Juanelo (1501–1585)

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Abstract Juanelo Turriano was a clockmaker, astronomer, mathematician, and a mechanical and hydraulic engineer. He worked for kings Charles I and Philip II during the Iberian Empire. His most important device was called the "Dancing Machine" and was built in the sixteenth century in Toledo, the capital city of Spain at that time, to raise water from the River Tagus to the city, 90 m above the river, with only the power of the water flow. He is also famous because he is supposed to be co-author of the "The Twenty-One Books of Devices and Machines of Juanelo Turriano" written in the second half of the sixteenth century.

Biographical Notes

Giovanni Torriani, known as Gianello Turriano or Juanelo Turriano, was born in 1501 in Cremona (Italy) to a humble family. During the long nights as a shepherd, he became very interested in astronomy and others sciences (Del Campo y Francés 1997).

When Charles I of Spain became Charles V of Germany, Juanelo's life changed. The governor of Milan, Ferrante Gonzaga, wanted to give Charles V an astronomical clock made in the fourteenth century by Giovanni Dondi, which was one of the most important medieval technological works. Charles V's interest in mechanical engineering, art and especially clocks was common knowledge. Dondi's clock did not work and Juanelo was the only one able to repair it. This made him a really famous clockmaker. And he received orders from all the courts in Europe for his timepieces.

Around 1530 he came to Spain and became clockmaker to Charles V (Valverde Sepúlveda 2001); he even accompanied Charles V when he retired to the Monastery of Yuste in 1557. One year later, Charles V died and his son Philip II became King

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of Spain. Philip II was not as interested in clocks as his father, thus Juanelo worked for him in other fields such as mathematics. For this, Philip II called him “The Wise Mathematician”. At the king’s court, he became friends with several important Spanish architects and engineers (Del Campo y Francés 1997).

A few years later, thanks to his remarkable water machine in Toledo, Juanelo became known as a magician by the Toledo inhabitants. Even though he was very wellknown at that time, he was very poor because no one paid him for his work; what is more, he had to pay for some of his hydraulic works with his own money.

Juanelo died on 13 June 1585 in Toledo and was buried in the church of the Monastery of El Carmen in Toledo. Up until the last moment, he demanded payment from the city of Toledo but he was never paid, and his family continued with the complaints to the city and even to the king.

Legend says that Juanelo was very old in his last years of life, so he used one of his automatons called “The Stick Man” that begged in the streets, and when someone gave him a coin, he bowed (Cervera Vera 1996). This legend provided the name for a street in Toledo: “Calle del Hombre de Palo” (“The street of The Stick Man”).

Figure 1 shows a plaque in the street in Toledo dedicated to “The Stick Man”, the text reads “Along this street passed the wooden automaton built by Juanelo Turriano, clockmaker for Charles V, to the amazement and perplexity of the crowd”. There is another street named after Juanelo in the centre of Madrid.

Although scarcely any of his works have survived, Juanelo was wellknown during the Renaissance. There are a great number of references to him and especially to his works in many books of engineering of the sixteenth and following centuries,

Fig. 1 A plaque in the Street dedicated to “The Stick Man” of Toledo

as well as in the Spanish literature of Góngora, Lope de Vega and Quevedo. As for portraits, we know that Charles V ordered one, but that portrait was lost as well as the one that Juan de Herrera had in his house. The only surviving objects that bear his likeness are a marble bust and a coin.

The bust, shown in Fig. 2a, was made by Leon de Leoni and is kept in the Santa Cruz Museum in Toledo; it represents Juanelo when he was approximately 45 years old. There is a copy, three times larger, of the bust in the Royal Palace of Madrid, shown in Fig. 2b.

The coin, shown in Fig. 3, is kept in the Archaeological Museum of Madrid. It is thought to have served Titian and El Greco and other anonymous artists of the seventeenth century as inspiration to paint some portraits which look like Juanelo, shown in Fig. 3 (Del Campo y Francés 1997).

As the Iberian Empire grew, Spain became the number one world political and economic power, enabling its empire to reach out to the five continents. It was said that, over the dominions of King Philip II, “the Sun never sets”.

