinding room. Using this technique, visitors can visualise on their smartphones or tablets the grinding process with the virtual machinery whilst inside the actual mill building.

CONCLUSIONS

Although the origin of the watermills is unknown, there is evidence of their use in the first century BC by the ancient Greek and Roman civilisations, long before the invention of windmills, so these devices could be considered as the origin in the use of renewable energy.[20] In Europe, the most common type of watermill has been the horizontal-wheeled, because it is simpler than the vertical-wheeled variant. To illustrate this, this project has focussed on a singular group of mills located in the southwest of Spain. In Alcalá de Guadaíra, known as 'Alcalá of the bakers' due to its famous flour mill and bakery industry, there were 40 watermills in the early of 18th century, many of them of Islamic origin.

Fieldwork in this project has shown that two types of horizontal-wheeled watermills can be found. Firstly, watermills located on river banks, where high and regular flow rate exists, with dams to raise and carry water into the supply channels. The second type is located on streams and springs, with lower and irregular water supply. These mills utilise a mill-race and chute, known as a penstock, to direct the water flow onto the wheel, raising the water level to compensate for the limited flow rate, often reaching similar water powers to the channel mills (3.6 - 22 kW). The information data obtained from this fieldwork (location, type, state of conservation, images) has been integrated into a GIS.

These mills stopped working in the middle of the 20th century and most of them are ruins today. Although a few of these mills remain in good condition, unfortunately their machinery has disappeared. In this project a 3D reconstruction and modelling of one of these watermills was carried out, including not only its building but also its lost machinery. This virtual model has enabled the production of virtual re-creations intended for a broad range of users, like researchers and general public. So, visitors of the building are able to scan a QR code and display the video on a mobile device. (This video can be viewed at https://youtu.be/KELCLAXRx1Q).

Another important outcome has been the creation of an augmented reality application, able to integrate a computer-generated model of the lost machinery into real-world environments. This work has been the beginning of a research project that is developing similar works of virtual re-creation of other water mills in the area of Alcalá de Guadaíra and is included in the overall context of the recovery of industrial heritage that has taken place in Spain in recent years, with some very notable examples, such as the restored mills in Córdoba.[21]

Finally, the most urgent task to be accomplished is to attract the attention of governments, institutions and the general public, to explain the alarming state of ruin of many of these sites and the importance of recovering and maintaining this historical, social, cultural and industrial heritage.

Picture captions

Figure 1. Iberian mill in Cabezo de Alcalá, Azaila, Teruel, Spain (Instituto de Estudios Turolenses)

Figure 2. Horizontal-wheeled mill virtual reconstruction

Figure 3. Vertical-wheeled mill, from *The Twenty-one Books of Devices and Machines*

Figure 4. Horizontal-wheeled mill, from *The Twenty-one Books of Devices and Machines*

Figure 5. Penstock mill, from *The Twenty-one Books of Devices and Machines*

Figure 6. *Benarosa* mill and *San Juan* mill, Alcalá de Guadaíra

Figure 7. Location of the watermills in Alcalá de Guadaíra

Figure 8. Penstock mill, *La Tapada*, Alcalá de Guadaíra

Figure 9. Channel mill, *Realaje*, Alcalá de Guadaíra

Figure 10. Real pictures versus rendered images of the virtual model

Figure 11. Two front sections of the *Algarrobo* mill virtual model

Figure 12. Frames of *Algarrobo* mill in operation

Figure 13. Screenshot of the augmented reality application

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WATERMILLS: THE ORIGIN OF THE USE OF RENEWABLE HYDRAULIC ENERGY IN SPAIN

Figure 1. Iberian mill in Cabezo de Alcalá, Azaila, Teruel, Spain (Instituto de Estudios Turolenses)

