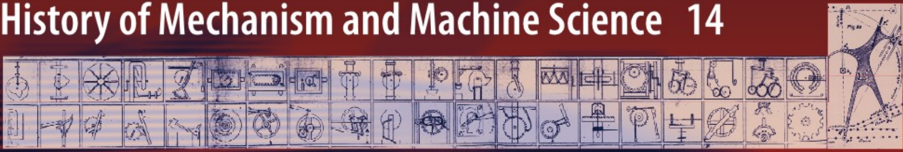
History of Mechanism and Machine Science 14



J. M. de la Portilla
Marco Ceccarelli *Editors*

History of Machines for Heritage and Engineering Development

Springer

History of Machines for Heritage and Engineering Development

HISTORY OF MECHANISM AND MACHINE SCIENCE

Volume 14

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History of Machines for Heritage and Engineering Development

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Preface

This volume contains a selection of papers whose content have been presented in the International conferences CIPHI on Cultural Heritage and History of Engineering in the years 2006, 2007, and 2008 at University of Las Palmas de Gran Canaria in Canary Islands, Spain, The organizers of these yearly conferences are The International Centre for Heritage Preservation (CICOP) and the Polytechnic Faculty of Engineering (EUP) with co-organizing institutions as Forum UNESCO University and Heritage and the TICCIH Spain. The International Centre for Heritage Preservation was created in the Canary Islands in 1992 with the aim to have an headquarter point of coincidence in Spain between Europe and Latin America.

The conference series is aimed at bringing together researchers, scholars and students from the broad ranges of disciplines referring to the History of Engineering and Cultural Heritage, in a unique multidisciplinary forum to stimulate collaborations among historians, architects, restaurateurs, and engineers.

The aim of the book is to collect contributed papers within an interdisciplinary framework that can serve as reference on history of machines for heritage and engineering development, as indicated in the title. The book scope has the characteristic that the papers illustrate, by attaching specific emblematic topics and problems, technical developments in the historical evolution of engineering with an attention of cultural heritage. Thus, emphasis is given to a discussion of matters of cultural heritage with engineering history by reporting authors' experiences and views. Indeed, most the authors of the contributed papers are experts in different topics that usually are far from each other. This has been, indeed, a challenge: convincing technical experts (engineering and architects) and historians to go further in-depth into the background of their topics of expertise with both technical and historical views to the problem of the conservation of material and immaterial goods of cultural heritage as related to the history of machines and engineering.

This volume has been possible thanks to the invited authors who have enthusiastically shared this initiative and who have spent time and effort in preparing the papers in much more details that in the conference presentations.

We believe that readers will take advantage of the papers in this book and future ones by supplying further satisfaction and motivation for her or his work (historical or not) with interdisciplinary activity in valuating the past heritage both in goods and engineering developments.

We grateful to the authors of the articles for their valuable contributions and for preparing their manuscripts on time. Also acknowledged is the professional assistance by the staff of Springer Science + Business Media and especially by Miss Anneke Pot and Miss Nathalie Jacobs, who have enthusiastically supported this book project with their help and advice.

We are grateful to our families. Without their patience and understanding it would not have been possible for us to work on this book and coordination of so many people from different fields of activity.

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June 2010 Editors

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Reutilization of Our Industrial Heritage: The Unique Example of the Royal Segovia Mint in Spain (1583)

Glenn Stephen Murray Fantom

In this conference we will explain the reasons for which the Royal Segovia Mint is considered to be the world's oldest, most complete, still standing, complex, departmentalized industrial manufacturing plant designed for in-series, mechanical production. We will also review the project currently under way to convert the historic site into a living workshop museum of coining technology (Fig. 1).

1 Introduction

No industrially manufactured product has been more important to the development of civilization as a whole than that of coinage. Coins -and by extension money- have been the workhorse of mankind for over 2,640 years. It is a manufactured product which has liberated virtually every person on earth from the tedious chore of having to tend to our own crops in order to simply eat, and thus enabling the multifaceted society which we know today.

Product security has always been the primary concern of governments in the manufacture of coinage from its very invention around 640 B.C. even until today. Every improvement made in the technical process for its elaboration has been purposefully designed specifically to insure product quality and its inviolability once placed in circulation. Indeed, each individual example of this industrially manufactured product was used day in and day out by an infinity of people, as it was passed from one hand to another over an extensive geographic range, for dozens and often up to hundreds of years before finally being melted down, lost, hidden, or eventually winding up in a museum or private collection. Contrary to many other industries, almost all new production techniques were specifically implanted in order to assure governments of this product quality or security, rather than to reduce labor force or cut production costs (Fig. 2).

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Fig. 1 Photo of the Segovia Mint in 1870, one year after all coin production ended (Photo: Laurent, 1870 (I.P.H.E., Madrid))

Fig. 2 Coins with different types of edges. Hammer struck pieces with irregular edges facilitated illicit clipping and filing of metal

Primary in the assurance of a quality product has always been the goal of making each coin not only resemble identically the others of its kind, but to adhere to the exact same specifications regarding weight, fineness, stamped design, etc. Indeed, the principle interest of any government concerning its coinage has always been to avoid its illegal falsification, a truly unique product concept not really appreciated until modern times. Today we see the falsification and sale of designer watches, apparel, cosmetics, entertainment CD's, etc. As a result, the one factors most important in producing a quality coinage has been the inception of in-series production, and the primary key which has enabled this important goal has been the mechanization of the coining industry, a technological achievement now over 440 years old.

Whereas coin manufacturing plants, or mints, have always been rigorously controlled by governments to assure quality, the mechanization of this process did not begin until around 1551. The origins of this major improvement are to be credited to German technicians from the city of Augsburg, where 100 years earlier, Guttenberg invented the printing press. Slowly spreading to a few mints in the surrounding area on an experimental basis, we can say that the first truly successful mint mechanization project was at the factory in Hall in Tirol, Austria (1567), from where this procedure was soon transferred to the Spanish city of Segovia (1584), in what is considered today to have been the largest, most important and distant transfer of sophisticated industrial technology ever undertaken by mankind up until then.[1] Today, the Royal Segovia Mint is recognized by TICCIH-Spain as the oldest still-standing industrial monument in Spain.[2]

As a general conclusion to this paper, we propose that authorities recognize the Segovia Mint as the world's oldest, most complete, still-standing, complex, departmentalized, industrial manufacturing plant, specifically designed from its origin for in-series, mechanical production of one of mankind's most important, oldest, highly regulated and controlled precision products of exacting specifications: coinage, the single manufactured product used by more people, over more time, than any other ever invented by mankind.

2 Industrial Products of the Sixteenth Century

In order to fully understand the relative importance of coinage as an industrially manufactured product in the sixteenth century, it is necessary to first review the nature of other products produced during the same period of time. We will use the sixteenth century as our base reference point, since that is when the coinage process was first mechanized, and also when the Royal Segovia Mint was built. Therefore this is the period in which we will intend to show that the industrial procedure used in coin manufacturing was the most sophisticated ever used in any industry.

To begin with, the manufactured products of those times were basically limited to relatively primitive manipulations of raw materials such as agricultural grains, textiles, metals, basic chemicals, wood, leather, paper and glass. Production was carried out in simple artisan-like work shops, with a minimum of hand-tools such

[1] García Tapia (1989).

[2] General Assembly of TICCIH-Spain, in Tarrasa (Barcelona), on October 22, 2004.

as hammers, saws, scissors, chisels, bellows, and the like. Occasionally, successive steps were carried out by different people in their own homes or workshops, each passing the unfinished product to the next, but organized manufacturing plants were simply not needed. Many different hand-tools were used, but machines were almost unheard of except for those used to mill, grind or roll, and these were generally powered by hand except in the most sophisticated cases where horses or water wheels were geared by wooden mills to move simple rollers, grinders, or pounders.

Agriculture is said to have been the first industry and the processing of its raw products was undoubtedly the first to benefit from mechanization. Grinding and pressing of grains, olives, sugarcane, etc. with wind, water and horse-powered turn-stones, was very common. These procedures were well established prior to the sixteenth century, but were never more than simple tasks able to be performed by one person with no specialized skills in relatively small non-complex factories.

In the mid fifteenth century Gutenberg invented the printing press with movable type, without a doubt a great step forward for mankind. The resulting product -printed pages and books-, though obviously produced in-series, were made in small artisan-like workshops and large staffs of different highly specialized technicians, or departmentalized manufacturing plants, were simply not required.

The production of textiles is also an ancient craft which required no specialized skills or machinery, though different steps were often carried out by different people, often organized, each in their own home or workshop. Looms were primitive and manual. Certain government imposed specifications, often quite detailed, were applied to the manufacturing procedure in order to assure a quality product, but none of these can compare to those imposed on the coining industry, which of course used gold and silver as a raw product, not wool or cotton. Regarding textiles, no industrial or manufacturing plant was needed until the mechanization of the process took place towards the end of the eighteenth century, leading to what we know today as the Industrial Revolution.

Metallurgical products -among which we find coinage- were quite varied in the sixteenth century, and their manufacturing procedures were, without a doubt, the most sophisticated of those times. Specialized plants worked to extract metals from ore or mineral, often refining them to a specific degree. Completely different plants specialized in manufacturing consumer products from the raw metal. Metallurgical expertise, though basically empirical in nature, has been fundamental in the advancement of civilization. However, complex manufacturing plants for in-series mass production of consumer ready products did not come about until the Industrial Revolution was well under way.

Smelters were plants where the raw ores were fused in order to extract the metallic constituents. Documents from as early as 1335 attest to the fact that these factories in northern Spain had water wheel driven drop hammers. By the sixteenth century, there were over 200 of these smelters in the Basque country alone, each one producing up to 100 t of iron a year. The factories were often quite large, had their own weir, canals and as many as six large water wheels. There were separate departments for the drop hammers, bellows, charcoal bins, warehouses, living quarters for up to 20 or more workers, etc. Vast quantities of charcoal and mineral were needed, and were often transported locally in specially designed boats. These operations were quite expensive to set up and run. After the fourteenth and fifteenth centuries the installations were gradually modernized and enlarged with bigger water wheels and drop hammers. The wooden canals used in the fifteenth century were replaced by stone canals towards the eighteenth century. Successive modernizations almost always obliterated or buried the remains of the previous plant to such a point that practically all of the ruins existing today date from the eighteenth century (Fig. 3).

Smelting plants were extremely important as a raw source of metal for other industries. These were quite possibly the factories that most resemble what we could call an industrial complex of the sixteenth century. But the process -though mechanized with drop hammers and bellows- technically speaking, was empirical in nature, requiring a specific skill, but not complex in that numerous very different highly specialized experts were needed. We should also consider that their final product was not a finished consumer-ready item (such as coinage), but a raw material -metal- that was later used by various other industries that subsequently produced the final product. Nor can the production of these smelting plants be considered an item mass produced in series. Indeed many historians of industry consider smelters to be examples of paleoindustry. For all these reasons, we should not confuse the smelting industry and its often large plants, with the type of industrial process being carried out at the Segovia Mint in the 1580s, and its highly complex, departmentalized manufacturing plant.

Refined metal served as a raw product for other industries, such as those which produced tools like saws, hammers, chisels, agricultural utensils, nails, sheet metal, wire, etc., produced by blacksmiths in small artisan-like forges or workshops. None

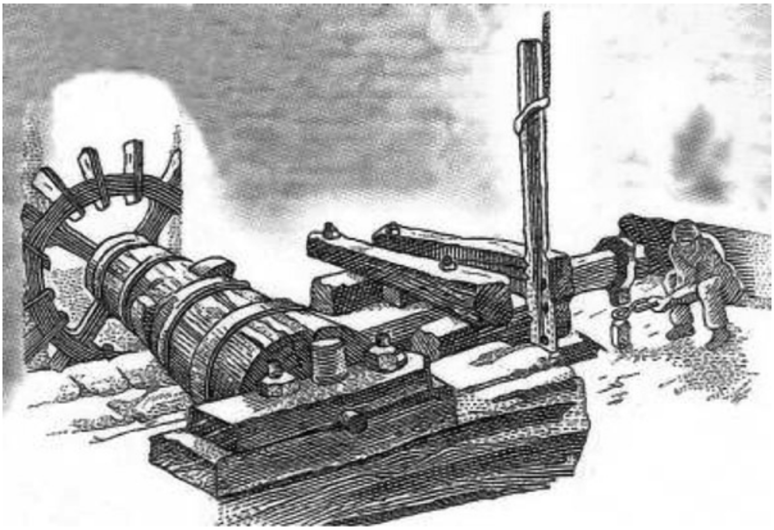

Fig. 3 The smelting plant at Compludo, Leon (Spain)

of these products were mechanically produced in-series until the Industrial Revolution. Jewelers and silversmiths have handcrafted magnificent works of art since the times of ancient Egyptians, Aztecs and Inca, and by the sixteenth century many of these were indeed quite elaborate. But these items were not mass produced in series or by mechanical methods until the Industrial Revolution.

Weapons manufacturing in the sixteenth century, just as today, has always enjoyed great interest from governments, and thus from inventors, technicians, and business enterprises. Finding money to fund this industry, then as today, was rarely a problem. Light arms such as pistols, harquebuses, muskets and the like were all being produced with a combination of metallic and wooden components. Nevertheless, production was always carried out in small artisan like workshops each one dedicated to a certain part of the weapon -barrel, lock, wooden handle, etc.- and another assembled the pieces together. The workers were often organized into guilds. The entire process was manual except for the boring of the barrel which was typically done with a water wheel driven machine.

Roller-dies used for the mechanical in-series production of coinage beginning in the second half of the sixteenth century, were high-precision tools made from specially hardened Milanese steel, using the combination of expertise of two specialized technicians: a highly skilled smith, and a master engraver. These two professionals, together with their assistants, worked in separate and specialized departments of the industrial plant, or mint: the smithy and the engraving office. The difficulty of preparing these roller-dies, coupled with the fact that they could only be used in specially designed water-powered mills, represents the maximum expression of purposely designed product security ever achieved by mankind until then. Spanish King Phillip II (d., 1598) often said that the best guarantee that existed against the falsification of his coins, was that no one else had similar dies or machinery (Fig. 4).

In Spain, King Phillip II constructed a building in 1558 for the purpose of receiving the arms which were bought from individual producers, testing them one by one, and later storing them until their distribution. This plant was named the Royal Arms Factory of Plasencia de las Armas, in the Basque country, but the production of the weapons was carried out externally by different artisans, and the royal

Fig. 4 Segovia roller die (Madrid Mint Museum)

organization was limited to placing orders, supervising, testing, storing and distributing the weapons. Another royal gun factory was built in Oviedo towards the end of the eighteenth century where weapons were built and assembled, but in general this artisan-type of organizational system lasted until the nineteenth century. Interchangeable musket parts were not designed until 1785 (Le Blanc). Eli Whitney (1765–1825) after inventing the cotton gin also worked on interchangeable parts for weapons, obviously requiring much greater precision than the interchangeable type letters used by Gutenberg. Samuel Colt obtained a patent for his revolver in 1836, but by 1851 still was not able to produce interchangeable parts for this famous weapon. This type of in-series production depended on high precision machine tools, and of course the industrial plants which eventually housed this type of industry were subsequent and essentially define today what we consider a "modern factory". These inventions are of course much later in time than the Segovia Mint, a factory we propose to be called the first truly modern factory. Nevertheless, we mention them to emphasize the importance that mechanized precision had in the development of industry, while pointing out that both the weapons and the coining industries were heavily patronized by governments and thus of relative priority.

The heavy arms industry, such as the manufacturing of cannons was another metallurgical based process, composed principally of founding large pieces of bronze, and later boring their center. The construction of these pieces was somewhat difficult and cumbersome due to their size and weight, but not complex in nature nor did it require specialists other than a skilled founder and a few well trained assistants. These same founders could also make large church bells, anchors, and other similar items, but always using one-by-one, artisan-like methods. Small items were in fact made in-series since early times by using molds, but again the only expert needed was a founder and his assistants. The same can be said for the manufacture of side arms such as swords and knives, generally made by blacksmiths in small artisan-like workshops often equipped with water wheel driven drop hammers and grinders. None of these products were mass produced in-series in large manufacturing plants by a highly diversified staff of specialized technicians during the sixteenth century, as was coinage. And certainly none were as influenced by specific efforts aimed at designing product security, as was coinage.[3]

Chemical products ranged from gunpowder to dies for tinting, but these were relatively simple products whose procedures were mostly carried out in artisan-like workshops where different ingredients were ground and mixed. Other products like paper and glass were also simple in nature and not demanding of industrial plants, mechanized procedures, or highly specialized technicians. A machine to automatically manufacture glass bottles was not developed until 1907 (Owen).

Finally, we should point out that the Industrial Revolution itself is defined as the totality of the changes in economic and social organization that began about 1760 in England and later in other countries, characterized chiefly by the replacement of

[3] Special thanks to José María Izaga Reiner for his assistance on non-coining industries.

hand tools with power driven machines, as the power loom and the steam engine, and by the concentration of industry in large establishments.[4] In these respects, the Segovia Mint, as we will see below, with its mechanized in-series production technique was truly -as numerous historic documents attest- the vanguard industrial plant of its days, successfully fulfilling a wide range of complex operational goals nearly 200 years before the Industrial Revolution began.

3 The Case of Coinage

The manufacture of the first coinage is today attributed by some experts to merchants, and by others to government authorities, and dates from around 640 B.C. in Lydia (Turkey), when bits of metal (electrolyte: a naturally occurring combination of mostly silver and gold) of uniform weight were stamped with identical designs for easy identification as they passed from one person to the next. Regardless of which sector first invented coins, governments rapidly realized that the new invention was an ideal manner in which to pay salaries of distant troops and a safer and more effective way to amass wealth. Obviously, the mass storage of grain, animals and the like, over time, as well as their transport, or division into fractions, had serious drawbacks.

As a result of government intervention in the new product -whose importance is difficult to exaggerate- specifications for its production were quickly mandated. First to appear was a symbol to identify the city of origin: a mintmark. Next, coinage weights were standardized and metal quality, or fineness, was also quickly established. While early Greek coins were stamped with designs of animals or gods, Roman authorities wasted no time in putting the ruler's effigy on their coinage, a truly effective manner to show power and exercise authority over each and every citizen in times before other media could constantly remind people of who their ruler was, as well as what he looked like. Indeed, due to these early characteristics, we can venture to say that coinage was the first mass produced product to carry a symbol of origin or guarantee (mintmark) and the first means ever used for mass publicity or propaganda (the ruler's name and effigy) (Fig. 5).