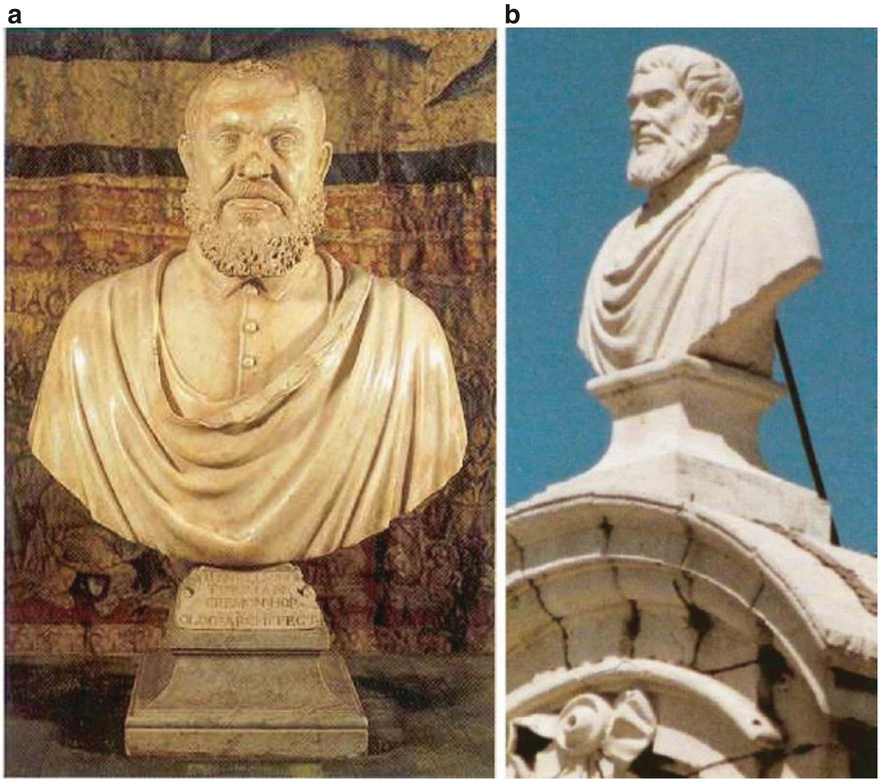

Fig. 2 (**a**) A marble bust of Juanelo Turriano by Leon de Leoni; (**b**) copy of the bust in the Royal Palace of Madrid

Fig. 3 Portrait of Juanelo Turriano on a coin, and a later Portrait of Juanelo (XVII anonym)

Nevertheless, there was a lack of qualified technicians and scientists in Spain at that time (Lusa Monforte 2004), which is quite evident in a letter of Francés de Álava (Bautista et al. 2007), written in the second half of the sixteenth century: "The persons I know in Spain engaged in the service of His Majesty as engineers, except for Fratin (Fratino) and Antonelli, are Jorge Setara, who lives in Perpignan and Baptista Antonelli, brother of the cited Antonelli, who lives in Peñíscola and Cristóbal Antonelli, his nephew, who nowadays is living in Barcelona, and Tiburcio (Spanocci), the one who His Majesty sent to Fuenterrabía, and Felipe Tercio (Terci) who lives in Lisboa. All of them are foreigners, and I do not know a single Spaniard who knows the half of what they do, although I have racked my brains…". In order to avoid such a negative position, a discussion arose about the convenience of establishing a scientific-technical centre in the court.

Juan de Herrera, Juanelo Turriano, Jerónimo de Ayanz and other outstanding engineers and architects in the court, were supposedly decisive in King Philip II deciding the foundation of a popular "Technical Academy" in Madrid (Esteban Piñeiro 2002–2003). The Academy was founded in 1583 and intended for everyone interested in jobs related to the different arts of all the technical activities practised at that time.

List of Main Works

Juanelo's main activities regarding engineering can be divided into two different groups: on the one hand, the design and construction of mechanical devices and, on the other hand, the elaboration of manuscripts.

Mechanical devices:

- Clocks: the "Astrarium" clock and the tower clocks of the monastery of El Escorial near Madrid.
- Two hydraulic devices for raising water from the river Tagus to the city of Toledo.

Manuscripts:

- Breve discorso alla Majestad de Re Catolico interno la reduttione dell anno et restitutione del Calendario con la dichiaratione deglo instrumenti da eso per mostrarla in atto prattico (Brief speech for His Catholic Majesty about the Calendar...).
- "Trattato dell'acque" (Water Treatise).
- Los Veintiún Libros de los Ingenios y las Máquinas de Juanelo Turriano (The Twenty-One Books of the Devices and Machines of Juanelo Turriano).

Review of the Main Works on Mechanism Design

Although he did not usually write about his works, they are cited in many books of other authors at that time. This is our main source of information because none of his clocks, machines or automatons have been found.