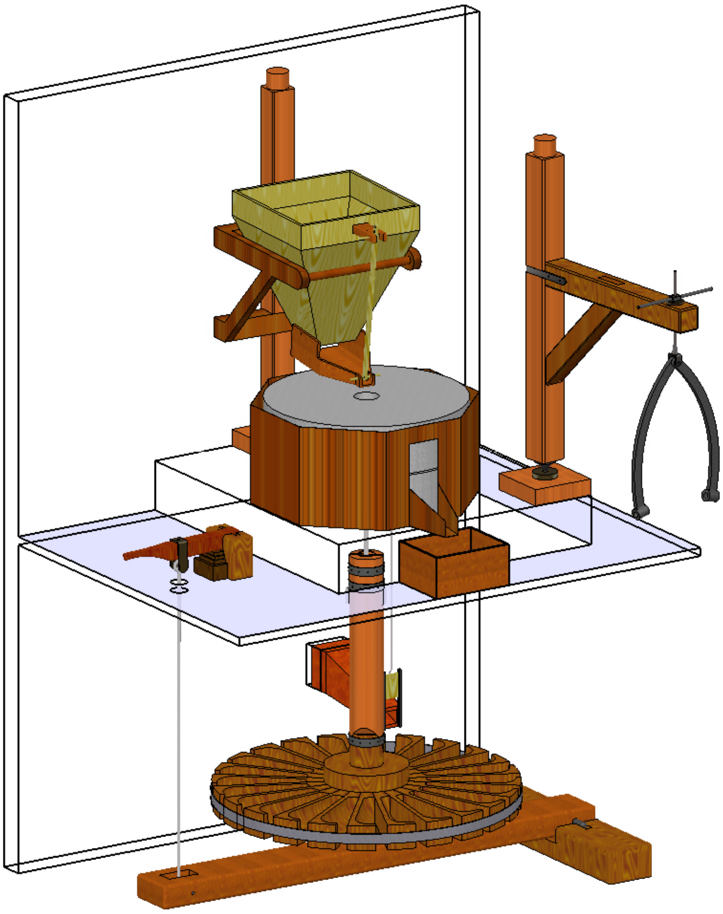

Figure 2. Horizontal-wheeled mill virtual reconstruction

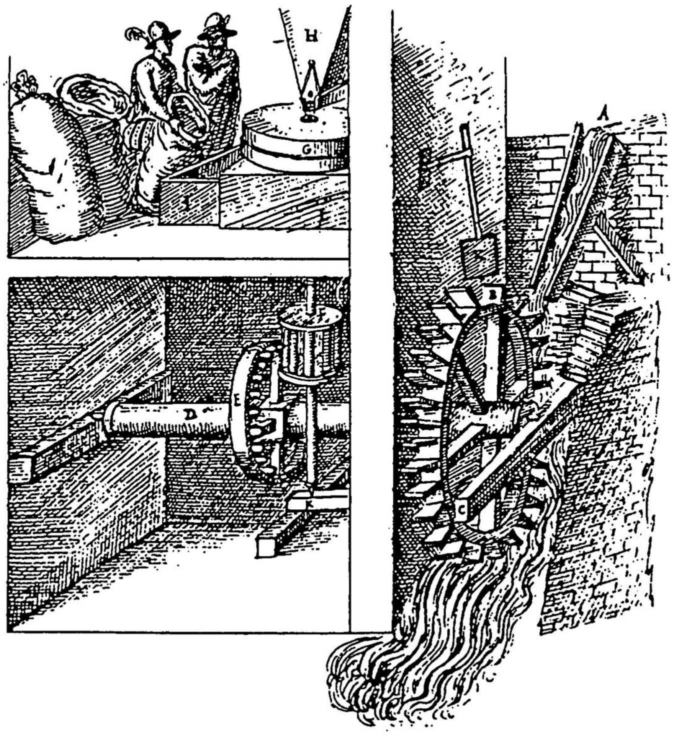

Figure 3. Vertical-wheeled mill, in "*the twenty-one books of devices and machines*"

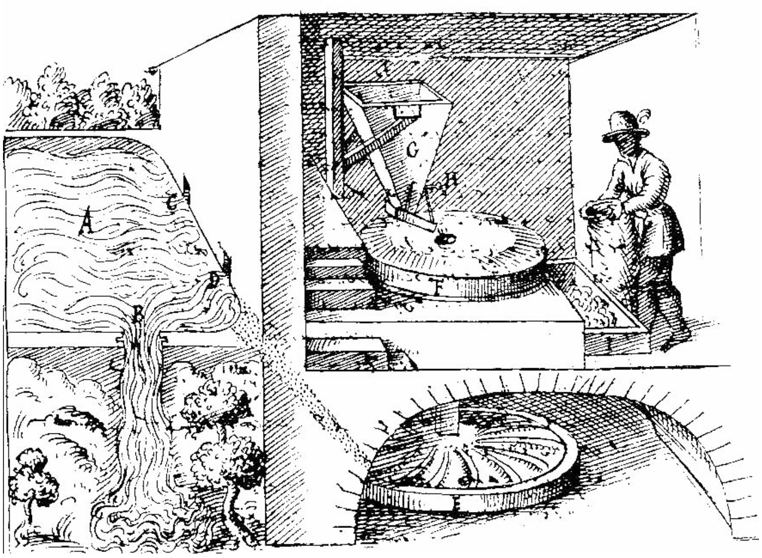

Figure 4. Horizontal-wheeled mill, in "*the twenty-one books of devices and machines"*