Over the centuries, other improvements were gradually incorporated into coinage. An assayer mark or symbol was to appear on each piece to identify the person responsible for the proper fineness of the alloy used to strike the coin. The date of production appearing on each piece provided an additional method of control which was first begun in Spain at the Segovia Mint in 1586 and ordered at all other mints in 1588. The combination of the mintmark, assayer symbol and date on each coin struck enabled the easy identification of the workers responsible for the quality of its production, and thus facilitated their punishment in cases of fraud, no matter when or where the piece was found in circulation. Indeed, we can venture to say

[4] *Websters Encyclopedic Unabridged Dictionary*, Portland House, New York, 1989.

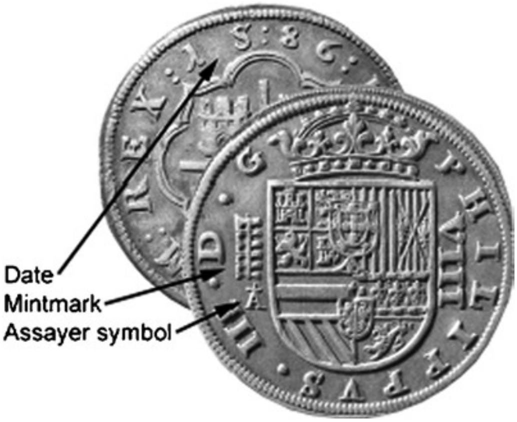

Fig. 5 National Museum of Archaeology, Spain

that coinage was the first mass produced product, intended for general use, which carried three different symbols or marks of guarantee, or government control, a truly modern concept in industry. Each of these individual improvements -regulated and controlled by way of specific mandates issued by the highest government authority as a matter of state- were carefully designed and implemented methods of assuring product security.

4 Problems of Early Coinage

During the first 2000 years of coinage production, the product had always been manufactured by the ancient hammer-struck technique. And though we can venture to say that at the dawn of the sixteenth century -the start of the Modern Era- coinage was perhaps the most sophisticated of all mass produced, industrial products, it was not without specific problems which needed to be solved. Among the most important of these were: obtaining an exact uniformity from one die to the next used for striking coins of the same kind; assuring that the design engraved on the die appeared fully on each coin struck; obtaining perfectly flat and uniformly circular blanks, all of the exact same weight; and perhaps one of the most important of all, finding a way to thwart the illicit art of those who clipped and filed bits of gold and silver from coins once placed in circulation; not to mention problems posed by counterfeiting (Fig. 6).

The solution to practically all of these problems was to be found in the mechanization of the manufacturing process. In this regard, it is important for us to realize that the primary goal of the minting industry has always been, and still is, the mass production in series of exactly identical pieces. The designing of product security in this industry has always been foremost in the minds of governments, inventors, and technicians. Considering the fact that the predominant value of coinage in circulation in the world until around the middle of the twentieth century has been in the form of pieces stamped of gold and silver, it is no wonder that product security has always been more important than reducing labor forces or cutting production costs, at least as far as this specialized industry is concerned, especially since governments were always able to manipulate standards or values in order to assure substantial profits (Figs. 7–17).

Fig. 6 A seriously clipped, hammer-struck coin. Madrid Mint Museum

Fig. 7 Bronze, circa 30 B.C. Segovia Savings Bank

Fig. 8 Billon, 1379–1390. National Museum of Archaeology, Spain

Fig. 9 Gold, 1497–1535. National Museum of Archaeology, Spain

Fig. 10 Silver, 1597–1598. Javier Verdejo Sitges. Hammer-struck coins produced at the Old Segovia Mint which show obvious defects which were eventually overcome by the mechanization of the industrial process in their manufacture

Fig. 11 Depiction of the preparation of cylindrical rollers in the Konstanz Mint (Germany) in 1624, thought to be the oldest known graphic representation of a metal-turning lathe. Rosgartenmuseum, Konstanz, Germany

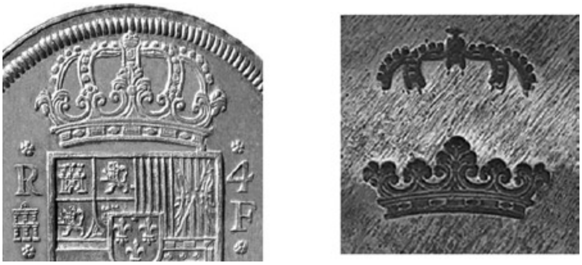

Fig. 12 Coin and punch-block for roller-dies from the Segovia Mint in 1728. The crown is composed of two punches since the vertical extension of the design is severely limited by the curvature of the cylinder. Madrid Mint Museum

Fig. 13 Punch and punch-block for flat dies made in Madrid in 1770 and sent to the mint in Potosí, Bolivia. The crown is composed of one punch. Glenn Stephen Murray Fantom

Fig. 14 Punch-block for cylindrical dies from the Segovia Mint circa 1700 – 1730. Madrid Mint Museum

Fig. 15 Collection of punches at the Mexico City Mint. Glenn Stephen Murray Fantom

Fig. 16 Punches and punch-block for flat dies made in Madrid in 1770 and sent to the Mint in Potosí, Bolivia. Glenn Stephen Murray Fantom

Fig. 17 Punch and punch-block for flat dies made in Cadiz in 1810 and sent to the Mint in Potosi, Bolivia

5 Design Innovations to Improve Coinage Die Making

Before we examine the improvements brought about by the mechanization of the minting process, it is fundamental for us to understand the importance of the dies from which the individual pieces are struck -or in certain cases rolled- and how they are produced. If one of the most important goals of the coining industry, as we have said, is to thwart counterfeiting, then nothing is more important to achieve this goal than the uniformity in the engraving from one die to the next.

Individual dies -made of tempered and hardened steel- last anywhere from the striking of a few hundred or thousand pieces with luck, back when coins were first invented, to up to 800,000 coins today.[5] As a result, in order to continue a series being issued, it has always been necessary to change dies when the ones in use fracture, break or simply become worn out, factors greatly influenced not only by the quality of the steel, but also the skill used in their tempering and hardening process. This die-life problem was also compounded by the need to send multiple dies to different mints striking the same issues, since the resulting product needed to be identical from one factory to the next (except for the small symbol or mintmark which identified the issuing plant).

So that each coin, from the first to the last struck of any one issue and from one factory to the next appear exactly identical, the primary key is the technique used in the making the die, which in its own right, should be considered a completely separate manufacturing process than that of striking the coin. Indeed, the continuous, day to day manufacture within a mint of these specialized tools -dies- which were needed to produce a totally different product -coins- within the same factory, bears testimony to the nature of minting as a truly complex industry and coinage as the earliest and most sophisticated product manufactured in series. Regarding the importance of die production: the slightest variation from one die to the next leaves the door wide open to counterfeiters, whose illicit art has always been facilitated precisely by die variations as they appear on coinage.

Historically, dies were engraved individually, one by one, by hand, by master craftsmen who were without a doubt, the most highly specialized and valued technicians of any mint. Eventually, and as a concerted effort to improve product security, steel punches were made of individual design elements such as letters, numbers, symbols such as the mintmark, animals, effigies and the like. These raised-relief punches were carved from tempered steel, then hardened and their imprint punched into a matrix, or punch block of tempered steel. Once the punch block was hardened, multiple identical punches could be produced by pounding a tempered blank punch into the incuse design on the punch block or matrix. Once these new multiple raised-relief punches were subsequently hardened, they could be used to punch out the incuse working dies needed to strike the raised-relief coins.

[5] <http://www.teercoatings.co.uk/index.php?page=mostind>

It is quite obvious that these matrices, or punch blocks, were the key to producing identical coins over a long period of time, or at a variety of different mints or factories.

Nevertheless, these punches and punch blocks were produced by manually hammering the two pieces of steel together, a technique which limited the size of punches and increased the number of different ones needed to compose the final and complete engraving on the working die. Obviously, the correct spacing of the impression of these punches on the working die was of critical concern as well, since any variation from one working die to another would show up as variations between the different coins themselves. This problem was not finally solved until matrices could be made of the entire coin impression, and this was obtained only when screw-presses capable of applying many tons of stable and controlled pressure were developed and installed in mints starting around the late seventeenth century. Also worthy of mention is the fact that the engraved coin design on the roller-die had to be oblong in order to compensate for the stretching or elongation of the metal as it passed between the rollers (Figs. 18–21).

Fig. 18 Sheet pounding, blank cutting and annealing, and coin striking in a non-mechanized hammer mint. National Library, France

Fig. 19 Problems of spacing are evident below the coat of arms on these coins. National Museum of Archaeology, Spain

Fig. 20 Pounding the edges of a stack of coins to round out the edges. Schweizerisches Landesmuseum, Zurich

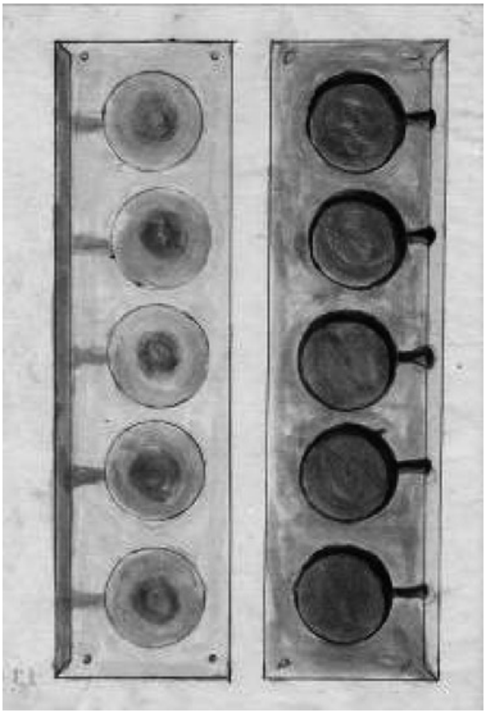

Fig. 21 A mold for making blanks. Saxony State Archive, Weimar, Germany

6 Rolling, Striking and Cutting Techniques

Next in importance after die quality in the coining process is the rolling, shaping and cutting of the metal onto which the coin image is to be stamped. The first coins were hammered onto blanks which were produced by pouring liquid metal into tiny, open-faced molds. This was not only cumbersome, but produced slightly rounded or almond-shaped blanks, onto which it was difficult to strike the coin design from a flat die and have the entire design appear or show up evenly with the same depth or intensity. Closed molds were also used, but the branch of metal remaining from the flow entrance had to tediously be removed later.

This problem led to the pounding out of sheets of metal, from which the blanks were then cut with metal cutting scissors or shears. The resulting blanks were much flatter, but still with significant variations from one part of the sheet to another, from one sheet to another, and from one worker to another. It was also difficult to cut round blanks with straight shears, and thus the blanks had to be filed or stacked and pounded with a special hammer to correct these deficiencies resulting from such a primitive, artisan-like production technique (Figs. 22–26).

Finally, in the early sixteenth century, rolling mills were developed by the metal-lurgical industries for flattening metal strips, a technique which eventually led to

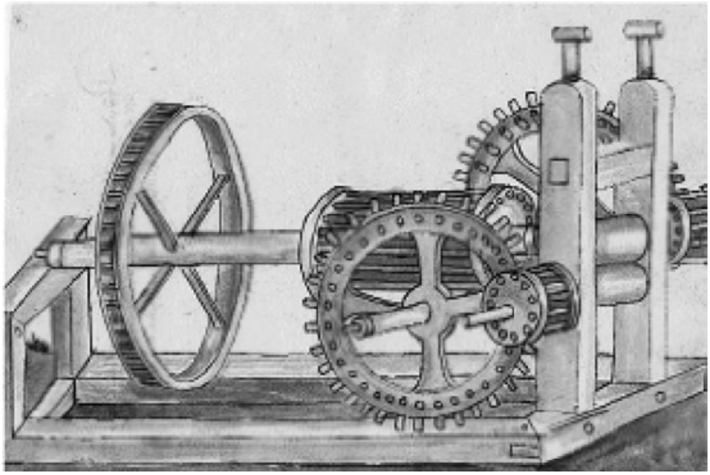

Fig. 22 First known proposal for the mechanization of the coining process, showing various coining machines proposed by Duke Reinhard Solms-Lich in 1551 and tested in presence of the Imperial Diet of Augsburg, Germany. The rolling mill (*above*), apparently with smooth rollers, is the machine that was later perfected at the Austrian Mint at Hall in Tirol in 1567, and transferred to the new Spanish Mint at Segovia in 1584. Some mills had smooth rollers to flatten the strips, and others engraved rollers to press the coin design onto the strip. This collection of drawings (*above* and *below*) is thought to be the oldest and most important graphic testimony of the most sophisticated industrial process of those times, created for the specific purpose of designing product security in coinage

the development of coin rolling mills by technicians who realized they had discovered the solution to one of coinage's historic problems: uniformity of blank thickness. In addition, it was discovered that a coin image could be repeatedly applied to the strip -by way of engraved rollers- with the precise same relief or intensity, over and over again, and each coin would have exact same uniformity of thickness as well as stamping or embossing. No doubt, the discovery was first made when the technicians observed that cracks or indented defects in the rollers repeatedly produced the same raised lines on the surface of the strip.

The first coin-rolling machinery was developed and first tested on an experimental basis in Augsburg, Germany, after 1551, and is the same production technique exported to the Royal Mint in Segovia, Spain, a few decades after its invention. During the same period, the screw mechanism (somewhat similar to the one Guttenberg invented for printing), was strong enough to punch the rolled coins from the metal strips, although this threaded spindle device would still not be strong enough to strike a large coin for perhaps another 100 years or so, as several unsuccessful experiments proved (Fig. 27).

The major benefit of the roller method over that of the hammer was that much less pressure was needed to apply the coin design onto the metal, since only a narrow band of the engraved rollers actually touched the strip at any one moment as it

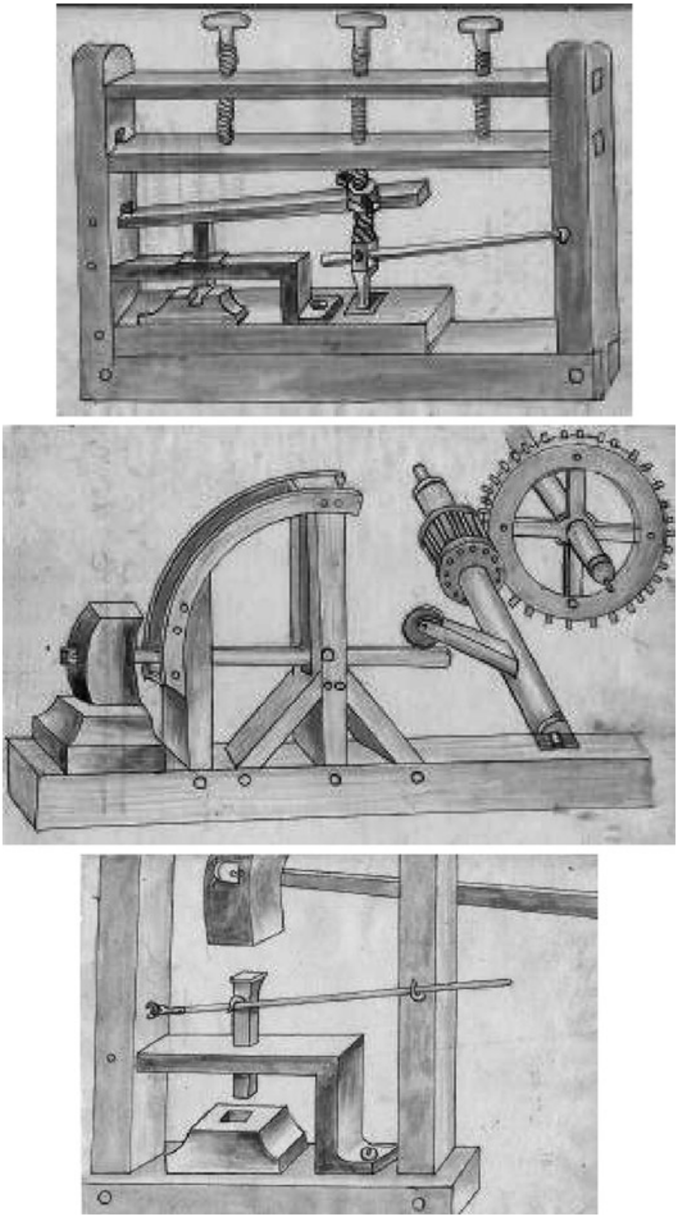

Fig. 23 Saxony State Archive, Weimar, Germany

passed between them. The resulting coins were not only more uniform, but could be of a much larger diameter. With the hammer method all the pressure was needed at one instant over the entire surface of the blank, and variables such as force and angle came into play.

Fig. 24 Roller-dies from the Segovia Mint. Madrid Mint Museum

Fig. 25 Blank cutting press from the sixteenth century. Museum of Science and Technology, Milan, Italy

Regarding the origin of these machines, it is important to point out that mint technicians were generally highly specialized experts from the wider field of metallurgy -founders, assayers, blacksmiths, etc.- and the most astute ones were always looking for new methods to improve coinage, since these innovations always had anxious and wealthy buyers: the government. While the inventors

Fig. 26 Strip of coins rolled onto copper at the Segovia Mint in 1625. These pieces were not cut from the strip because it was too narrow and the resulting coins were thus incomplete. National Museum of Archaeology, Spain

Fig. 27 The author striking coins by hammer. Juan José Bueno

often mentioned the effortless ease in which the machinery could produce coinage -sparking protests among mint workers who feared loosing their jobs-, the governments were always more conscious of the improved security which a better coinage provided to their interests. Of primary concern was properly controlling the weight of gold and silver coins being issued and avoiding having bits of these metals robbed from coinage in circulation by the unscrupulous clippers and filers who constantly preyed on these freely circulating metals, of which the governments were ultimately responsible for guaranteeing their stamped value (Figs. 28–32).