In 1530, Ferrante Gonzaga gave Charles V a medieval astronomical clock called the "Astrarium", which was repaired by Juanelo, shown in Fig. 4a. Not only he did repair it, but he also made another one which also showed the planetary

a b

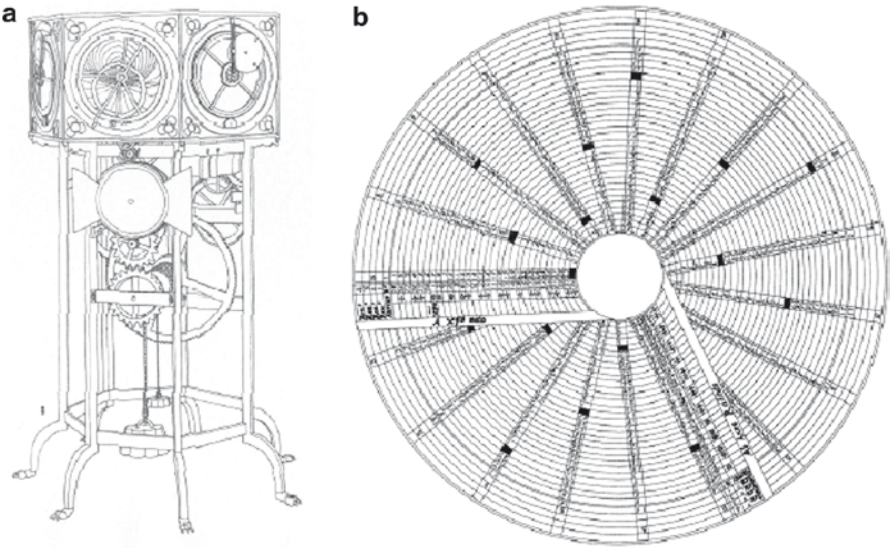

Fig. 4 (**a**) Astronomical clock; (**b**) table obtained from the "Breve discorso alla Majestad de Re Catolico…"

movements. This was called “Crystalline” and it showed the hours, minutes, solar and moon hours, as described planetary movement and it showed the signs of the Zodiac. It was built with more than 1,500 parts, three springs which produced the movement and eight planetary spheres.

When Charles V died and Philip II became king of Spain, Juanelo met Juan de Herrera, one of the most important Spanish architects of the Renaissance and who built the monastery of El Escorial near Madrid (1563–1584). Juanelo took part in the project by helping to build the tower clocks (Del Campo y Francés 1997).

His last job as a clockmaker and astronomer was the solution to the problem of the Catholic calendar. Pope Gregory XIII asked all the kings of Europe to ask the most intelligent people in their courts to give their opinion on this topic. Juanelo not only gave his remarks but also he wrote “Breve discorso alla Majestad de Re Catolico interno la reduttione dell anno et restitutione del Calendario con la dichiaratione deglo instrumenti da eso per mostrarla in atto prattico”, where he detailed two solutions for Easter to be always on the same date (Fig. 4b).

Juanelo also invented automatons with human aspects. Apart from the cited “The Stick Man”, another famous automaton attributed to Juanelo is “The lady from Vienna”, shown in Fig. 5.

His main work is considered to be the hydraulic device built in Toledo between 1565 and 1569, which was ordered by the Marquis of Vasto.

In those days, Toledo suffered from a shortage of water in its reservoir, so they needed a machine which was able to raise water from the River Tagus up to the

Fig. 5 The automaton called “The Lady of Vienna” (García-Diego 1982)

Alcázar, the highest part of Toledo; this meant that the water had to be raised 90 m and it could not be done with a pump because the pipes would not withstand the pressure, as happened with the previous device built by German mining engineers (Bautista et al. 2000).

It had to raise 12,400 L round-the-clock, which meant that the machine had to work non-stop. The current of the Tagus itself served as the driving force as well as supplying the water needed for the city. It was the machine's size that made it very significant as a work of mechanical engineering (Porres Martín-Cleto 1987).

We have no complete drawing of Juanelo's device but there is a manuscript description with a rough diagram, shown in Fig. 6, made by the Precentor of Évora (Portugal) in 1604.

His machine was undoubtedly a great feat of engineering for the time, both in size and complexity. The sizes of its parts and the high forces received were a considerable challenge to the technical know-how of that period. In addition, being a machine with so many moving parts meant the dynamic effects would be significant and its joints subjected to considerable tribological actions (Bautista et al. 2007).