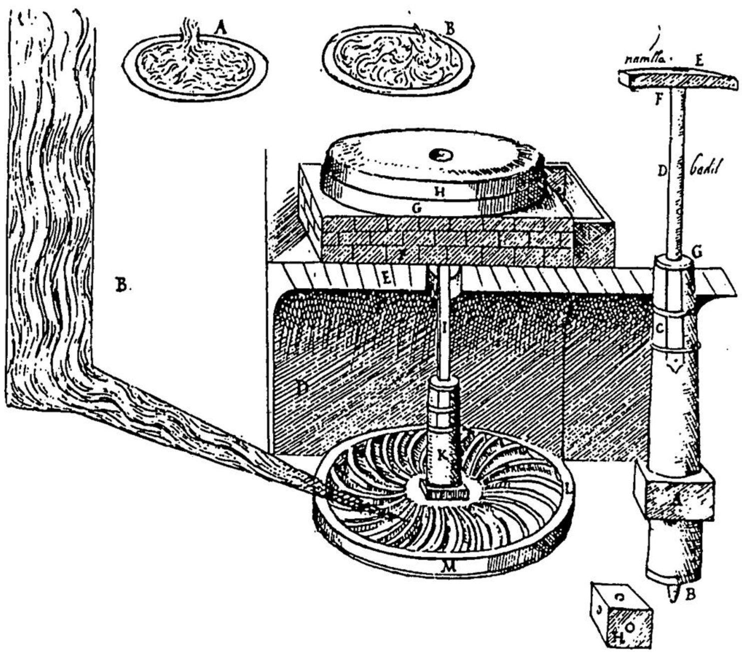

Figure 5. Penstock mill, in "*the twenty-one books of devices and machines*"