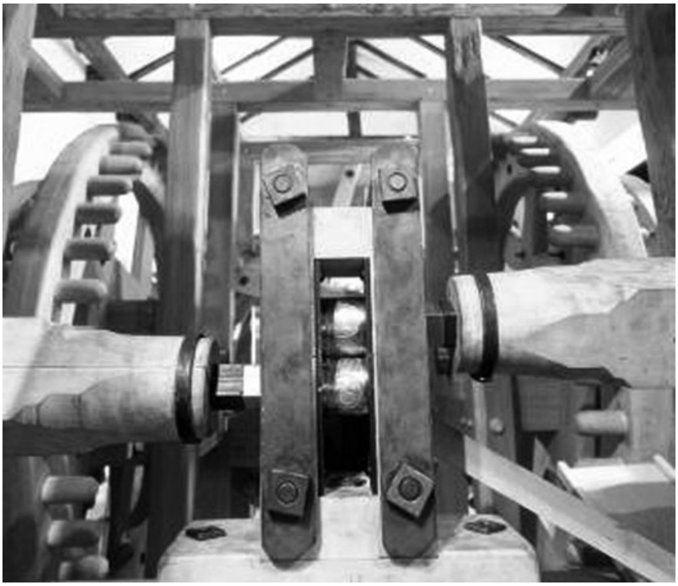

Fig. 28 Coin rolling mill at the Hall Mint, in Tirol. Hall in Tirol Mint Museum, Austria

Fig. 29 A roller-die which fractured probably due to poor quality steel or improper tempering and hardening. Though only one engraving is damaged, a total of six are wasted. Madrid Mint Museum

Fig. 30 Roller-dies had from 5 to 12 engravings on them, depending on the size of the coin. Madrid Mint Museum

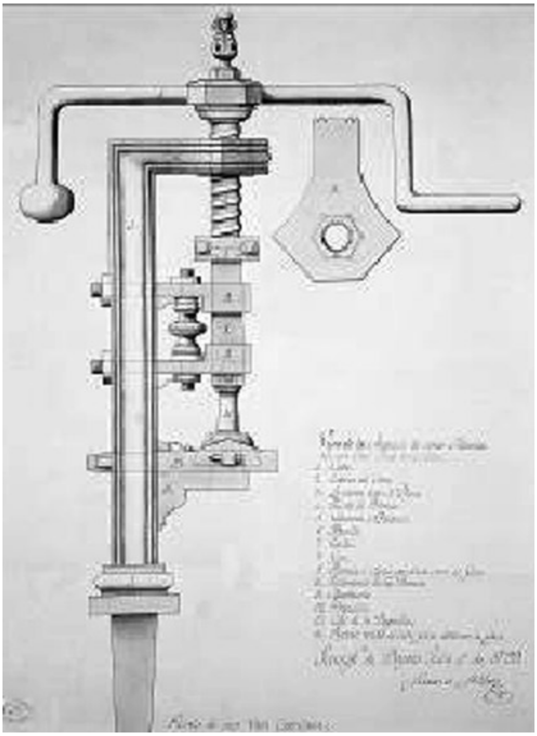

Fig. 31 Blank cutting press from the eighteenth century. General Archive of the Indies, Sevilla, Spain

Fig. 32 Rolled stripping from Segovia (1662) showing an incomplete piece which was not cut out, and the hole where a complete coin was removed. Gary Beals

Nevertheless, in order to fully appreciate the benefits of the next major improvement introduced to the coining industry -the screw-press-, we must point out the drawbacks inherent to the rolling technique. These consisted primarily in the difficulty of preparing cylindrical dies, with curved surfaces, using flat punches which limited greatly the vertical extension of the design on the punch. Another drawback to these dies was the fact that they contained multiple engravings of the coin, ranging anywhere from 5 for the larger coins up to 12 or so for the smaller ones. Of course, since each of these engravings was prepared by individual punches, slight variations always occurred from one engraving to the next on the same roller. When one of these dies cracked or became worn out, it was necessary to discard a large amount of detailed engraving work; whereas, with flat dies as used in screw presses (or even hammer method) only one coin engraving was wasted.

Apart from the drawbacks to the roller-dies, coins rolled onto strips usually had a slight waviness as one of their inherent characteristics and often had to be pounded flat with a mallet. Even though they had a uniform thickness –and thus it was much easier for mint officials to control their weight– they were never perfectly flat and due to this it was difficult to stack them for counting. In addition, since the coin was cut from the strip after the design had been rolled onto it, there was often damage to the coin impression due to its being raked-over or scratched by the cutter. It was also difficult to center the cutter exactly over the coin design, since this was done by eyeball, and depended on the ability as well as the sight or vision of the operator of the cutting machine. When the edge milling machine came into use around the end of the seventeenth century, this machine also produced scratches on the surface of coins which had been first rolled onto the strip and then cut. These negative effects were all overcome with the introduction of screw-presses in mints

Fig. 33 Waviness of a roller-mill produced coin

Fig. 34 Blank cutter of the seventeenth century. Rosgartenmuseum, Konstanz, Germany

towards the end of the seventeenth century, since with this method the last step was the actual striking of the coin itself (Fig. 33).

The screw-press was capable of producing absolutely perfect and identical coins, one after the other. The concept these machines used was known since the dawn of the Renaissance and indeed Leonardo da Vinci drew such a machine. The coin cutting press used in the mid-sixteenth century by German mints and at the Segovia Mint shortly thereafter employed the same concept. Nevertheless, foundries of those times were not able to produce a threaded screw mechanism capable of withstanding the many tons of pressure needed to strike coins, and particularly larger pieces, until around the late seventeenth century (Fig. 36).

The benefits of the screw-press were quite notable when compared to the hammer or even the roller method of producing coins. Rolling mills were still used to produce the metal strips, but the blanks were first cut from the strip and the edge milling applied to the blanks before the coin impression was applied. The great pressure used to stamp out the coins was sufficient to obliterate any scratches left on the blank's surface by either the blank cutter or the edge miller. Also, this pressure was more than enough to perfectly flatten any waviness of the blank left by the strip rolling process. Since the dies only had one perfectly flat coin image on their working surface, the matrices and punches were able to contain the entire contents of the coin design, not just individual elements. This provided the benefit of being able to make an almost limitless number of perfectly identical working dies with absolutely no variations whatsoever in the design or placement of elements. The added degree of security which governments obtained by this new technique was more than enough to outweigh the fact that the largest screw-presses required a minimum of five workers to operate each press: two to pull the ropes on each end of the swivel-bar mechanism and one to place blanks and remove struck coins (Fig. 37).

The edge milling machine to which we briefly referred was one of the final improvements designed in the late seventeenth century to specifically improve security of the struck coin in circulation. The main idea was to thwart the clipping and filing of the edges of the coins -particularly gold and silver issues- as they passed from one person to the next. Nevertheless, even regarding copper issues, which few people were interested in filing, it had the beneficial effect of making the coin much more difficult to counterfeit. This was a serious problem with copper pieces which had a high extrinsic (stamped) value compared to their low metallic worth (intrinsic) (Figs. 38 and 39).

Aside from the benefits or drawbacks of one means or another of producing coinage, we should keep in mind that the implantation of each technique at different mints in one or another country, or indeed the world as a whole, greatly overlapped. In 1664, Spain had over 20 mints both on the Peninsula and in the colonies.

Fig. 35 Strip with uncut coins from 1723. National Museum of Archaeology, Spain (and *above* coin)

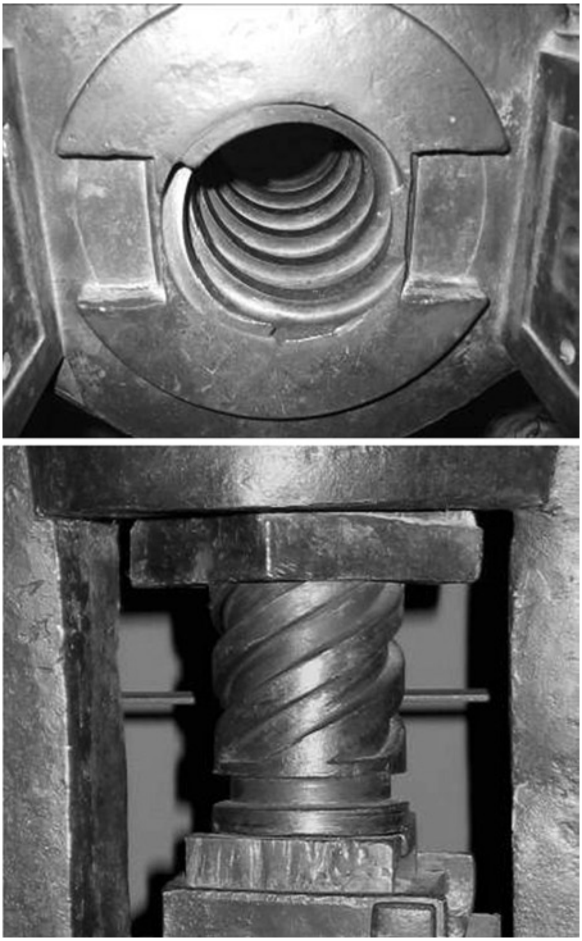

Fig. 36 Threaded guide of a screw press. Alcazar of Segovia (above) and threaded spindle from another. Museum of Navarra

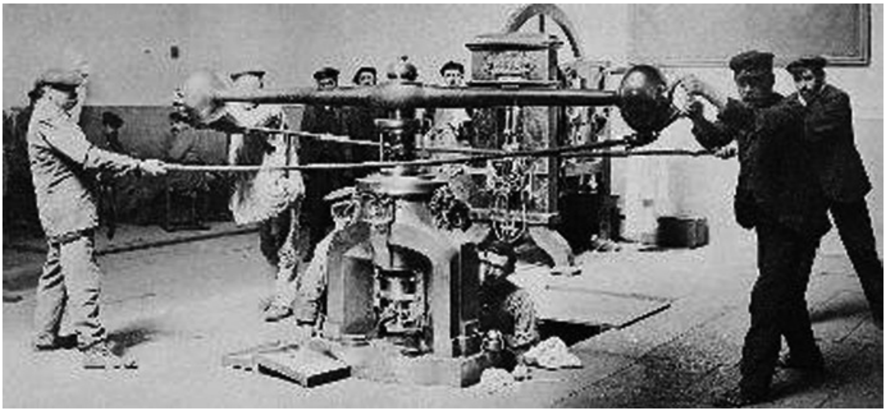

Fig. 37 A 5-man screw-press in operation in 1899 in Madrid (*left*), and details of the thread and screw on other presses (*above*). Museum of Navarra

In 1772 France had up to 30 different mints in operation all at once. Germany still has multiple mints striking euros and has had many more in the past, as did most countries. (Obviously the existence today of multiple mints in a country like Germany does not reflect the incapacity of one factory to produce all the coinage needed, rather it demonstrates the observance of time honored privileges which certain cities had to mint coins. Indeed many countries today have no mint at all, and contract their coin production out to the lowest bidding firm on a worldwide basis).

The mechanization processes was not implemented at all mints and the use of different techniques not only overlapped from one mint to the next, but also within the same mint. Segovia in 1586 was the first Spanish mint to switch from hammers to roller-dies to produce coins, but was the last in 1772 to receive screw-presses, the same year Potosi (Bolivia) stopped striking coins with hammers and went directly to the screw-press. Madrid used both hammers and roller-presses during the late seventeenth century, and used both roller presses and screw-presses during the early

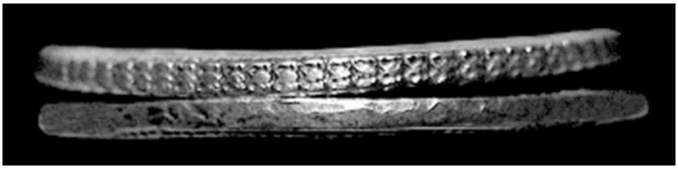

Fig. 38 The edge-milling machine was invented around 1685 by the French Mint technician, Castaing. Detail of coins with and without the safety milling, and engraving by Diderot showing how the machine worked

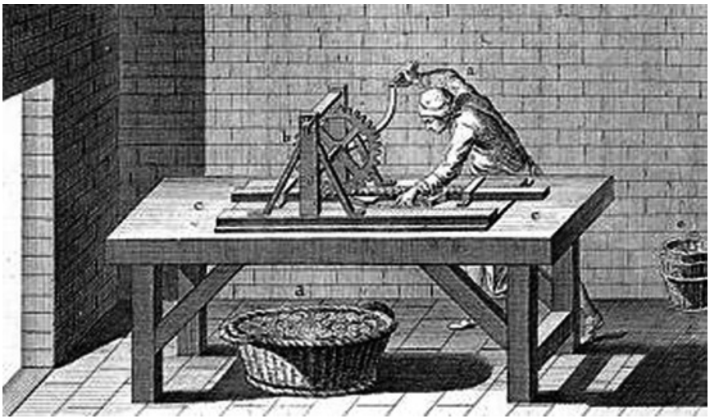

Fig. 39 Edge milling machine. Diderot

eighteenth century. These differences were due to many factors too complicated and individualized to consider in this paper, but mostly depended on what metal was predominantly being struck at each mint, problems with the implementation of machinery due to the need to build new mint buildings that could house them, and protests of workers who feared loosing their job to a machine. But perhaps most important of all was the shortage of specialized technicians needed to construct, install, and maintain the sophisticated machinery.

Nevertheless, by the end of the eighteenth century, the coining process had finally been perfected to the limits necessary for product security almost as well as today. Further improvements -for instance those introduced by Mathew Bolton around the mid nineteenth century- were mostly designed to reduce the labor force and strike greater numbers of coins, more than improve on their quality. These new inventions used arms, belts and levers that could automatically turn the screw, while others employed a knuckle-movement to strike the coin. Automatic feeders and tweezer mechanisms were invented that could supply large quantities of blanks to the press and remove coins from the die surface after being struck. Other improvements have been made, of course, since then, such as high speed hydraulic presses capable today of stamping out up to 800 coins per minute.[6] But again, these have been introduced more to streamline the labor force, eliminate the need for multiple mints in most countries, and produce the vast quantity of coins in circulation today than to improve on product security. These later developments have also gone step in step with labor-rights movements and major increases in worker's salaries, whereas these questions were much less important centuries ago, at least in this highly profitable industry. At any rate, we can rightfully say that governments have always been directly interested in the production of their coinage, and thus technicians and inventors have always had a source of inspiration to look for ways to improve the industrial methods and procedures involved in its manufacture (Fig. 40).

7 The Departmentalized Manufacturing Plant

As we have already mentioned, coin production even from its very beginning, has always been a complex industry, or one involving many very different steps. Contrary to most other artisan-like industries, no specialized worker alone could produce a quality coin. While almost any strong person could swing a hammer or pull a lever, only a master craftsman could engrave a quality die, a skill vastly different from that needed by the assayer to prepare an alloy to exacting fineness, or the founder who needed to know temperature ratios not only for melting alloys, but also for tempering and hardening the dies and punches, and annealing the metal strips. When mints were equipped with machinery, a full time mechanical technician was also necessary to keep the machines in proper working order, and a carpenter to build

[6] <http://www.jeryong.co.kr/Prod-Import/grabcoin01-e.htm>

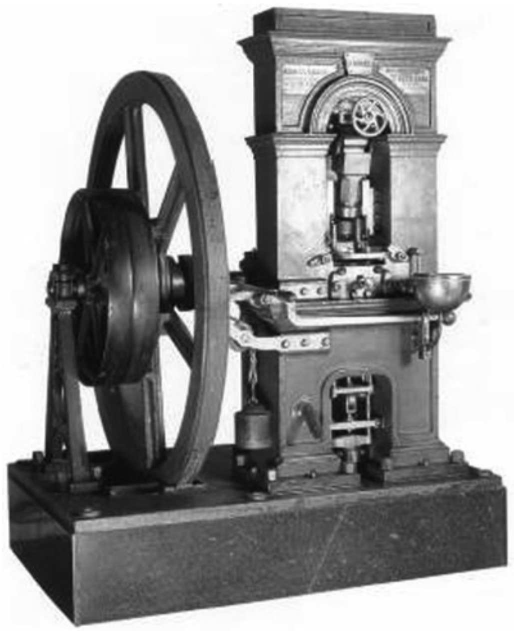

Fig. 40 Modern belt-driven coin press with automatic blank feeder, from the mid nineteenth century. Madrid Mint Museum

and maintain water wheels, horse-mills and their wooden gears. These and other specialized skills required to make a mint function efficiently meant that a large and highly diversified staff of officials and experts, as well as workers, was necessary, certainly more so than in any other industry during the sixteenth century, and perhaps even until the end of the nineteenth century when new chemicals, inventions, and products began to exponentially multiply (Figs. 41 and 42).

The great diversification of skills and tasks present in the coining operation meant that mints as factories were subject to early departmentalization. While early non-mechanized mints which struck small amounts of coins by hammer were barely more than artisan-like workshops, the incorporation of numerous different machines meant different specialized departments were necessary. The use of water wheels or horse mills to power this machinery added greatly to the complexity of these mints, which we can truly define as the first mechanized industrial manufacturing plants specifically designed for the production of millions of identical products in series. We should also keep in mind the production of dies as a specialized sub-industry, with its own department within the mint, giving further testimony as to the complexity of the coining industry as a whole, and its manufacturing plant in particular.

Rigorous government mandates spelled out every step in the industrial process. In Spain, the famous Pragmatic of 1497 (issued 86 years before the country's first mechanized mint was built in Segovia) consisted of 74 individual chapters regulating every conceivable aspect of a mint's operation. So important was it to follow each

Fig. 41 Tooth and spoke gear mechanism of the mid eighteenth century horse-driven rolling-mills at the Potosi Mint, in Bolivia. The slightest imperfection of these wooden parts caused great wear and tear. Glenn Stephen Murray Fantom

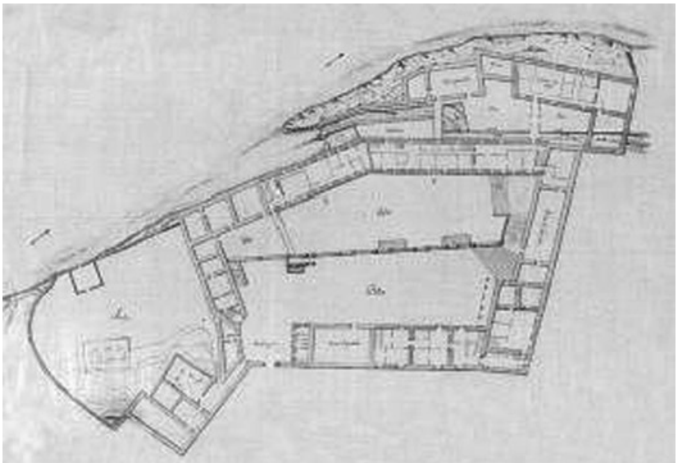

Fig. 42 Plan of the entire Segovia Mint complex in 1861. Then, as today, the basic original structures dating from 1583 are still intact. National Historic Archive, Madrid

step with maximum precision, that the violation of rules spelled out in any one of twelve different chapters, carried a mandatory death penalty! These industrial plants, often brimming to the seams with the king's gold and silver, were subject to stringent security measures enforced by armed guards, which also had their own department or station, measures obviously not needed at any other type of industrial plant.

Most mints had their own private judicial jurisdiction, sheriff, and jails and the local authorities were not permitted to enter or make arrests. We can imagine that this measure was designed principally to dissuade workers and officials from trying to steal coins. Indeed, mint employees had many privileges designed to help keep them honest. They paid no taxes and were exempt from military service at least until the end of the seventeenth century in Spain.