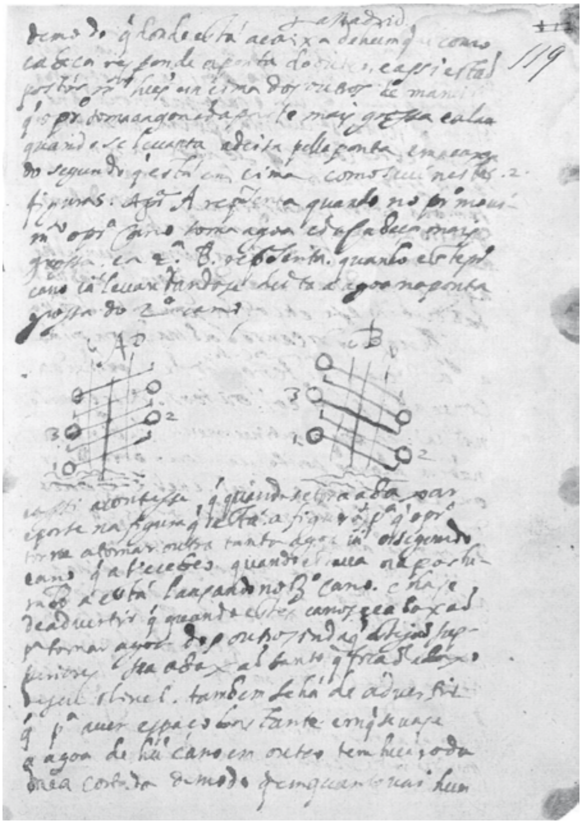

Fig. 6 Manuscript description of the hydraulic device, by the Precentor of Évora (Portugal)

An attempt to explain how this machine worked was published by Luis de Escosura in 1888, though the author himself recognised his doubts about the reconstruction proposed, shown in Fig. 7a. It was based on Valturio's adjustable ladder (1534) shown in Fig. 7b, obtained from the book "De Re Militari" (On the Military Arts).

The different documents of the period and later studies enabled Ladislao Reti to make a fairly close reconstruction of the mechanical device, in 1967, which is shown in Fig. 8.

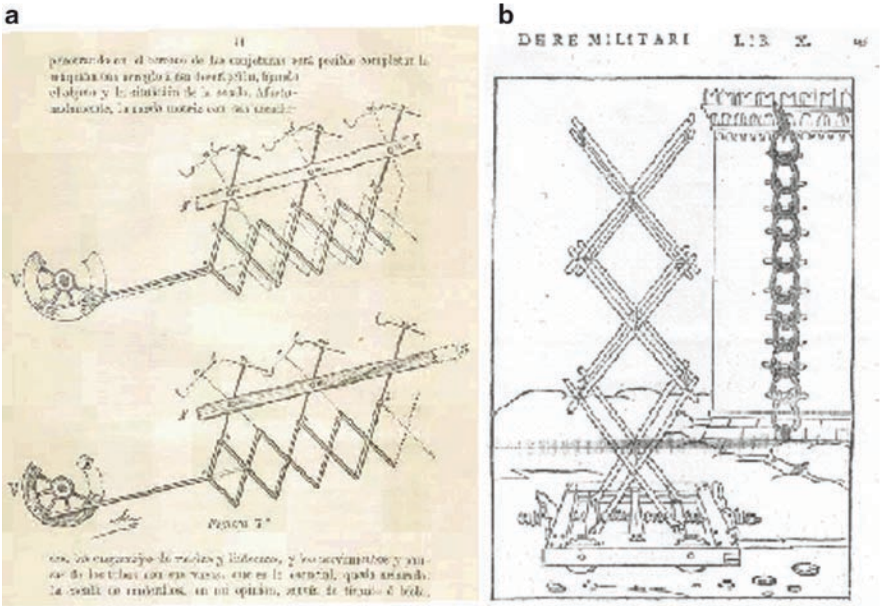

Fig. 7 (**a**) Explanatory sketch of Juanelo's machine, by Luis de Escosura (1888); (**b**) Valturio's adjustable ladder (1534)

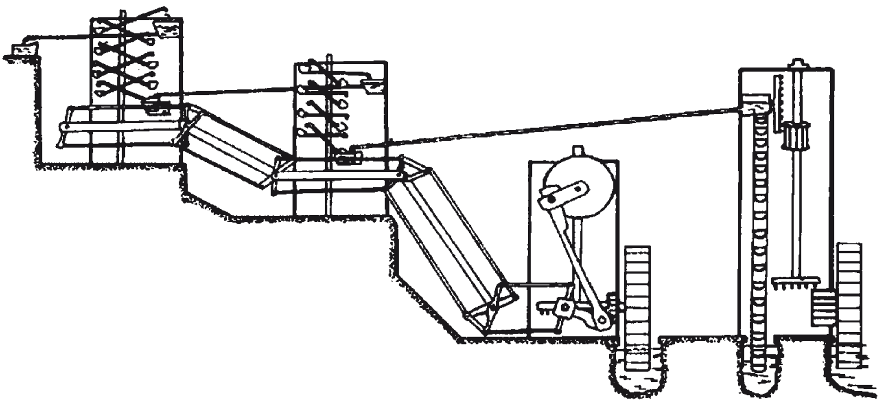

Fig. 8 Diagram of Juanelo's device in Toledo, according to Ladislao Reti's reconstruction

This illustration shows how the river flow operated two water wheels with paddles. The first moved a mechanism with a water wheel that raised the water several metres to a reservoir. The second wheel used another connecting rod-crank-based mechanism to start up the rocking movement of the vertical systems called towers, which enabled the water to be raised from the reservoir under atmospheric pressure.