Figure 6. *Benarosa* mill and *San Juan* mill, Alcalá de Guadaíra

Figure 7. Location of the watermills in Alcalá de Guadaíra

Figure 8. Penstock mill called *La Tapada*, Alcalá de Guadaíra

Figure 9. Channel mill called *Realaje*, Alcalá de Guadaíra

Figure 10. Real pictures versus rendered images of the virtual model

Figure 11. Two front sections of the *Algarrobo* mill virtual model

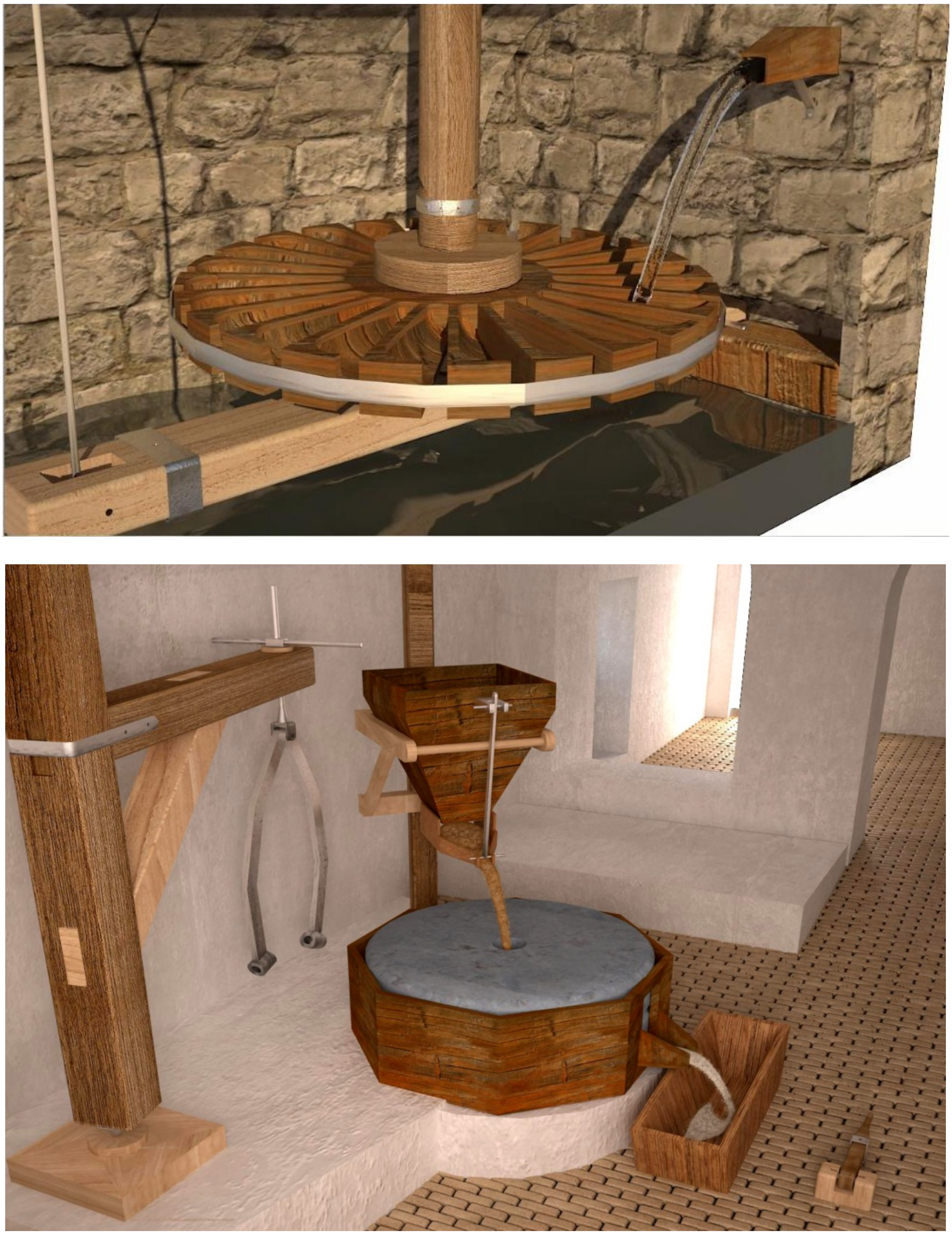

Figure 12. Frames of *Algarrobo* mill in operation

Figure 13. Screenshot of the augmented reality application

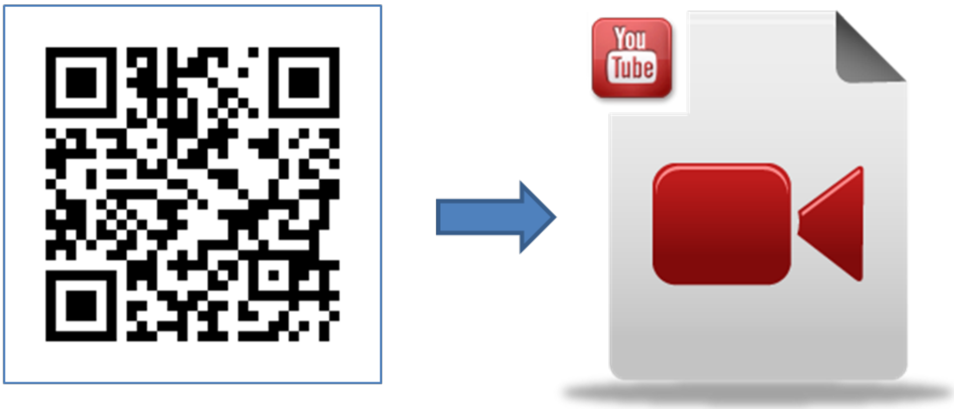

Figure 14. QR code linked to the video in YouTube

NAME	TYPE	STATE
Hundido o Rincón	Channel	Ruins
La Aceña	Channel	Good
Benarosa	Channel	Good
San Juan	Channel	Good
El Algarrobo	Channel	Good
Arrabal	Channel	Vestiges
Realaje	Channel	Good
Pelay Correa	Channel	Ruins
Cerrajas	Channel	Ruins
Arriba de Gandul	Penstock	Ruins
En medio de Gandul	Penstock	Vestiges
Abajo de Gandul	Penstock	Ruins
Tragahierro	Penstock	Vestiges
Pared Alta	Penstock	Good
Cañiveralejo	Penstock	Vestiges
Pasadilla	Penstock	Vestiges
Granadillo	Penstock	Good
Hornillo	Penstock	Ruins
Pared Blanca	Penstock	Good
La Boca	Penstock	Vestiges
Cajul	Penstock	Ruins
La Tapada	Penstock	Good
Oromana	Penstock	Vestiges
La Caja	Penstock	Vestiges
Las Eras	Penstock	Good
Vadalejos	Penstock	Good
El Águila	Penstock	Ruins
La Mina	Penstock	Good

MILL	TYPE	STONES DIAMETER (m)	WATER HEAD (m)	FLOW (m^3/s)	POWER (W)
Arriba	Penstock	0,90	6,85	0,110	3696
Enmedio	Penstock	0,95	5,73	0,130	3654
Abajo	Penstock	1,05	7,76	0,160	6090
Traga-hierro	Penstock	0,85	3,43	0,365	6141
Verealta	Penstock	1,12	5,11	0,245	6141
Cañabaralejo	Penstock	1,10	5,92	0,210	6098
Pasadilla	Penstock	1,12	3,32	0,375	6107
Granadillo	Penstock	1,10	2,75	0,910	12275
Hornillo	Penstock	1,10	2,58	0,970	12275
San José	Penstock	1,25	5,09	0,885	22095
Boca del río	Penstock	1,25	5,16 5,67	0,580 0,530	14680 14740
Benalosa	Channel	1,25	1,76	0,850	7338
San Juan	Channel	1,33	1,35	1,130	7483
El Algarrobo	Channel	1,26	1,88	0,795	7331
Pelaez y Correa	Channel	1,25	1,76	3,410	29438