Aside from these unique qualities, one of the chief characteristics of a mint is the need to weigh metals each time they pass from one department to another. In general, and especially at the time mints became mechanized and truly departmentalized manufacturing plants, the responsibility or possession of the metal was in the hands of three different principal officials. Each one was solely accountable for the precise weight of each batch: the treasurer, the founder, and the chief coin-master. The plant was designed and set up around these three officials, each responsible for his own department: treasury, intrinsic, and extrinsic departments (Figs. 43 and 44).

The treasurer weighed the incoming metals and when the founder was ready to perform his task, he would transfer them to his responsibility. When the founder finished making the small ingots, with the help of the assayer who prepared the ingredients of the alloy -the intrinsic process-, he returned the metal to the treasurer.

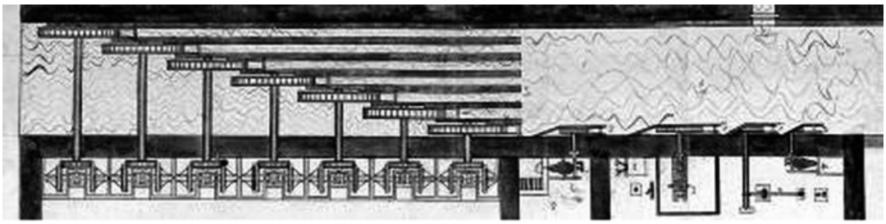

Fig. 43 National Historic Archive, Spain

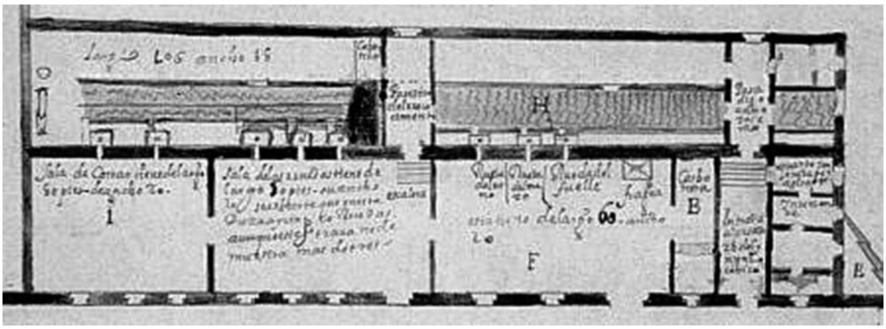

Fig. 44 General Archive of Simancas, Spain. Plan of the mechanized departments of the Segovia Mint in 1678, with the canal, and 8 of the 14 waterwheels drawn as square s(*lower*). The plan of the same departments of the Cuenca Mint in 1664 (*upper*) is much more detailed, and they were built as an exact copy of the Segovia departments in 1662. The smithy department for making the steel rolling cylinders is on the right hand side in both plans

Then, when the coin-master was ready to roll the strips, punch out the blanks, and strike the coins -the extrinsic process-, the treasurer would pass the metals to him, later receiving the coins and scrap striping in return.

Of maximum importance in this process of transferring the responsibility of the metals from one person to the next, was the mandatory weighing of each batch changing hands at each step. Bearing witness to each transfer, aside from the two major officials implicated in the handing over and receiving, was the weigh-master who had his own department equipped with the most precision balance scales of those days, and the scribe, who also bore witness to the transfer and took note of the exact weights for mint records kept in the factory's archive. The presence of the superintendent was also mandatory to witness the weighing act. Security measures were so stringent that even when the metals were safely locked in the vault, the treasurer could not access them alone. Three separate keys were required to open the vault, and he only had one, while the other two were kept by the superintendent, founder, assayer or other appointed officials. Thus, no one person could gain access to the metals alone, being required a minimum of three different officials. The detailed level of controls involved in this highly specialized manufacturing process, carried out in a truly departmentalized factory was certainly not equalled or surpassed in any other industry, as we have suggested, perhaps until around the end of the nineteenth century (Fig. 45).

Worthy of quick note is the intrinsic portion of the coining process. It is extremely important regarding product security, but not subject to mechanization or

Fig. 45 Pouring of metal into the molds to form the flat ingots which are later rolled into strip. Glenn Stephen Murray Fantom

significant modernization of techniques, topics of this paper. Indeed, the exacting skills required of any mint's assayer was of such importance, that he was the only mint official ever required to put his own private mark or symbol on each and every coin (engraved onto the dies) bearing testimony to the fact that he, personally, had prepared the alloy from which it was struck. Great sums of money could be lost (or gained) by accidentally (or purposefully) erring on the amount of copper added to the base gold or silver in order to form the correct alloy. As a result, this highly specialized technician, with great responsibilities, was considered to be one of the most important, and thus highest paid, of any mint's staff. His contract conditions also included the most possibility of receiving the death penalty for violation of even the smallest detail.

8 Summary – The Case of the Royal Segovia Mint

As a summary of what we have covered above, we will explain our proposal that the Royal Segovia Mint be recognized as the world's oldest, most complete, still standing, complex, departmentalized industrial manufacturing plant designed for in-series, mechanical production, and thus worthy of special recognition by entities such as ICOHTEC, TICCIH, UNESCO, etc.

The Royal Segovia Mint was ordered built by King Phillip II in 1583 and constructed by the famous architect, Juan de Herrera, builder of the fabulous El Escorial Monastery in the province of Madrid, being his only example of industrial architecture. The Mint was designed and built, and operations started, with special assistance from a team of German and Austrian technicians. It was designed and constructed from its inception as a mechanized, departmentalized, industrial manufacturing plant for the specific purpose of producing millions of identical, high precision pieces in series, and not adapted at a later date in order to house the specialized machinery as were so many other mints or industrial buildings. The Mint is strategically located on the banks of the Eresma River, which provided the energy to power its 14 giant water wheels, most of them being 3,75 m in diameter (Fig. 46).

Fig. 46 The Segovia Mint complex, on the Eresma River. Sancho González-Green

If we accept that the coining process was the most sophisticated and complex of all industrial procedures at the end of the sixteenth century, as we have explained above, then the next step would be to identify similar plants built prior to the one in Segovia in 1583, where the machinery was installed and began to work in 1585. In these respects, we know that the first coin-rolling machines were used on a trial or experimental basis in Augsburg (1550–1551), Paris (1551), Zurich (1558), London (1562), and Heidelberg (1567). But more than specialized industrial plants constructed to house minting machines, these were efforts by private technicians to set up the coining machines in these cities in order to persuade government authorities to purchase them. These early efforts were largely unsuccessful and discontinued.

The first mint to be successfully equipped with this machinery and which continued uninterrupted production was that of Hall in Tirol, AT (1567). Other mints which also received the coin rolling machinery before Segovia were those located in Köln, DE (1568); Dresden, DE (1574); Kremnica, SK (1577); Gdansk, PL (1577); Baia Mare, RO (1577); Kyköping, SE (1580); Magdeburg, DE(1582); and Ensisheim, FR (1584). These were relatively small mints with insignificant production when compared to the limitless supply of gold and silver for which the Spanish King, Phillip II, was famous and which he planned to process into coinage at the Segovia facility. Indeed, starting at around 1550, Spain was inundated with vast amounts of silver which arrived at the docks in Seville, mostly from the famous deposits discovered in Potosi (Bolivia) in 1545. It was impossible for the existing mints in Spain to hammer all this silver into coinage fast enough to please debt ridden Phillip II, who found himself having to pay these debts with raw silver in bars, and thus unable to take advantage of the additional benefits he would have received by converting them into coinage. Indeed, the Segovia Mint was built by Phillip II using his own private funds, and was owned and operated by the King's Royal House, very different from all other Spanish mints, run by the national treasury. The reasoning as to why the Segovia Mint was designed as the world's biggest mechanized industrial manufacturing plant of those times is thus quite clear. Among the previously built mechanized mints, only the much smaller one at Hall in Tirol (where the original Segovia machinery was built) still exists, today housing an interesting minting museum with a newly built coin rolling machine (2003), powered by an electric motor. Nevertheless the Hall Mint has been significantly altered over the years since it was also the city's castle, and most significantly, its water canal which fed the small number of waterwheels is today completely disappeared (Fig. 50).

In favor of the Segovia Mint, aside from its shear size and importance when compared to the Hall Mint, is the significant fact that the canal which once powered the 14 giant water wheels not only still exists today, but still carries water. In this regard, the Hall Mint was distant from its water source and a long elaborate canal was required to carry the water through the center of town since that mint was located in a pre-existing castle. In Segovia, the Mint sits right on the banks of the river which directly feeds the canal, and the original dam, or weir, still exists, with its two gates which allow water to enter the mint complex, and two sluice gates for emptying the stored water, all having been properly refurbished in 1995 (Figs. 47 and 48).

Fig. 47 The Segovia Mint. Glenn Stephen Murray Fantom

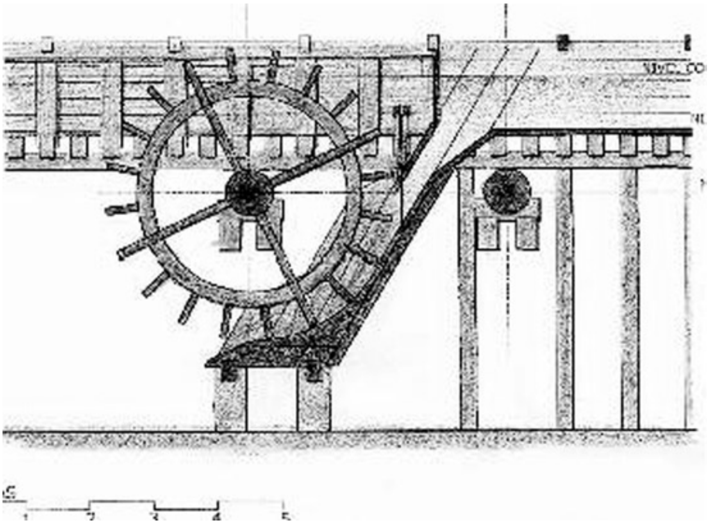

Fig. 48 Weir and sluice gates of the Segovia Mint, and drawing for the reconstruction of the wooden canal and water wheels. Jorge Soler

Also important to note is that the complete original structure of the Segovia Mint still remains intact today, essentially as it was designed in 1583. Three modern additions built when the plant was used as a flour mill from 1878 to 1968 have been recently removed. It is a truly departmentalized industrial complex consisting of several different buildings: one for the intrinsic processes and the treasury, two for the extrinsic labors, and one dedicated to the security of the plant, where armed guards were permanently stationed. Worthy of special note is the die-making department, which was equipped with three separate water wheels: one to drive a mechanical drop-hammer, another to power a bellows and a third to spin a metal-turning lathe. The complex also contains other separate buildings: one where the wheel-master had his carpentry shop, and another located in the Mint's unique romantic garden with a small fishing pavilion and delightful trellised patio where the king took special pleasure in catching trout during the annual visit to his factory. Unfortunately, the Mint is devoid of all machinery, though this is now scheduled to be rebuilt.

The Segovia Mint was almost completely unknown except by Segovians themselves, until the author of this paper (a lifelong numismatist) began studying its past in the historical archives of Spain in 1988. True, those in numismatic circles had always known about the Mint by way of its spectacular coins, which include the largest pieces ever struck anywhere: the fabulous cincuentines (50 reales, silver) and centenes (100 escudos, gold), both 76 mm in diameter, produced during the seventeenth century on the roller-presses in extremely limited quantities (300 pieces being the most in a single year), and only under special license authorized by the king himself. Unfortunately, numismatists tend to dwell only on the coins and have over the years shown little or no interest in the history of the factories in which they were produced, nor in the industrial processes used in their manufacture (Fig. 49).

Indeed, even experts on historic industrial plants rarely, if ever, tend to include coining as a separate and specific industrial process, which as we have seen above, is of noted merit in and of itself. It is often considered that truly complex mechanized industrial plants did not come into existence until the beginning of the Industrial Revolution in the late eighteenth century. Nevertheless, as we have seen above, the Segovia Mint was mechanically producing millions of identical, high precision products in-series, which even carried specific symbols of control and guarantee (mintmark, assayer symbol and date of manufacture), in a truly departmentalized complex industrial plant, a full 200 years before the start of the Industrial Revolution (Fig. 51).

One of the first conclusions made recently by a Spanish historian (Nicolas García Tapia, 1992) is that the industrial convoy which transferred this sophisticated technology along with technicians from the Hall Mint in Tirol to Segovia in 1584–1585, is that this expedition was without a doubt the largest and most important transfer of complex industrial technology, over the longest distance ever undertaken by mankind until then.[7] In 2004, TICCIH-Spain recognized the Segovia Mint as the oldest still-standing example of an industrial manufacturing plant in Spain.[8] Now the author of this paper, wishes to take this recognition one step further, since apparently no other earlier, similar, more complete or more important factory exists today anywhere in the world.

[7] Ibid, note 1.

[8] Ibid, note 2.

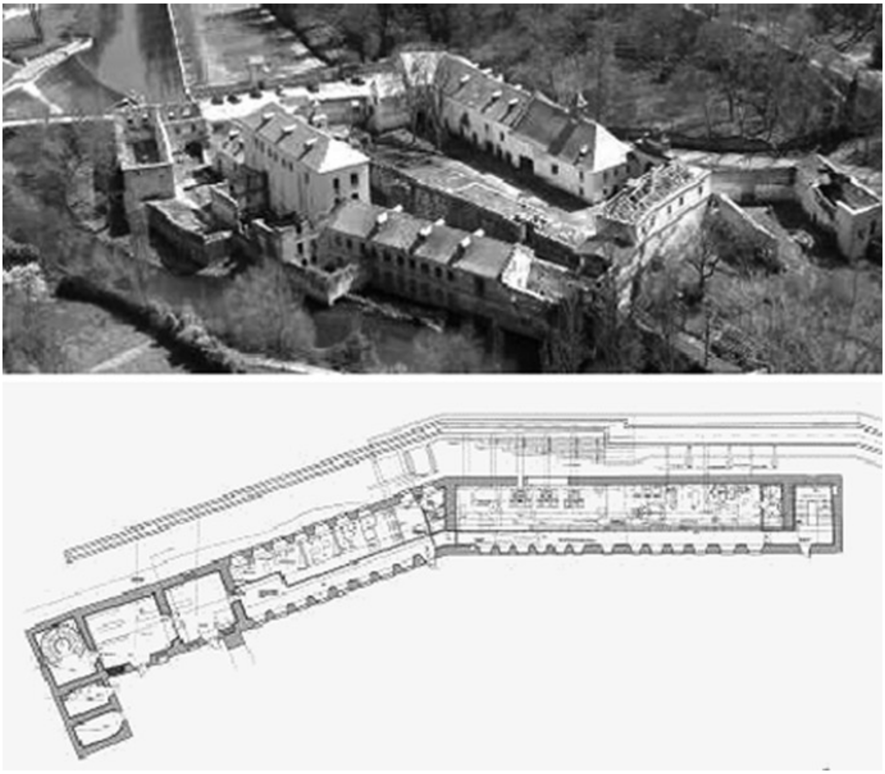

Fig. 49 Photo of the Segovia Mint on the Eresma River in 2003, and the architect's plan for its reconstruction. The factory still maintains its historic dam, or weir, and the canal still channels water into the complex. Eduardo de la Torre Alejano

The six-million euro restoration project for the Segovia Mint, financed by the local, regional, and national governments, was successfully begun on February 14, 2007 and is now well underway. The project includes the rebuilding of a battery of 10 waterwheels, three of which will be in the historic die-making shop to show how this specialized department functioned, another to drive a metal-flattening rolling-mill, and yet another to power a coin-rolling mill. These last two machines are scheduled to be built through a special cultural agreement with the Museum at the Hall Mint in Tirol, builder of the original Segovia machinery, and which successfully inaugurated its own rebuilt coin-rolling machine in 2003. The idea is to celebrate the 420 years passed since the first cooperation between these same two mints. In Segovia, the entire industrial coining process is scheduled to be reconstructed, featuring the three historic techniques used to strike coins -hammer, roller-die, and screw-press- all in a living, workshop-type atmosphere where visitors will be able to witness the entire process and purchase samples in the gift shop.

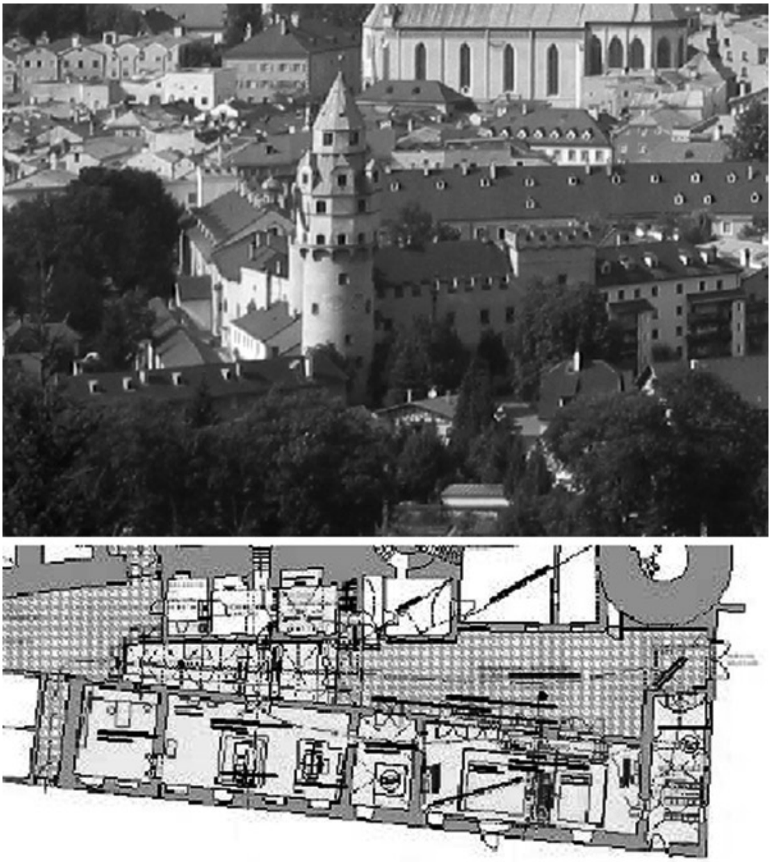

Fig. 50 Hall l in Tirol Mint Museum. Photo of the Hall Mint in Tirol in 2003, the year the renovated mint museum was opened, and the architect's plan for the reconstruction

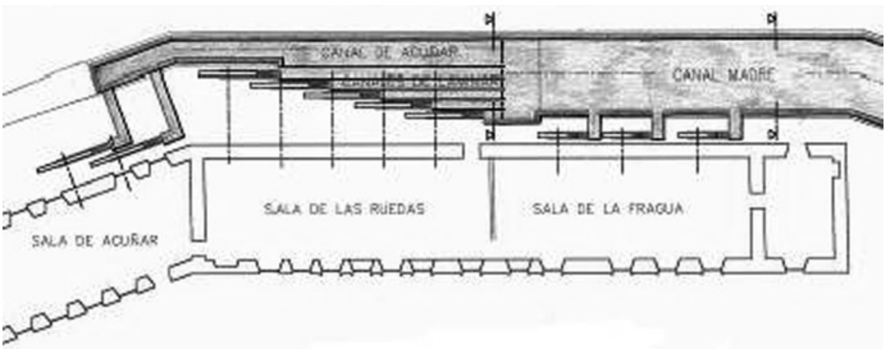

Fig. 51 Drawing of the coin-rolling, strip-rolling, and smithy departments (*left* to *right*) of the Segovia Mint, showing 10 of the factory's 14 water wheels. Jorge Soler

A restaurant will provide unique vistas of the 10 waterwheels as they turn in the canal, with Segovia's nearby castle -the Alcazar- providing the backdrop (Fig. 51).