It was designed to overcome any difference in level, since, as the water ran in contact with the air, no excesses of pressure occurred due to the pumping height, as would happen in a usual pipe system. A greater difference in level only required an increase in the number of sequentially connected towers.

The tower diagram in Fig. 9a shows two working positions for the device, based on a set of pivoted buckets and cups that raised the water in stages, due to the backward and forward motion of the cups. When the water reached the top, it was fed through some pipes to the next tower, and so on until it reached its destination.

Both the device and the way it worked were very curious at the time. These facts contributed to its inventor's fame and the name by which it became popularly known, "The Dancing Machine". A contemporary traveller named Kenelm Digby wrote in respect of the device "…and so the two sides of the machine were like two legs that trod the water in turn".

This gives strength to Nicolás García Tapia's reconstruction (2002) concerning the existence of arches for collecting water from both sides of a tower.

Indeed, Nicolás García Tapia's reconstruction in Fig. 9b of Juan Ramos' diagram shows there were two input and two output arches, situated either side of the tower. When the first cup was introduced into the arch to take water, the opposite one was raised, passing the water on to the next, and each container was full when its

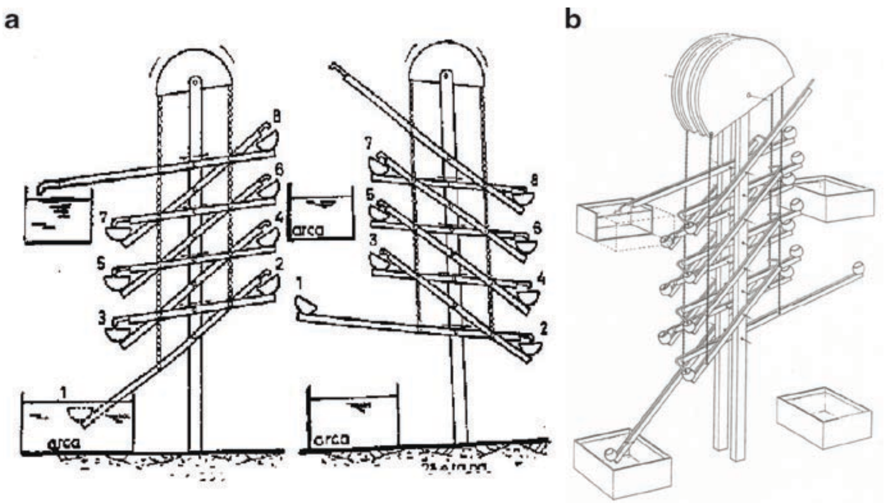

Fig. 9 (**a**) Details of Juanelo's hydraulic device; (**b**) a recent three-dimensional reconstruction of the tower by Nicolás García Tapia

opposite one was empty. The water was thus made to flow continuously with a co-ordinated and precise movement.

Once the device was finished they measured the water volume and it was 50% per cent greater than expected, which meant 17,000 L of water per day.

The first device was a great success, so there was a proposal to build three more devices. However, only the first project came to fruition.

The second device was started in 1575 and finished in 1581 and the water that it supplied was for the town.

When Juanelo died, the only one who knew how to use the device was his grandson who died in 1597.

In 1617, the machine finally stopped working due to lack of maintenance and knowledge of how to use it. The last official document where it is mentioned was an inventory written in 1639.

A machine with a tower quite similar to Juanelo's device can be found in the famous book called "Le diverse et artificiose machine del Capitano Agostino Ramelli" ("The various and ingenious machines of Captain Agostino Ramelli"), a large catalogue of machines finished in 1588, a few years after the death of Juanelo.

Ramelli's book contains 195 superb figures of various kind of machines along with detailed descriptions of each one, including comments on how it was built and how it worked. He endowed his drawings with such clarity that he could be later studied in a large number of fields.

One of the more than 100 water-raising machines described is shown in Fig. 10 (Ceccarelli 2006). It was driven by a water-wheel which moved two gears, the movement being transmitted to a tower with a water-raising system in stages, using a method similar to Juanelo's hydraulic device.

Juanelo shared his knowledge with some of the most important engineers in Spain, during important irrigation works carried out while Philip II was king. The last time that Juanelo was asked for his opinion about a large project was in 1580. The best engineers of that time, Giorgio Fratin, Juan Baptista and Cristobal Antonelli worked on the project of the biggest dam in the world.

One engineering treatise which was supposedly due to Juanelo is the "Trattato dell'acque" (Water Treatise) which is kept in the National Library of Florence. It is considered as a previous work of one of the few written works attributed to Juanelo: "Los Veintiún Libros de los Ingenios y las Máquinas de Juanelo Turriano" (The Twenty-One Books of Devices and Machines of Juanelo Turriano). These books were written in Spanish at the end of the sixteenth century.

Though this work is signed by Juanelo, some experts say that it was not written by him but dedicated to him because of his fame at that time all around the world. Others consider that the reference to Juanelo is used to remark the quality of the manuscript.

Some experts consider the possibility of this manuscript having been written by various different co-authors. In the opinion of Nicolás García Tapia (1987, 1990a, b), one of them could be Pedro Juan de Lastanosa, because the manuscript contains words taken from a Spanish dialect spoken in the area where Lastanosa lived.

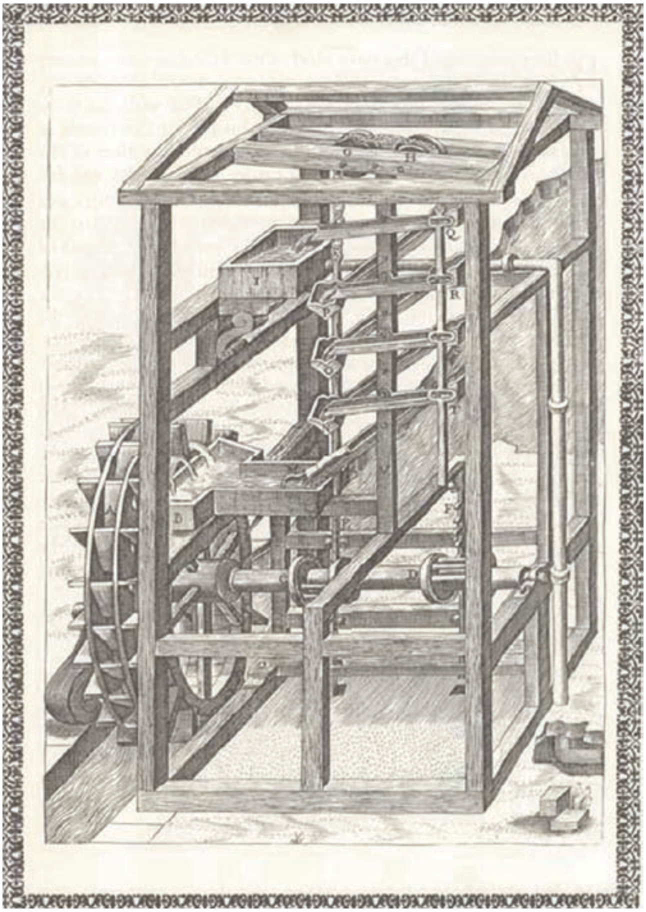

Fig. 10 A water-raising machine included in Ramelli's book

The search for the authors of the Twenty-One Books has promoted the in-depth study of this work.

This collection of books, ordered to be written by "the Catholic King Philip II, King of Spain and the New World", represents an impressive written source for the knowledge of the mechanical arts known and practised in the sixteenth century. Some historians and engineers define it as a Machine Encyclopaedia (Goicolea 2000).

These books, finished in approximately1570, include descriptions of a high number of machines of the time, classified by their function (Instituto Cervantes 1998). They are remarkable in their references to practical devices, such as pumps, mills, elevators, presses and others machines, mainly powered by water, wind, gravity or animal traction.

The front page and some illustrations of machines are shown in Fig. 11. All these machines, and their components, are widely explained and commented on in the text. In detail, this work includes the following contents:

- The first chapter talk about water: its quality, properties, source and effects.
- The second chapter examines the signs that we can follow to find water.
- Chapter 3 teaches how to distinguish between drinkable and non-drinkable water.
- The fourth chapter talks about water levels.
- The fifth chapter teaches how to make water pipes and water conduits.
- In Chapters 6–10 we can read about the different ways of moving water, and storing it.
- Chapter 11 talks about different kinds of mills.
- Chapter 12 teaches how to separate flour from straw.
- Chapter 13 explains the different uses of mills
- Chapter 14 talks about boats that were used to cross rivers when there was no bridge.
- Chapter 15 talks about wooden bridges.
- Chapter 16 talks about materials like wood and stone.
- Chapter 17 includes more precise information on stone: how to treat it and its quality.
- Chapter 18 sets out different ways of building stone bridges.
- Chapter 19 talks about how building in ports should be done.
- Chapter 20 explains how to protect ports from the open sea.
- The last chapter talks about tides, water clocks and the different effects of water.

On the Circulation of Works

Thanks to official letters, literature and some engineering books of that age, we have been able to earn something about Juanelo's devices, mainly regarding the hydraulic devices built in Toledo.

During the Iberian Empire, the interest in mechanical engineering remained patent with the manuscript "Trattato dell'acque" (Water Treatise). The treatise is written in Spanish and was discovered recently in Florence by the researcher María Teresa Cacho. It has 84 pages and approximately 350 images and is supposedly a preliminary work of the most important manuscript attributed to Juanelo: "Los veintiún libros de ingenios y máquinas" (The Twenty-One Books of Devices and Machines), completed in 1570.