Aside from being a living, working example of a historic coin factory, the primary intention is to convert the historic Segovia Mint into a showcase for the study and teaching of historic industrial processes in general. For this reason, we feel the cultural mission of the future museum could only benefit from the historic plant being recognized as **the world's oldest, most complete, still standing, complex, departmentalized industrial manufacturing plant designed for in-series, mechanical production.** On the other hand, we feel the cultural mission of institutions such as ICOHTEC, TICCIH and UNESCO, can only be furthered by hunting down and recognizing the rarest and most singular examples of civilization's industrial past.

9 Segovia Mint Chronology

1577 – German coiners send proposal to Spanish King.
1581 – Decision made to build mechanized mint in Spain.
1583 – Segovia chosen as location.
1586 – First coins produced on roller-mills.
1756 – Last coins produced on roller-mills.
1772 – First coins struck on screw-press.
1865 – Automatic coining machines using turbine installed.

Fig. 52 Coins shown actual size. Museum of Segovia; Madrid Mint Museum, and National Museum of Archaeology, Spain

1869 – Last coin struck. Mint closed definitely.
1878 – Mint sold and used as flour mill.
1968 – Flour mill ceases operation. Building abandoned.
2007 – Restoration project begins.

The silver 50 real and gold 100 escudo pieces, both 76 mm in diameter, are compared here in actual size to the 8 escudo gold piece (Fig. 52).

These were the largest coins ever struck at any mint anywhere in the world, and were exclusive products of the Segovia Mint, rolled on the mill-presses during the seventeenth century only by special and individual authorization by the King himself, and issued in extremely limited quantities: 300 being the most produced in any 1 year.

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Javier Verdejo Sitges, member of the Scientific Committee of the Royal Segovia Mint Foundation, for photographs.

Credits

Archivo General de Simancas, Valladolid, Spain
Archivo General de Indias, Seville, Spain
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Spanish Mint Museum, Madrid, Spain
Saxony State Archive, Weimar, Germany.
Schweizerisches Landesmuseum, Zurich, Switzerland.
Rosgartenmuseum, Konstanz, Germany.

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The Image of Factories

Aingeru Zabala Uriarte

Abstract In this chapter a survey is presented on the evolution of factory presentation through images. Examples are discussed with illustrations and significant cases with a historical perspective but considering the industry purposes.

Keywords History of illustrations • Factories • Images • Logos

1 Introduction

In 1997 Barrie Trinder published *The Making of the Industrial Landscape* and gave us a clear vision on the image of industrialisation together with certain keynotes for interpretation which, however, have not been clearly contrasted in the various spaces in which there has been an effectual implantation of an industrial landscape throughout the nineteenth and twentieth centuries. And the Basque Country is one of them.

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Without intending to undertake such a task but just simply wanting to initiate it, I wish to present today certain initial norms on the change of image, or more concretely on the change of the way in which we look at such landscapes.

2 The Image of Factory

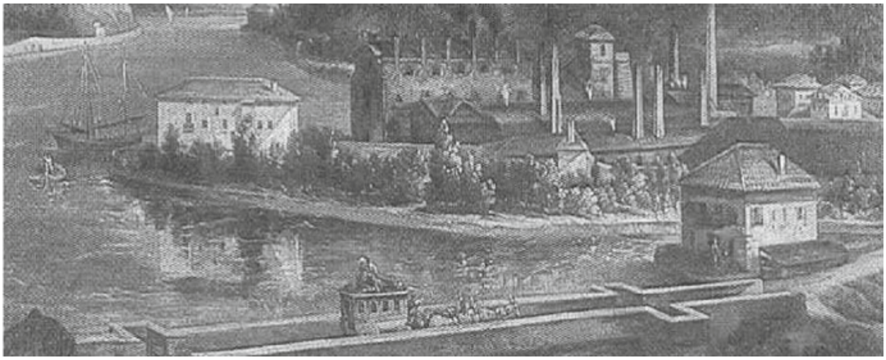
When the second half of the nineteenth century had already started, contemplation of an industrial landscape was still a largely romantic affair. A huge cordage factory and even a steam tug with its enormous wheels were contemplated as but a small detail in the environment, nature was still most of everything.

So much so, that even when the factory was the protagonist of a picture it still had a secondary nature, it was still not the centre of the picture. When factories were pictured, except for certain testimonial cases, they were usually covered by something else, and when this was not the case, factory elements were never relevant. What's more, in some cases it was even necessary to specify them.

There is an extensive catalogue of examples thereof, but in any case it is revealing to see how the smoking chimneys of the predecessor of the *Altos Hornos* factory do not stand out as aggressive at all when pictured.

The reasons for this seem obvious; the landscape, and together with it agriculture, which the picture represented, was still the dominant factor and the buildings, which were invariably on the shore, as in this case of a river, or elsewhere, appear to be hidden behind a mask inasmuch as possible. This is clearly the case in the Basque Country, which inherited the concept of the old ironsmitheries.

We could provide many more examples, although we would have to pick out their pictures from certain publications dating back to the second half of the century, concretely from "illustrated journals" from those times, which were the great



paladins of modernisation; but our perception of facts would hardly change at all. Romantic pictures had still not yet been substituted, at least not in the Basque Country, by the new era, that of industrialisation and machinism.

Towards the end of the nineteenth century a new phase starts, the period of pictures which we are going to pay some attention to, a period of time in which factories change not only the landscape but also swap the nature of an economy of survival for a market-based model, a modern industrialised model. And, just like in the Middle Ages with castles and the Modern Age with palaces, this is the time in which not only factories but the whole of their environment become a symbol of the new era.

It is true that photography has already accumulated some experience on the matter but its results were not practical for the new era; it was not a matter of reproducing reality more or less faithfully, the idea was to build a new image, a new reference. As a consequence, another technique was used – engraving. This was an "occupation" with more than enough experience and which, in those times, on the other hand, was also undergoing considerable transformation of means and possibilities. Thus, since then, but also long before, pictures had contributed to the construction of a collective perception. Its degree of reality was relevant, but not final.

When using corporate archives dating back to the end of the nineteenth century and even the beginning of the twentieth century, concretely those parts of them in which correspondence is kept, particularly incoming correspondence, such as invoices, researchers can find a set of graphic documents, some of which make reference to such a perception.

At the end of the nineteenth century, companies which had commercial relations with foreign countries or were dependent on them frequently received correspondence or invoices with wonderful "letterheads". In those times it was frequent in Europe, concretely in Germany, England and France, albeit not only there, to design special letterheads for correspondence, invoices and even for other items also.

These designs were usually views of the companies that issued the document being examined, designs that coexisted with other motifs which we are not going to be looking into here, such as floral motifs, architectural elements or simply more or less sophisticated fonts.

Early on, such practices were incorporated to certain Spanish corporations, and gradually became generalised. In Bizkaia some of the first companies to incorporate this model, before others did, were filial entities of foreign firms that had already been following such practices, as was the case of "*Construcción Mecánica del Nervión*", which was an associate of "*Fundiciones Averly y Compañía*", and which had a similar image to that of other foreign foundries already back in 1894.[1]

[1]After 1906 the firm was renamed *Gracia y Cia* and would continue using the same letterhead in its stationery.

Companies that had just recently been set up, in some cases, started their trajectory with very simple stationery and then gradually got incorporated into this tendency when they did adopt it. But the adaptation process had certain defined phases, which cannot qualify as universal, but in those cases where they can be pointed out, turn out to be quite illustrative.

It is convenient to clarify that not all companies were set up with the same external image; that is to say, a textile industry was not the same as a steel mill and therefore their external image, the image they used to show the factory, was not and could not be interchangeable. But bearing in mind such nuances, inasmuch as possible we shall be pointing out that many elements have a clear common character.

In some cases it is possible to find an overabundance of pictures. Some companies that had installations in more than one place exhibited them and others had certain urban premises apart from the factories and they showed all. Their letterheads sometimes showed the two types of installations, but at the same time they used to use other stationery with separate images. Information and ostentation went together.[2]

An initial element is that nearly all the images we can find have the pretension of being aerial views, that is, pictures that show us the factory as it would be seen from an airplane, with the peculiarity that this is something that is quite assimilated by us nowadays as a collective experience but this was not the case at the end of the nineteenth century. It is true there had been balloon flights for over a century, but the generalisation of aerial pictures and other similar experiences would still take a few years. In general it is admitted that up to the First World War, and more particularly up until after the Civil War in Biscay, aerial photography was simply not carried out.[3]

When the pictures are not aerial pictures, above all in cases of partial installations, what is contributed is a very different view from what would have been a normal view, and were pictures that were as if taken from a far-away position from the object to be pictured. There are even cases of urban images, street houses, that reach a level of distance that would be impossible in reality, since the other side of the street was much nearer than what those images would lead us to think.

[2]The *Lizariturri y Rezola* firm in Gipuzkoa had a factory in Lasarte, the "*Biyak-Bat*" factory, and another called "*La Providencia*" in San Sebastian itself. Its correspondence gathers images from both installations. The Bilbao jewellery and silver shop Anduiza even incorporated four different views. In any case this is a discreet case, far from the example set by the "*Farben fabriken vorn Friedr. Bayer and C^o Elberfeld*" company that inserted *circa* 1900 two wide views of their installations in Leverhusen and D'Elberfeld and another four smaller ones of those in Croix Nord, Barmen, Sgheldploh and Moscow.

[3]The first company to exploit photographic flights was founded by J. Albiz in 1958 with the *Aeropro* denomination. But in October 1929 the Aurrera company already receives a letter of publicity from the "*Bolckow Vaughan & C.*" from Middlesbrough with an authentic aerial view of its installations.

There were pictures that sometimes were completed with inside views of the pavilions.[4] Such panoramic views did not even have the pretension of being aerial views and they did not distance themselves from the object, but, in nearly all cases, they falsified space quite considerably.

On the other hand, a common characteristic is the insertion of these factories into the landscape. It is very probable that in their era, these factories were far from urban environments, but in any case it is noteworthy how much attention is paid to nature by the artists. In fact in some cases, the referred artists are not Spanish but they provide, together with the view of the company, something like a postcard-like

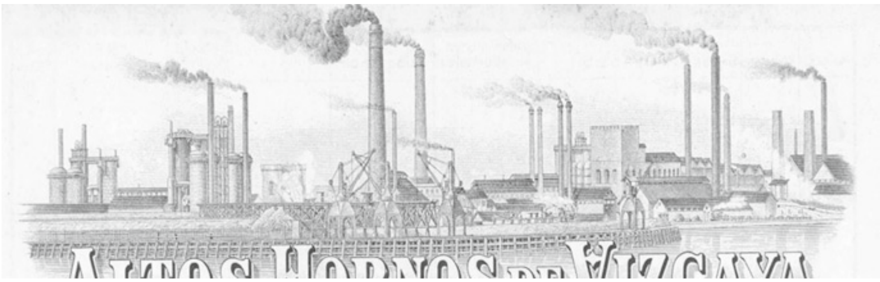
[4]This is the case of the already mentioned jewellery and silver shop *L. Anduiza* from Bilbao situated in 17, Correo Street and of which we have a picture of the façade and another of the shop as well as another two of both interiors at the same time.

view of its emplacement.[5] It is clear that some urban factories would have had difficulties in so doing, but even so, in the case of Bilbao, an escarped terrain allows the artists almost always to present mountain slope backgrounds.

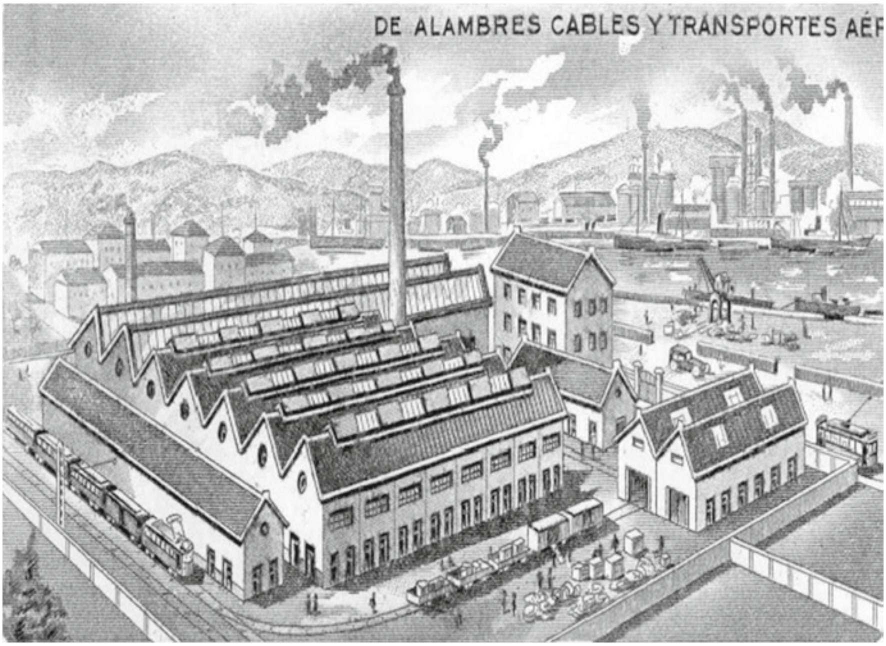
This is the framework in which factories are presented, but in most occasions not only factories, but also a set of diverse elements, which are different in every case, that illustrate daily aspects that are connected to the factories. These are miniature-character images that turned out to be very illustrative indeed.

In any case there are also exceptions in this, as in part of the stationery of *Altos Hornos de Vizcaya S.A.*. Towards 1901 this company used a type of letterhead which was surprising because of its aesthetics that were different from the rest in that it was more modern, and with a wide image of smoke and smokestacks in which buildings are almost not distinguishable.

However, this was not the only image of the company, since it simultaneously used another image that fitted better into the preponderating models.



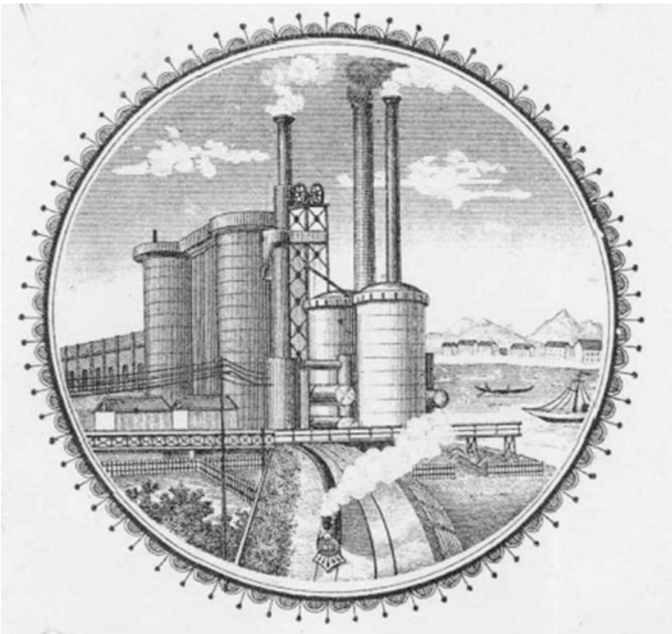
[5]This is the case of *Manufacturas A*, *Canard* from Le Puy in the Haute Loire. Its letters used to include a picture of the silk factory, medals of prizes obtained in Lyons and Brussels in 1894 and 1897 and a wide view of the Le Puy emplacement.



On the other hand, and with respect to the buildings themselves, independently from their perspective or their interpretative framework, obviously the image was supposed to be mostly realistic. We can actually compare some examples and in fact we know of cases in which ulterior modifications of the buildings also brought about changes in the stationery image. There was, therefore, a general wish to depict reality. Another different matter was that companies, depending on the context and culture they were in, had to have a different image; this was a matter to which the purpose the pavilions had been built for also contributed, since not all such pavilions were attributed the same representative and symbolic values.

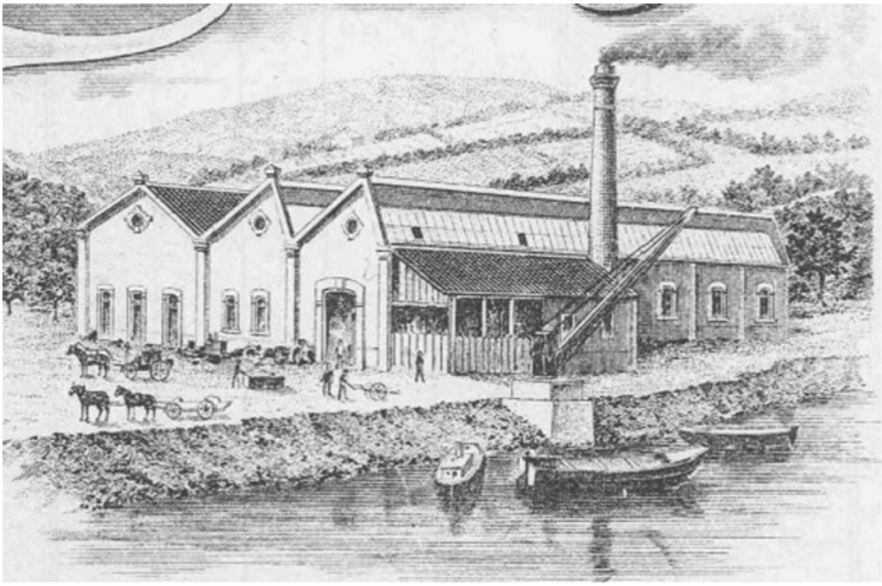
In this sense, the very concept of factory also had its influence. At the beginning it was possible to see pictures that did not only include industrial pavilions but also the owner's house and those of the workers if they existed, apart from the odd chapel. With time, as is well known, companies would reduce their activities to the production level, and managers would distance themselves from ever more "conflictive" workers; and the space destined before as housing for the workers would end up incorporated into productive activities. And with all of this the image of factories was to change once again. However, in the period we are analysing, various models were to concur.