The Twenty-One Books kept in the National Library of Madrid (www.bne.es) have 949 pages and 509 images, including most of the illustrations of the previous Water Treatise. In addition, in these Twenty-One Books, the author improves the clarity of the comments and the quality and details of the figures.

The original manuscript was not published at that time due to the information about materials and works that required the Royal Permission of Philip II. Its publication would have allowed a dissemination comparable to the most

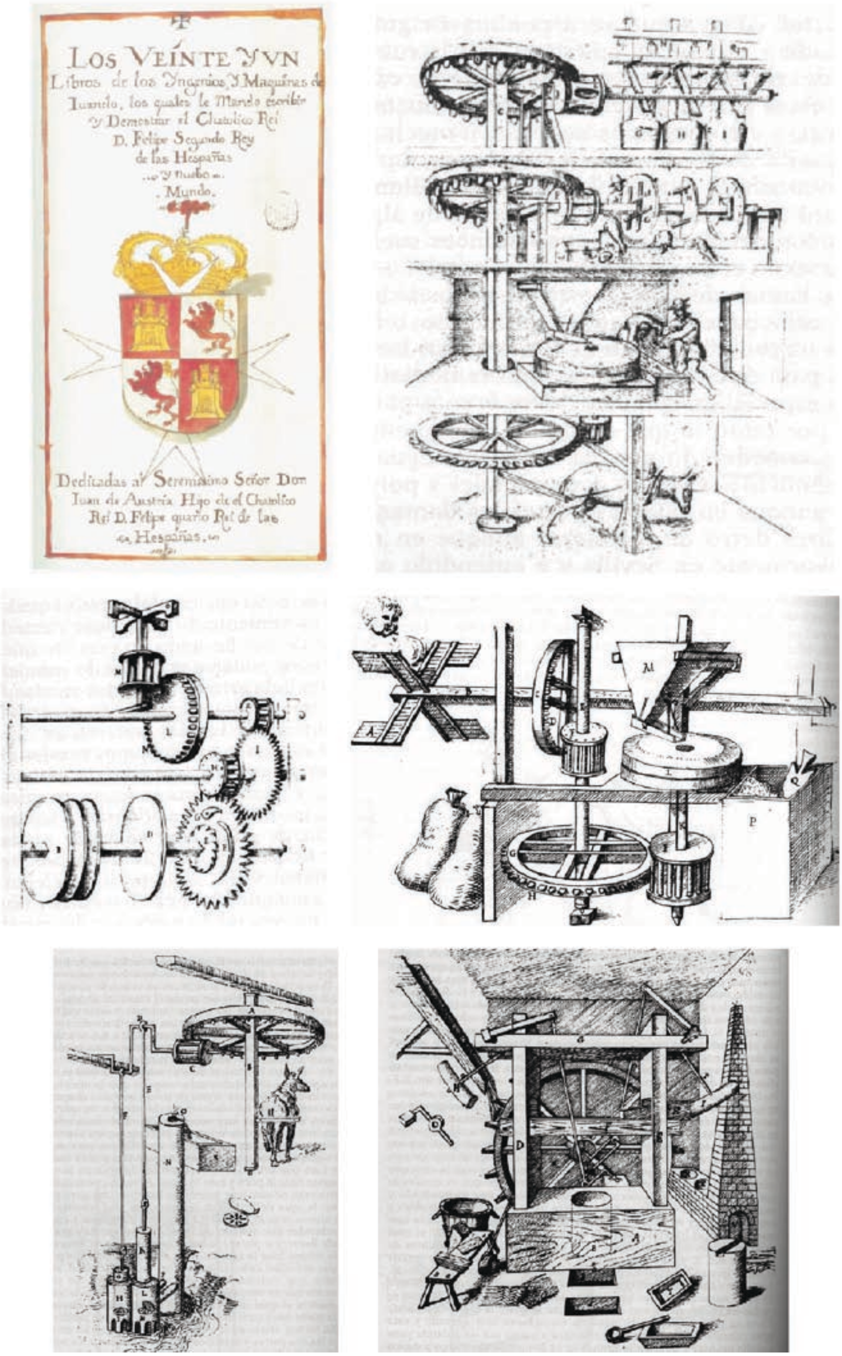

Fig. 11 Front page and some machines in the Twenty-One Books

remarkable European treatises of the Renaissance. It was known and probably used by important engineers and architects during the seventeenth and eighteenth centuries, such as Gómez de Mora, Teodoro Ardemans and Benito Bails.