With all the predominating value, what are depicted are the factory and the industrial pavilions. In fact, somewhat later, in order to stress the importance of these pavilions there are examples in which one can see how perspective alters reality to the detriment of a main façade that was occupied by offices.[6]



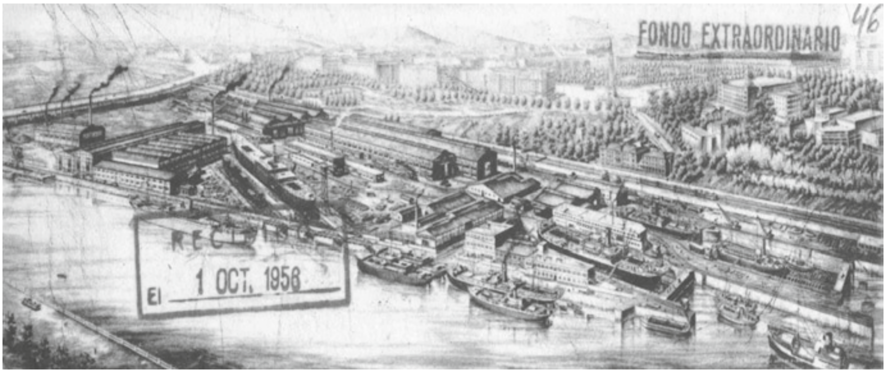
Along the same lines there are cases in which the image is more mechanic than identified with buildings, that is to say, the factory is identified by its machinery. It is evident that in the most emblematic case, *Altos Hornos*, the image of the blast furnaces was more significant than a view of the company offices, but they must have considered that it was also more significant than the wide pool of pavilions the steel mill had from its beginnings. In other pieces of stationery from the same company, as we have seen, the image of the front of the estuary with its cranes, docks and smokestacks almost shows us a space without buildings.

[6]This is the case, among others, of the stationery of the *Sociedad Franco Española de Alambres y Cables* which reproduces its installations in Erandio but in which the estuary appears not in the foreground but in the very background, with its cranes and docked ships, and farther still there is a misty background with the blast furnaces of *Altos Hornos* and its chimneys and farther still are the mountains. In the foreground is the railway and the company loading platforms, together with its pavilions and – of course- its chimney in the centre of the image.



As is well known, the physical characteristics of factory buildings were to change with time too. At the beginning of the twentieth century models inherited from the pre-industrial era shared spaces with certain samples of temple-like factories. Only by coincidence can we find almost modernist influences and incorporations of wide glass windows and lattices. There is no lack, however, of simple adjoining huts. Little by little, the palace-type factories like the one that still housed the foundry of the sons of Enrique Sánchez in Las Palmas de Gran Canaria in 1941 were phased out. Soon the first series-produced pavilions will be substituting the initial models with lattices and a considerable degree of development. This brings about new perspectives which are increased, providing the installations with an image of giant proportions which, on the other hand, was exactly what was being pursued. These are authentic factory cities[7]; the landscape is situated in an imprecise horizon. There are cases in which that landscape acquires the same grandiosity as the factories, it is as if the factories challenged nature in a singular struggle, but in others, as in the case we are dealing with, it even manages to supplant the factories.

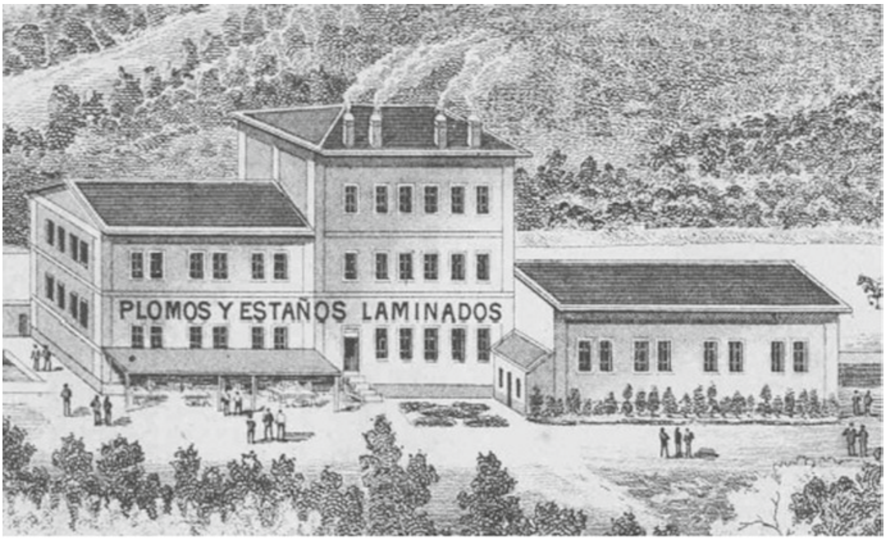
[7] In Bizkaia the clearest case, an approximation to the idea, can be found in the *Euskalduna* factory, the stationery of which has a similar image which, in those times, was quite common in the northern Europe.



In the meantime, in some noteworthy borderline examples, modernity and tradition went hand in hand, configuring a short-lasting but very significant industrial landscape.

In general the size of the installations is a determining factor, both in terms of the height of the perspective and the significance of the landscape, as well as the setting chosen to describe the factory.

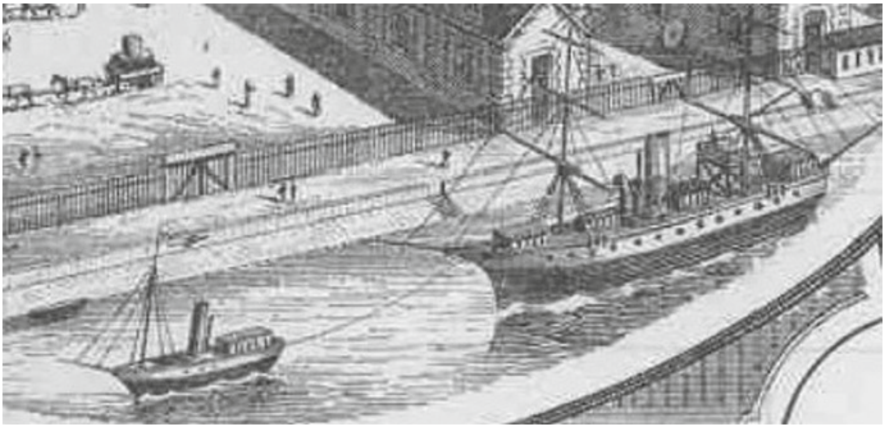
In those cases in which the pavilions were aggregated, the perspectives were very deep, whereas in those cases in which the installations were segregated from each other, the image tended to be more nuclear. In the former the point of view is imposed by the axes of the pavilions, in the latter ones other variables take over, such as façades and the noteworthy position of the boss's house or, occasionally, workers' housing.



The proliferation of smokestacks is extremely noteworthy, and the previously commented view of *Altos Hornos* from the river accumulates up to 20 of them, but even in urban installations, such chimneys stand out. It would seem they are a symbol of the factory. When there are no smokestacks, they are made up.

Thus, in 1899, in the stationery belonging to the "*Plomos y Estaños Laminados*" company in Balmaseda, company buildings are pictured, and such buildings, for whatever reason, did not have the nimble smokestacks in use at the time and what is pictured is four small chimneys with their corresponding smoke puffs on the roof of a building that scarcely looks like a factory.

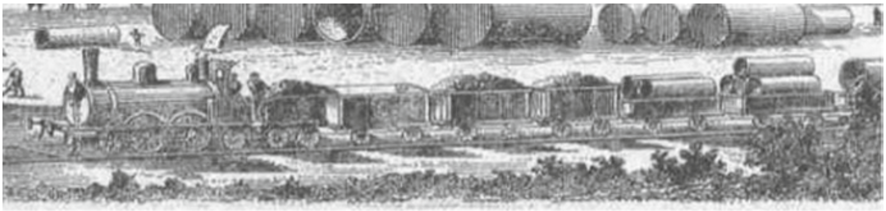
The case of *Anduiza* is somewhat more complex, in that it is a company that shows us two smokestacks on its buildings situated in the very streets of Bilbao in its depictions towards 1905, in spite of the fact that in some photographs dated 1920, such chimneys do not exist. Was there a change in the form of production and together with that, were chimneys eliminated? Or did they simply never exist?



But smokestacks were not to be the only symbolic element. Initially, it is possible to see some automobiles and even the occasional lorry near the installations, and in river perspectives there are even steamships,[8] and in other urban spaces the occasional tramway. But, gradually, the other indispensable protagonists, together with smokestacks, are to be trains. What's more, in the revolution of these logotypes it is possible to follow the formal development of this means of communication, all the way from the first machines up to the locomotives of the 1940s.[9]

[8] In the case of the "*Nervión*" company, which has from the end of the nineteenth-century included a beautiful building with its long steam chimney and a tug steaming up the river. The tug is, of course, a steam tug.

[9] In the case of the *Aurrera* company, machines are the protagonists in the late 1920s. The train pulled by a locomotive that belches dense smoke chugs along a landscape in which electric line posts stand out as especially noteworthy. The four wagons that provide perspective to the picture are loaded with tubes, which are the main product of the company.



Now, this line of pointing out modernity is compensated with another equally present practice of contrasting the modern with the traditional worlds.

From this point of view, these are very interesting materials, as in most cases they offer us images of realities which have already disappeared, and not only from the point of view of the complementary elements, but also from that of the very buildings which were almost always substituted and seldom photographed, and even of the profoundly transformed landscape over the last 100 years. If that in itself were not enough, we must also not forget that the images of interior spaces also tell us what the installations of the past were like. And we have to remember that these installations even show us the workers; that is to say, the testimonies we are talking about even transmit us information on the conditions in which workers had to carry out their activities, that is on the working conditions.

It is even possible to see packs of mules, batteries of carts, cargo carts, horses pulling carts and carriages, elementary cranes and boats or river boats, which were already sailing 100 years ago. In some instances there are even representations of barrel makers carrying out their jobs of building barrels.

However, we can not ignore the fact that these are engravings, not photographs, so in general terms the degree of image precision is pretty low. These engravings do not inform us on clothing or on punctual forms of work or on many other things in the way photographs do and in the manner photographs will do several years later.

It is difficult to regulate the process of implementation of such image elements. Those we have pointed out as the initial ones, always connected to foreign companies, are going to be readily joined by those from local companies and by 1905 they will already be quite abundant.

In the case of the "*Boinas La Encartada*" company, its initial letterhead paper was anonymous; however, early on the correspondence and invoices it receives brings more and more images of the factories of its interlocutors, and not only from the foreign ones, but also from some Spanish ones.

As a result of this, at a given moment, the management decides for an intermediate option: it includes a photograph of its pavilions in its new letterhead paper. The image, in accordance with the technical characteristics of the time, is pretty rough. It is therefore used very briefly. Sometime later all its stationery is substituted and the photograph is swapped for the first of a series of drawings which, for a pretty long period, the firm was to use as the image of the company.

An administrative example of this practice is that of "*Julián Abando y Compañía*" a small workshop that produced enclosed balconies, the premises of which was a simple and small single-floor pavilion with six narrow windows, in spite of which its owner, influenced by the tendency that was involved by 1898, already ordered stationery with an engraving that represents the place, an image in which the always-present smokestack is also there[10] although in this case, strangely enough, the smoke tends to heavily float on the ground instead of majestically elevating itself towards the heavens.

From another point of view, another characteristic of these times is that the engravings are anonymous. Anonymity was a general trend, if one is to believe the international logotypes consulted. The first case with an author dates back to 1905, it is the "*Manufacture Française de Coiffes*" company founded in 1879 which presents an engraving by A. Canard.[11]

In 1935 "*Aurrera*" seems to be working with "*Gráfico-Hispano Fotograbado S.A.*" from Madrid which makes reference to the authors of such works. And at around the same dates "*Creaciones Bonaparte*" from Barcelona seemed to dedicate itself, at least in part, to the same activity. In any case no authors' signatures are visible.

However, although that is all partially true, one must be cautious not forget that the images we are making reference to are, in real terms, propaganda in an age which was when modern industry was only just dawning and in which industry was considered the best possible testimony of modernity and efficiency. This is to say that there is probably a higher component of idealisation in them that should be corrected in the light of other testimonies such as photographs of similar areas and reasonably close times, and even of other kinds of documents, including really technical ones, such as drawings, designs or projects. From a methodological point of view this implies a certain amount of problems since the incorporation of photography to printing was something that took place somewhat later, and therefore we need to be lucky to be able to have original copies. One should not despair, however, as the companies themselves used to make photographic reports which sometimes still survive. Those owners who took stakes for modernity understood that photography was part of it. Besides, it would seem that in certain cases engravers also used photographs for their work.

It is probable that along these lines we shall be able to approach reality to a certain extent, as it is possible to find photographs in the documental archives of companies. The engraver that designed the stationery of the already mentioned *Anduiza* jewellery and silver merchant in Bilbao is one of those cases – we do in fact have an extensive photographic compilation about it- although curiously

[10] In fact, there are doubts that this is a real image. It is said that this workshop is "*La Esperanza*", belonging to "*Julián Abando y C*[ia]" the address of which was in Henao Street; it is true that until not too long ago that the sloped landscape that is visible behind the workshop is not possible, so it may just be a creative invention.

[11] Of course the company owner was the very same or a different A. Canard.

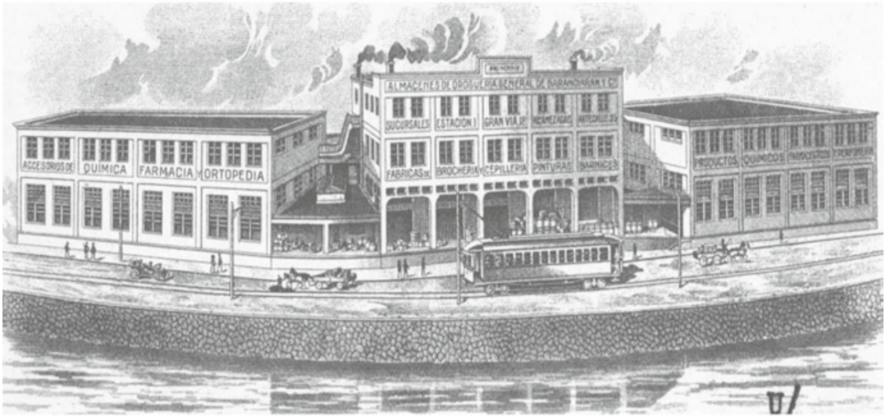
enough the photographer had a different point of view from that of the engraver, who would often forget about people, which are, however, present in the work of the former.

One of the stationery engravings from this company has a lateral view of the Arriaga theatre at the end of the century; it is an aerial view, but from the opposite side of the river in those times one could achieve a pretty similar view, as the left bank in front of the town was quite higher than the right bank. This was therefore also, to a certain extent, an aerial view. They are, therefore, comparable images.

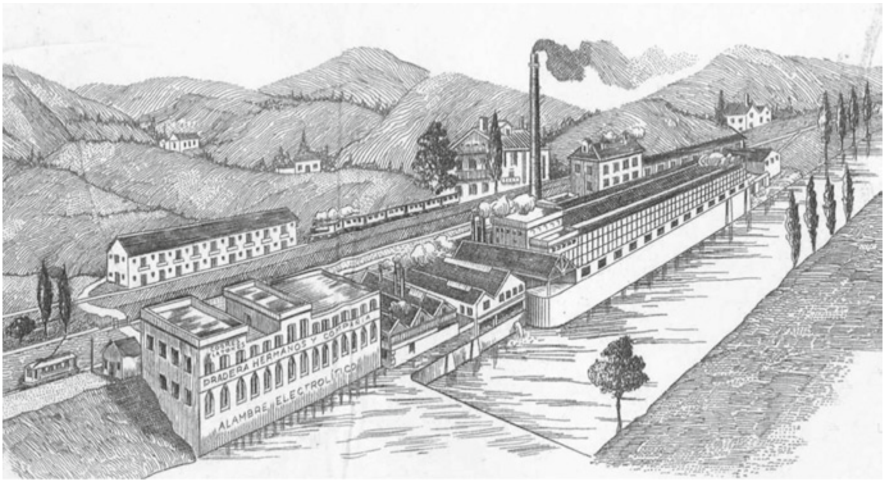
But what is more, as has been said, there is an interesting photograph album of the company dating back to 1920. It is true that during the 15 years between the engravings and the photographs there must have been changes. We can however conclude among other not unimportant things that it is possible that the smoke-stacks shown in the "factory façade" were just a symbol and not a reality. We can also conclude that the corner finish at street level was set to deepen perspective, independently from a certain degree of truth or fantasy. In this sense, we should not confront image with another reality; we should interpret both in terms of complementarity instead. And as can be imagined, *Anduiza* is not the only case in which this happens.

By the late nineteen-twenties this practice is generalised and it is applied even in clearly urban companies like the view of the *Barandiarán y Compañía* company that illustrates its correspondence with a beautiful perspective of one of the blocks that face the river in Bilbao together with the corresponding electric tramway.

In order to assess this circumstance it is necessary to bear in mind that this company, a grocery wholesaler that even managed to produce soaps, for many years had been using a certain calligraphy or, at the most, for a few years, the image of a small lighthouse. But at a given moment, in the opinion of its managers the time had come to modernise and adapt to the new times and in this manner, the new corporate image, chimneys included, fulfilled its objective.

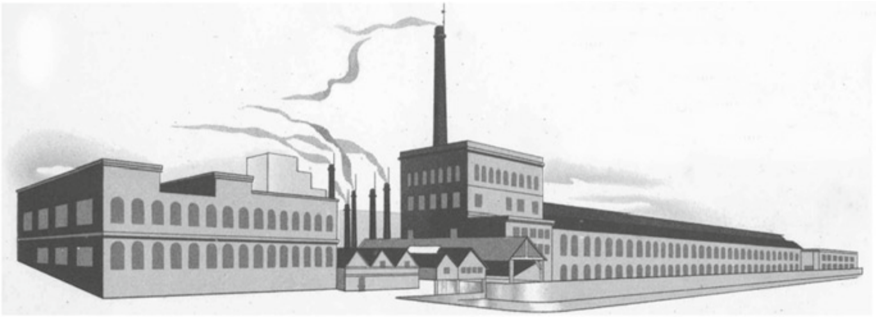


In the years after the Civil War some companies were to continue with this practice in what we could call the "traditional" manner, but others adopted in their designs the new aesthetic tendencies, the image of the factory becomes synthesised and elements of colour are introduced.



To a certain extent the engravers lose ground and the artists who interpret the volumes of the factory in a Bauhaus and synthetic cubism keynote gain it.

The new designs will tell us little about reality, they will no longer have the ethnographic character of their predecessors, nor their testimonial value. However, as is indicated, some companies will continue using the previous system. Now images will be less lineal, in some cases they will attempt to look like photographs, with an abundance of shades and substituting perspective by depth of field.[12]



These new orientations put aside the aerial perspective as well as references to landscape, the new designers no longer need to invent an impossible flight, nor do they need to show us the connection between what is new or progress with the past; the factory is a value in itself, it no longer needs justification.

In other words, the process we have seen appearing in force in the transition between the centuries begins to change after the Civil War and this, bearing in mind its implications is not an unimportant matter, but it transcends the contents of these few lines.

[12]The two views of "*Pradera hermanos*" are, I hope, clear illustrations in this respect.

It is difficult to trace up to when this tendency definitely lasts, what we do know, however, is that it had an interesting epilogue when some companies, at least in the Basque Country, commissioned certain artists landscaped views of their installations, not for their exterior image, but to decorate their offices, which in these times were often quite far from their centres of production. In this tendency especially noteworthy over anonymous logotype engravers are artists like *D'Abraida*,[13] a Portuguese who would still be signing his work in the nineteen forties.

So over nearly half a century we see how there was a certain factory image stereotype and how this image stopped being necessary, which opened a new phase with new needs. But in the meantime a systematic search of those images has become necessary, as many of them are unrepeatable testimonies of a time that is now past.

3 Machines as a Sign of Modernity

On the other hand, the relationship of man with machines has been the subject of many a reflection, above all because that relationship has been neither straightforward nor lineal. That is, there have been times of positive – almost reverential-relationships, as in certain areas during the Renaissance, in the Court of Phillip II, and even in other courts in the late sixteenth century, but together with that there have been episodes as significant as mechanism and the well-known "Revolt of Captain Swan". So there have been all kinds of relationships.

However, in my opinion, in very few occasions like those in the late nineteenth and early twentieth centuries has there been such a high degree of appreciation of machines and their significance by the population as a whole. For a few years machines were considered a paradigm of modernity, when being modern was a declaration of faith in that present and in the future.

An especially sensitive area for this phenomenon was the field of publicity and in particular that of the image that companies wished to project to others, to customers and to the general public. This image was disseminated by various means, among them that of official documents from the companies themselves: their correspondence, their rubber stamps, advertisements and others.

We have seen how in Spain and in the Basque Country in particular, as in other places, corporate official correspondence letterheads were the vehicle chosen by many entrepreneurs to disseminate a certain image of their companies, and we have also pointed out that such images depended to a considerable extent on a codified comprehension system of what was, in those times, the concept of a "factory".

Well, in the same manner in other occasions these letterheads were used to disseminate other values which were then on the upswing, like the almost magical values of machines. Letterheads were used, by means of codes that were logically different from those of the image of the factory, to transmit to the spectators, who

[13] SOBRINO SIMAL, Julián "*La arquitectura de la industria y la organización territorial en España, 1925–1965*" in the *Documomo Ibérco* Register: *La arquitectura de la industria 1925–1965* page 8 where one can see an image of the picture by D'Abraida on Babcock Wilcox.

were the targets of such messages, an undeniable corporate commitment with innovation and, by extension, with modernisation.

This was a general phenomenon, but also a phenomenon of a behaviour that reached, in each company and in each stage of industrial development, various levels of dissemination and which was implanted in various different moments. Thus, as in the initial images of factories in Spain, these were copied from other foreign factories or were incorporated by foreign entrepreneurs to the stationery of their Spanish businesses, and the use of machines as an element of corporate identification also started outside Spain and was later incorporated into the Spanish corporate culture wherever it reached a certain degree of implantation.

And in this case, as in that of the factories, chronology is very significant as this does not become generalised practice in Spanish companies until well within the twentieth century, when similar practices had been current in Europe since at least a decade before that.

Now, the fact that the image of factories and the image of machines followed similar chronologies and conjunctures does not mean that both received identical treatment. In fact they had very different characters with the passage of time, which does not exclude certain similarities.

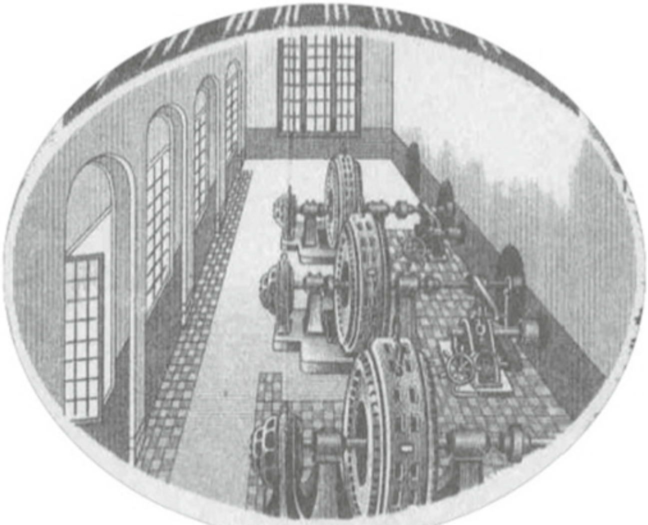
These images were used preferentially in correspondence, both in letters and, to a lesser degree, in envelopes, but also in the publicity in the media and in specialised commercial and industrial publications. In contrast to the landscaped images of the big factories, I do not know of any cases of them being used to illustrate shares and other property certificates, which is something that cannot be absolutely ruled out, considering the ample dissemination of such drawings.

As is well known, and has already been said above, in the huge majority of the cases these were realistic drawings, carried out by professionals, usually employed by the printing presses and publishing houses, following the technique of presenting first an ink-penned original and then proceeding to its treatment for the printing of a wide range of supports in the correspondence of each company.

In general, at the beginning it is not frequently that one finds colour prints. Prints in black ink are much more common. However, in prints designed for specialised magazines, such as the annual reports of the Chambers of Commerce and other similar publications, it is occasionally possible to find versions with more colours than the standard types. We should point out, in any case, that with the passage of time, as we come into the twentieth century, there are more and more cases of correspondence letterheads in two or three colours; but by then the pioneering years will have been over and there were other key modes to bear in mind to which we are not going to make reference to here.

Machines were usually presented in perspective and are almost never – and this is an aspect of the matter that makes sense up to a certain degree accompanied by the image of a worker that could give the spectator a clue to its size. Given the very wide possibilities that existed, there are examples for all possible variables; and in fact it is possible to find images with workers. A noteworthy case could be that of the Guruceta foundry, that together with the image of the company includes a picture with a view of the workshops in which next to a lathe it is possible to distinguish up to eleven workers. One cannot rule out that the crowding of men in the image was intentional in order to counteract the tendency to blame machines for competing with men for their jobs.

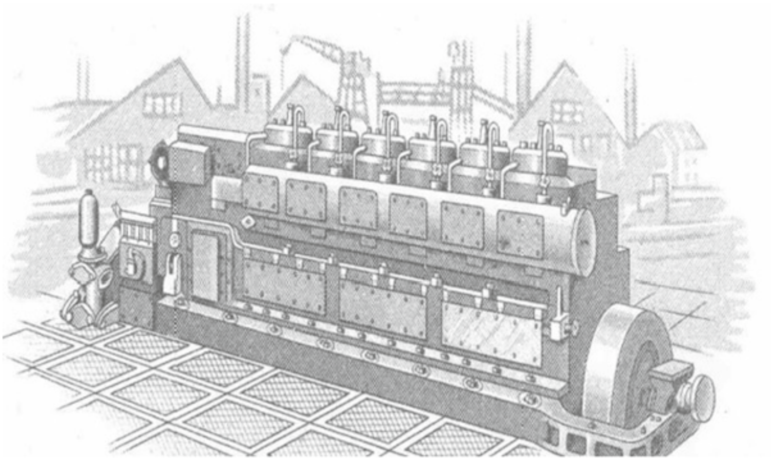
It would therefore seem as if all machines were the same, all of them immense. Probably that was what was actually intended. In fact, there are some simple images of dynamos which, out of context and without references of proportion, could stand in for machines as big as any, especially in those times.



This effect is reinforced with the technique of not limiting the space of the image to a mere letterhead, which is more or less displaced on the paper; often the pictures invade the whole of the page heading as if the machine reflected did not fit into reasonable limits, i.e. as if the machine itself was absolutely huge.

As a consequence of the various parameters of interpretation that such proposals had with respect to the landscape, which was better interpreted by those spectators and which, therefore, was not so open to possible manipulation, there were very few companies that combined in their image a landscaped factory with the machines that were lodged inside it. One example of this is the *Ajuria* Factory which incorporated, together with the views of its two installations in Araya and Vitoria, a central picture with a perspective view of the great pavilion in which the 3000 horse power machinery of the waterfall at Cabrina, on the Ebro River, was lodged. By the standards of the day this was a state-of-the-art installation. It was so important for the company to disseminate both images that the model is maintained even after stationery changes, showing us different points of view and independently of the fact that the company is called *Ajuria SA* or later renamed *Ajuria y Aranzabal SA*.

In this case, the underlying intention is exactly the contrary to the general trend. It was matter of showing the magnitude of the machine without taking it out of context but precisely showing how it occupied by itself a whole great industrial pavilion. The machine dominated the space. Technology, science and power joined forces to guarantee modernity and the vanguard for the spectators.

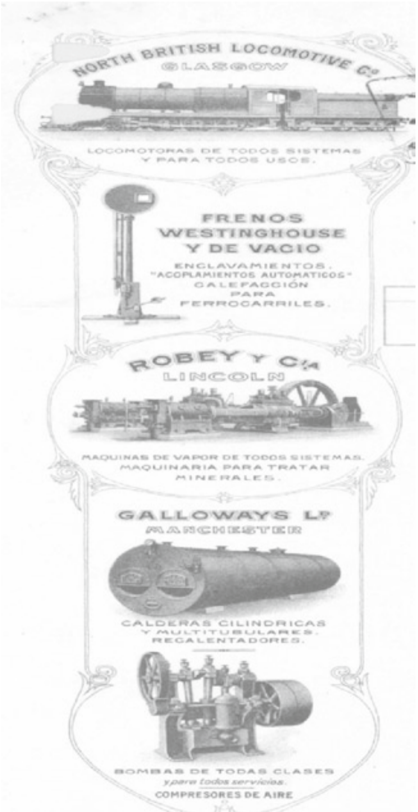


In an extreme circumstance of machine assessment, we can see one of them perfectly and painstakingly drawn in the middle of a wide space, almost out in the open and with a background of anonymous factory installations which are simply sketched.[14] In other words, the machine becomes more important than the factory itself.

None of this means that, depending on what company we are talking about, only a single machine is pictured. In production companies, normal practice was to recur to a single machine or at most to the most significant from the point of view of production in itself, but in machinery commercialisation companies, in some cases the option was to convert correspondence into a kind of sampling of the products represented, including in each page the image of various machines, more often accompanied by their denomination, all of which contributed to disseminate generalised expressions such as “Revolver Lathe” or “Universal Grinding Machine”, the generalisation of which was unthinkable just a few years beforehand.

The case of the *Azlor* company clearly reflects the various keynotes for the interpretation of such drawings. The company, set up in 1925 and dedicated to the commercialisation of machinery, opts for a letterhead that includes the image of a machine, the nature of which is not specified, although it is an electric generator, a connection with electricity that is clearly not devoid of its dangers. However, the stationery is completed with a figure of other machines illustrating the left margin of the letter, where up to four different machines are visible, and perfectly defined, which are the ones that *Azlor* is commercialising in that moment.

[14]This is for example the case of Madina S.L. de Ingenieros in Bilbao.



As is natural, in these cases, stationery changes as the company incorporates new machines which, therefore, were then added to the margins of its correspondence. One company, like the aforementioned *Goenaga*, in just a few years was to modify its stationery, and as a consequence thereof has left us images of six machines, and not only of the four initial ones.

This aspect of the corporate image is completed with the circumstance that it is not only the intermediary companies which represented or sold motors manufactured by third parties illustrated search engines; the very manufacturers did the same whether they produced machinery or other diverse manufactures.

And this is not only an industrial matter, this also happened in agriculture. *Ajuria* the agricultural machinery company, as we have seen, included two landscaped views of its installations and a view of its electric power plant in its stationery. A few years later, another company in the same sector, *Antonio Bodet*, radically changes the concept and reproduces in its letterheads images of tractors, cutters and harvesters. So this matter had also fully reached the rural world.

Now, machinery is not only a symbol of the company, it frequently appears in other kinds of correspondence, in letters from engineers and even from their engineering companies. It is as if in those times engineering was associated with machinery. And indeed in these circumstances the publicity factor is less important, since what the engineers in these cases wished to transmit is their familiarity with the machine, their capacity to assemble them and even manufacture them; without making reference to one machine in particular, although the image of one concrete machine is used as the company insignia. In fact it is significant that it has not been impossible to find engineering company letterheads that show installations of factories but it has been possible to find examples of the use of engines.

But all of this, although undeniably interesting, is to be placed within what we can qualify as publicity. We need to distinguish between commercialising and use. What is relevant, from the point of view in which we are observing, is to point out how some companies, quite a lot of them in fact, considered that disseminating their degrees of technical equipment was an added value. This was also publicity, albeit of another nature.

Some companies, such as "*La Flor de España*" sausage factory in Casalarreina made that statement of modernity with a simple declaration: "moved by our own driving force", but others went even further. But not much, as when their manufacturing system is indicated, as in the case of *Talleres de Deusto*, stating that their modelled steels are produced either following the "Martin Siemens" system or that they are "Electrical ".

In some cases there is a real exaltation of technique by means of machines, in that they are the paradigm of that identification between modernity and machine, or if you prefer, while making reference to the principles of the nineteenth century, between contemporary times and technology. Only machines, inasmuch as they are technology, guarantee modernity, guarantee being up to date, and guarantee the value of the future of a determined production, whatever it is. Machines are the guarantee; technology is the desideratum.

Pedro Juan De Lastanosa and "The Twenty-One Books of Devices and Machines of Juanelo"

Nicolás García Tapia

Abstract This lecture is about the enigma of the manuscript known as "The Twenty-One Books of Devices and Machines of Juanelo" ("Los veintiún libros de los ingenios y máquinas de Juanelo") which is kept in The National Library of Madrid (Biblioteca Nacional de Madrid 1983). This book has prompted numerous investigations and some discussions. As years go by we have been able to carry out an in-depth study and correct the mistakes that a hasty discussion often causes.

Our aim is to reveal the results of our research on the manuscript mentioned-above. These results are related to both the content of the book, especially the parts regarding the water technique – the subject of this conference – and the ups and downs it has gone through. In this research, we explain the reasons and present the documentary evidences which allow us to keep maintaining, more convinced than ever, that the author of the book is Pedro Juan de Lastanosa from Aragon (Spain).

1 The Enigmas of the Manuscript

The manuscript known as "The Twenty-One Books of Devices and Machines of Juanelo" has several enigmas which have attracted the interest of those who have read it. First of all, it is a large sixteenth-century treatise on engineering buildings and devices, especially related to water, of great importance for the History of Technology. The title of this book contains the word "Juanelo", name by which Gianello Turriano was popularly known in Spain. He was one of the most famous engineers and clockmakers for Charles V and Philip II, the two greatest Spanish kings in the sixteenth century. Gianello Turriano created, among other things, a

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J.M. de la Portilla and M. Ceccarelli (eds.), *History of Machines for Heritage and Engineering Development*, History of Mechanism and Machine Science 14,
DOI 10.1007/978-94-007-1251-5_3,

machine for lifting water from the Tagus river to the Royal Palace of Toledo becoming one of the most amazing inventions at that time.

Juanelo Turriano had been considered so far the author of the book due to the fact that his name appeared in the first cover. However, Ladislao Reti and García-Diego's researches have definitely proved the contrary. He could not be the author, on one hand, because the content of the book and his work had little in common. And, on the other hand, due to the language, more typical of an Aragonese man than of an Italian one. Finally, the manuscript was rightly named "Pseudo Juanelo" by García-Diego.

Nevertheless, the enigma of who was the real author still remained. We have devoted great effort to this task and the research leads us to conclude that an Aragonese man, who worked as an engineer for King Philip II and was called Pedro Juan de Lastanosa, could be the real one.

In spite of that, José Antonio García-Diego didn't agree. He thought Lastanosa was too educated to deal with devices. As well as that, Lastanosa died in 1576, date on which, according to his researches, the book had not been written yet. However, the linguistic studies of Frago, who is a well-known researcher, have proved that it is quite possible the author came from an area in the Cinca river valley in the north of Aragon. The very same place where Pedro Juan de Lastanosa was born (Frago Gracia and García-Diego 1988).

The second enigma regarding the title of the manuscript is the number of "books" or chapters in which is divided. Whereas in the cover it is said to be twenty-one books, in the text there are more that have not been numbered. In addition, it is clear that its numbers have been changed in a later checking. Therefore, "The Twenty-One Books of Devices and Machines of Juanelo" neither are twenty-one books nor are Juanelo's, what adds more confusion to the research.

The third enigma is the sudden ending of the manuscript which finishes without explaining some subjects that had been announced previously. That is due to the fact that the author had no time to finish it, leaving it unsigned. It is not known what happened to the manuscript, who used it and how it got to the National Library of Madrid where it is kept. It is hardly surprising that the research on the manuscript had been the butt of controversy (Garcia et al. 1988–1989). Now, we will try to answer the enigmas that the manuscript raise.

2 The Covers Added in the Seventeenth Century

One of the first things observed when studying the manuscript is that its covers were added in the seventeenth century. Nevertheless, not everything in the new title, which was added to the sixteenth-century text, is false. Firstly, the "twenty-one books" resulted from a rearrangement of the chapters, responding to the new technical ideas developed in the seventeenth century. Secondly, the added phrase "and devices of Juanelo" does not necessary mean Juanelo Turriano was the author but it may mean that the devices described in the book were so ingenuous that they could have been worth of the sixteenth-century mythical clockmaker, who became a legend a century later. The rearrangement of the chapters and the new title was done by Juan Gómez Mora, an architech who worked for King Philip IV and was admirer of Philip IV's bastard brother, Jonh of Austria, to whom Gómez Mora dedicated the new arrangement of the beautiful manuscript. This fact let us date these new covers between 1643 and 1648, dates of the recognition of Jonh of Austria as Philip IV's brother before the Court and the death of Juan Gómez de Mora, respectively.