These Twenty-One Books remained in hiding until the 1960s of the past century when some historians interested in technology rediscovered them, publishing diverse works. Professor Alexander Keller, researcher in the field of History of Science, contributed to the spread of Juanelo's work by translating the Twenty-One Books into English. The Civil Engineers Association published an edition in 1983 and the Juanelo Turriano Foundation (www.juaneloturriano.com), created in 1987 by the Engineer José Antonio García-Diego, prepared a facsimile edition in 1997.

There is another copy of this work, also entitled The Twenty-One Books, kept in Barcelona. This issue is quite similar to the one in Madrid, with 609 pages and 404 figures. It belongs to a private collection and this is why it is not yet well known.

Modern Interpretation of the Main Contributions

Although we do not know exactly what they were like, Fig. 12 shows some modern reduced-scale models of the hydraulic devices originally designed and built by Juanelo (www.juaneloturriano.com) (Jufre 2007).

In addition, Fig. 13 shows some recent virtual reconstructions of the hydraulic devices and the spheres of the astronomical clock made by Juanelo (Bermejo 2005, Jufre 2007).

It is remarkable that the Proto-industry in the sixteenth century, regarding early industries involved in manufacturing goods for trade, has been recently studied by Keller and Silva Suárez (2004), following the contents of The Twenty-One Books of

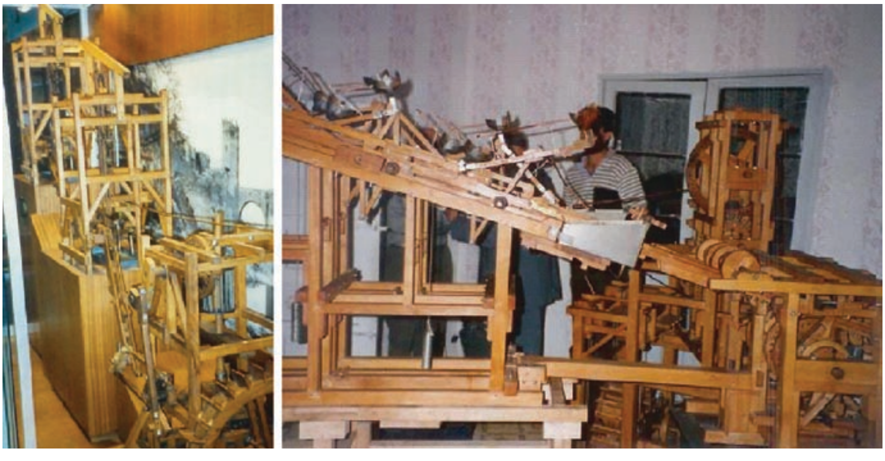

Fig. 12 Reduced-scale models of the hydraulic devices

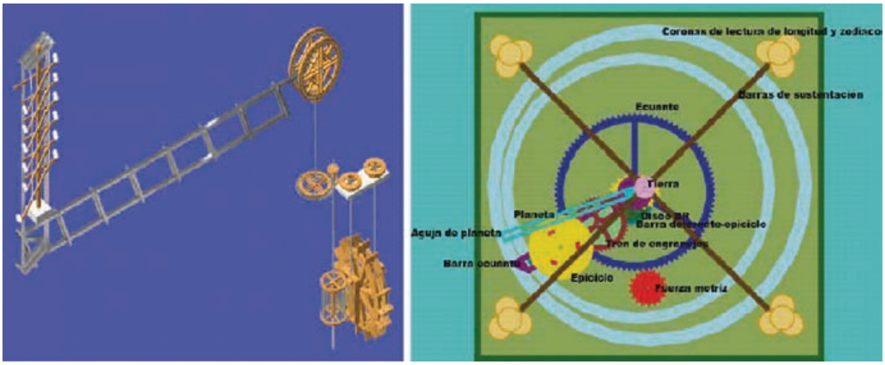

Fig. 13 Virtual models of some famous devices: the hydraulic devices and the spheres of the astronomical clock

Devices and Machines. The detailed analysis of the treatise from this point of view enhances the knowledge on the state of technology at that time concerning different kinds of grinding mills and other devices moved hydraulically, such as oil-presses or fulling hammers. Other Proto-industrial processes are also described, such as the washing of wool, and the production of starch, alum, vitriol and saltpetre.

The discovery of the Twenty-One Books of Devices and Machines, was added to the recent studies developed by García Tapia (1990a, b, 2001) concerning "Royal Privileges for Inventions" (or Spanish Patents) mainly at the end of the sixteenth and the beginning of the seventeenth centuries.

The quantity and quality of the registered inventions, with or without Royal Patent, lets us suppose a rapid increase in the number of scientists and technicians, coming mainly from Italy and other European countries, to serve the Spanish Crown, constituting a genuine community, essential for the technical and scientific growth of the Iberian Empire during its Golden Age.

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