There is another thing which was added in the new covers: the manuscript was ordered to be done by the Catholic King Philip II, Spanish Territories and the New World's King. Indeed, at the time of Philip II (1527–1598), the Spanish King used to order scientists and engineers to write at least a book about their own field so as not to lose their knowledge by being transmitted to the next King. In fact, in the sixteenth-century book, some references were made to King Philip II. These references reflected that he was in the service of the Crown as an engineer. We know the original book was written between 1564 and 1575 for several reasons. In first place, due to the date of edition of the last book mentioned (1564) and secondly, because the Archbishop Hernado of Aragon, who lived until 1575, appears in that book. At that time (1564–1575) Spanish technology was in its heyday, an issue that is discussed in the manuscript and about which we first need to make a few things clear.

3 The Spanish Technology Scene in the Sixteenth Century

At the time the original book was written, several public works were being building. Most of them related to the manuscript content. For instance, important fountains such us the one in Ocaña (Madrid) and dams such as the one in Ontigola (Aranjuez) which had an extensive network of canals to irrigate the gardens and supply the fountains with water. Fairways, ports, bridges, aqueducts…were also built. In all the Spanish territories, including those in America, the engineering made great progresses (García Tapia 1992). This progress was due to the fact that Philip II wanted to provide his vast empire with an infrastructure worthy of its extension. In addition, he was interested in knowing all the issues appropriate for a Renaissance Prince according to the Italian Renaissance. This fact proves Philip II was far from being that cruel and gloomy king that people described. It is known that Philip II had a great taste for art and culture (Checa Cremades 1993). However, the fact that he was keen on science and technology was not that popular (Anonymous). Philip II surrounded himself with not only artists but scientists from all over the world, creating a Court where the study of Mathematics and Applied Technical science was the priority.

Thanks to new studies (Isabel Vicente Maroto and Mariano Esteban Piñeiro 1991), some matters of great interests are being clarified. In the reign of Philip II, some institutions were set up. For example, The Academy of Mathematics in Madrid and others similar, which was dedicated to the study of cosmography.

Even in the Court in Madrid there was a Mathematics School for pages where future King's servants were taught science and technique. Among these servants, some were chosen because of their scientific and technical knowledge in order to teach others and advise about the large amount of problems arisen in the vastest monarchy in the world. Their job involve advising about astronomy, navigation and cosmography; establishing the scientific basis for measuring the Hispanic territory; solving engineering problems; reporting on the feasibility of the inventions that were offered to the monarch as a potential patent (García Tapia 1990) and last but not least, as we have already mentioned, writing about their specialty. On account of the fact that these treaties were written in Latin and people in charge of putting things into practice did not understand the language, Philip II ordered treaties to be translated or directly written in Spanish. In addition, treaties had to be easy to understand by technicians. The analysis of the numerous manuscripts on science, technique and engineering which are kept in the Spanish files is a work that still need to be completed. However, the work we have done so far shows that during the reign of Philip II important progresses were made. We think that only within this framework it was possible to write "The Twenty-One Books…" Only a King as Philip II could promote a work of this magnitude and such features. It has 473 sheets of paper which are written double-side and 440 drawings which are most hydraulic machines. As done before, the King's scribes and draughtsmen made several copies for all the water specialists who worked for the King and one for the Royal Library, the same copy that nowadays is kept in the National Library of Madrid. With regard to the rest of the copies, one of them has been found recently in a library in Florence and another one is a private property. Fact that confirms our theory.

4 Hydraulic Engineering and Architecture

In the sixteenth century, architecture and engineering were part of the same knowledge field. In both Renaissance Italy and Spain, architects were also engineers at the same time. "The Twenty-One Books…" was also a book about architecture. In that respect, the book tells about the well-known treaties of Vitruvio, Frontio, Serlio and especially of Alberti. In fact, the Aragonese author copied almost exactly the Alberti's treaty which was translated into Italian by Cosimo Bartoli (Florence 1550), some of the paragraphs translated into Spanish are practically the same as the Italian ones.

It is interesting to know that a copy of this treaty is kept in the National Library of Madrid. This copy contains interesting margin notes and drawings about engineering and architecture which match up with some of the issues explained in "The Twenty-One Books…" Specialists state that these margin notes and drawings were written around 1560 by a Catalan architect. This is due to the places named and the idioms used (Bustamante and Marías 1985). Nevertheless, it has not been possible to find out the author's identity of the margin notes. However, it is obvious that the one who wrote "The Twenty-One Books…" took them into account (García Tapia 1994).

The fact of including things of other architecture books does not mean that "The Twenty-One Books…" lacks of originality but quite the opposite. This book includes studies of the author's works on engineering and architecture. For example, it is interesting the building system proposed for the watchtower in the Alfaques (mouth of the Ebro river) which had to have a foundation in the sea. It is also curious, although it has been discussed, the way of building a bridge which is opened in the central arch to allow high boats to pass and has a slippery footbridge used as a pedestrian and carriage crossing. This system was successfully built and praised later on by famous Spanish architects such as Benito Bails (Bails 1790) in the eighteenth century.

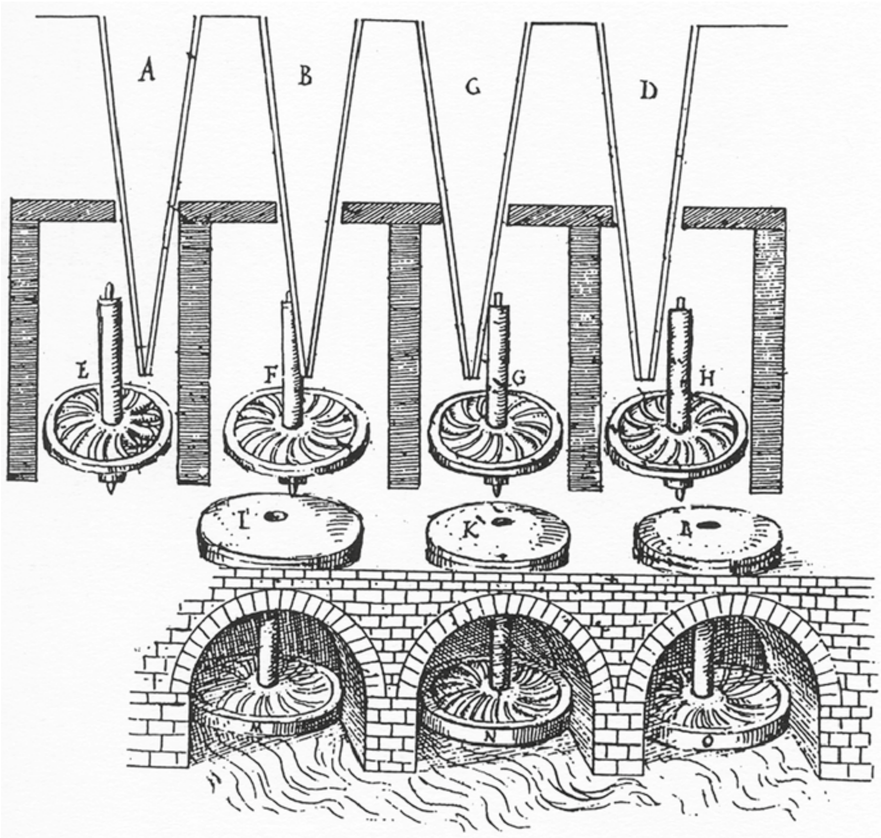
This part of "The Twenty-One Books…" helps us to confirm the date in which the book was written. In fact, several renaissance treaties about bridges are mentioned in the book. The most modern one is from 1564. However, it is not included "The Four Books of Architecture" which was written by Palladio in 1570 and spread around Spain a few years later. There is no doubt the author of "The Twenty-One Books…" would have mentioned Palladio's work if the manuscript had been written later. That confirms "The Twenty-One Books…" was written before 1575. It would take too much time to analyse one by one all the engineering works set out in the manuscript. Apart from the bridges and fortifications, the author seems to know well the hydraulic building such as dams, canals, water supplies, aqueducts, ports…which means the author knew perfectly well the architecture and its applications in hydraulic engineering.

5 Water Science and Technique

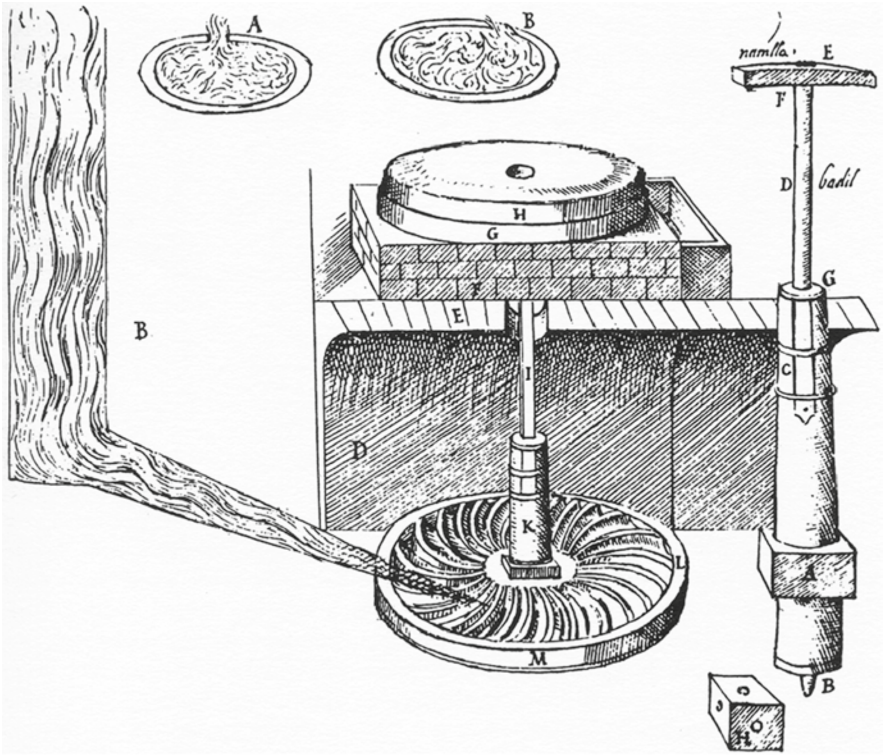
As architecture and engineering, science and technique were closely linked in the sixteenth century. A book about water technology had to contain the scientific principles in order to be understood. Although "The Twenty-One Books…" was aimed at people with little knowledge of basic science, the author did not forget to include the scientific basis but at the same time he tried to avoid complex mathematical proofs. The book contains some mathematical elements which are presented in a very elementary way. Even so, most of them are right. If there are any mistakes is a copyist's error, which you realize when you read carefully the manuscript.

Contrary to what has been said, the author proves to be acquainted with the mathematics of his time and well informed about its theory. But the author does not only know about mathematics. He perfectly knew about physics in the sixteenth century, which was elementary until Galileo's revolution. He was even ahead introducing some concepts such as the falling bodies. This proves that he was in touch with the circle of scientists from the court of Philip II, where these principles were already known (Vicente Maroto).

The strength of the author was what we now call fluid mechanics, about which a theory had not been formulated yet, regardless of Leonardo's notes. From the physical concept of water, properly defined, until the basic knowledge about speed and flow. He could reason about the flowing water and some concepts, such as the speed with which a liquid goes out through a hole, were introduced even 70 years before Torricelli formulated that theory. The author also came to understand the concept of friction loss in a pipe and he even experimented friction loss in a trap to find out its magnitude.



Everything which has been said it is important, but we cannot forget the aim of "The Twenty-One Books…" which is the presentation of water technology and devices. With regard to it, we can highlight the machines for raising water but what has drawn people's attention is the fact that the famous "Juanelo's device" is not mentioned in the book. However, the explanation is clear: Juanelo Turriano is not the author of this book and, as well as that, neither the device had been finished nor it was known how it works by the time the book was written. On the other hand, a full chapter is devoted to the mills, revealing information, unkown until recently, about how the hydraulic wheels work. Thanks to this manuscript and the Francisco Lobato's one, which we have found out and published lately (Diego Garcia and García Tapia 1987), we now know how the regolfo mills work. This kind of mill abound in Spain, they were previous to reaction turbines. In "The Twenty-One



Books…", it is described how the vertical and horizontal water wheels work, which are called respectively "aceñas" and "rodeznos" in Spanish.

There is something remarkable in the author's analysis about the most suitable stream's angle of incidence and its connection with the output of the mill. As this is a book about water, few other kind of mills are mentioned, for example, manual and animal mills. Wind mills are not analysed, except from a special case which works almost like a water mill. It does not mean the author was ignoring wind mills which also abound in Spain and were well-known. It was just a question of subject, the book is about water devices. Nevertheless, there is a strange mill moved by weights which is said to have been invented by the author. Anyway, the device's description is short if we compared it to the one given for other devices. On the other hand, the device's drawing is wrong which is very odd considering the author is the inventor, unless he wanted to keep the right one in secret for some reason. Later on, when we talk about Pedro Juan de Lastanosa's inventions, we will solve the enigma. There are other inventions, the author says to be his. For instance, a tunnels building system, a kind of suspended scaffold, a dam with arches and buttresses, the design of a "bucket" mill with a different way out for the water and the bridge with a slippery footbridge mentioned-above. These inventions are important because they show the author's knowledge about technology. However, it is more important the amazing information he gives about a great number of sixteenth-century water devices.

6 Philosophy and Religion

Although this is a book devoted to water and its applications, in “The Twenty-One Books…” it expresses the thinking of a Renaissance humanist, the author’s. The classical Greek philosophers are often mentioned but not as dogmatic authorities. For example, about Aristotle, it only mentions his fusion of matter and form. This concept, applied to the subject of the manuscript, means to combine the conception with the practical work, a method that other Renaissance theorists, such as Alberti, used. Nevertheless, unlike the Neoplatonists, the world of ideas is not mentioned in “The Twenty-One Books…” Neither is Plato is quoted nor does the ideal of beauty appear in the text. For the author, the ideal beauty is not an ideal device itself but the result of all the parts of a machine working at the same time. Raymond Lully is not mentioned either. His philosophy, which Juan de Herrera was so fond of, does not appear. Juan de Herrera was the architect of El Escorial and the founder of The Academy of Mathematics in Madrid.

All this is important to establish where to place the book. For example, we will not find the author among Juan de Herrera’s fans. On the other hand, the thoughts expressed are similar to those of Benito Arias Montano, a famous humanist who had arranged the edition of a Bible in Plantin’s printing workshop, in Antwerp. Arias Montano, who ran the Library of El Escorial, was the leader of a group of humanists who opposed Lully’s philosophy and were in favour of the religion Erasmus recommended. This religion, which was against dogmatisms, can be found in “The Twenty-One Books…” The book does not refer to the Virgin or the saints of the Catholic Church. God is barely mentioned and when he is mentioned it is as a creator of a rational order where everything has its place depending on a natural need. It cannot be stated that the author was not concerned about religion which was almost unthinkable at that time. However, the beliefs expressed in the book are rational and reject all forms of superstition and even popular devotion. When he refers to the Old Testament, information he obtained from the historians Flavius Josephus and Tacitus, he talks about biblical episodes removing any moral and religious sense and giving them a purely practical nature. There is a part where he tells how Moses turns venomous water into drinkable water not working wonders but watching some signs in the water and then ordering that it be boiled. A non-traditional view of the Bible for the Spain of Philip II at that time. However, it is more similar to the one printed and commented on by Arias Montano. Actually, the Spanish King was not as intolerant as people have always thought. The author rejects any belief which is not backed up empirically. For instance, he did not agree with the practices of soothsayers (also known as water searchers) and alchemists, who were supported by Juan de Herrera and his circle. That is why these people were craftily criticized in the manuscript. If we have insisted on this matter is because it is very important to determine who the author had contact with in the Court of Philip II and to find out why the book was not published at that time.

7 Looking for the Author

We have already seen some details that will make possible for us to know the author.

Firstly, there is no doubt that he was from Aragon and probably from an area located in the Cinca Valley where the most important population at that time was Monzon, headquarters of the Aragonese Courts. This information is supported not only by detailed linguistic studies, but also by the mentions of Monzon and nearby places that the author of “The Twenty-One Books…” makes. Only someone born in this place or a very expert person could write it.

Secondly, the author had travelled around different places in Europe, he had been in Flanders and he knew very well some Italian cities from both the North and the South, especially Naples, repeatedly mentioned. He was an educated author and he may have had an extraordinary library as his literary and scientific quotes from classical writers are very precise.

Although his career may have been related to hydraulic architecture, the text that stands out is in the scope of machines. Nowadays he would be described as an extensive practical and theoretical training engineer.

It is a fact that Philip II ordered someone to write the book between 1564 and 1575. Inside the Courts, the author was involved with the Arias Montano Erasmian trends society.

It could seem easy to know the author with all this information but a series of adverse circumstances have formed an alliance in order to complicate the matter. In first place, we began our work in 1983 when the engineers who had worked in the Renaissance in Spain were not well known. So we had to make a difficult research since this kind of information was still uncatalogued in Spanish files. Once we had done this work, and after we determined the details of the engineers who had worked for Philip II in those days, we verified that the only person who fulfilled the conditions for being the writer of the manuscript was Pedro Juan de Lastanosa.

In the second place, but the worst bit, we had to face up to strong opposition by those who had denied our first hypothesis about the only person who fit in the authorship diagram that we had drawn: the Aragonese engineer Pedro Juan de Lastanosa. However, our entire searches later confirmed that this was the author of “The Twenty-One Books…”

8 Pedro Juan de Lastanosa

Pedro Juan de Lastanosa was born in 1527 in Monzon (Aragon, Spain) in a family of merchants. He could not achieve nobility at that time, perhaps due to reasons of converted Jewish origin. Some descendants, such as Vicencio Juan de Lastanosa who lived in the seventeenth-century, did get it thanks to their wealth. They even embellished their genealogy with non-existent noble ancestors, a fact that has confused some historians about Pedro Juan de Lastanosa's noble condition. On the contrary, he was the youngest of 21 siblings, and because of economic needs he had to work as an assistant to Jerónimo Girava, a cosmographer and engineer in service to Charles V, who taught Pedro the profession. He stayed with Girava in Flanders in 1553, where he helped to translate one of the books about Practical Geometry by Orence Finé (Tapia García and Vicente Maroto 1991). He went with Girava to Milan, on the way to Naples where Girava would act as an adviser to the viceroy about hydraulic engineering matters. But his master died in Milan, so Lastanosa obtained the hydraulic engineer post for the viceroy of Naples. Lastanosa acted as an adviser in different matters such as bringing water to the city, which led Lastanosa to write a document entitled "Discurso sobre las aguas de Serino" (National Library of Madrid), ("Discussion about water in Serino").

On the 14 May, 1563, Pedro Juan de Lastanosa returned to Spain as a "machine expert and main master" of Philip II. Required to be informed about all types of necessary machines for both civil and military uses, as well as factories and fortifications in the kingdom. Lastanosa was considered as the best devices specialist, and for that reason he had to write about them. Thus the manuscript we are talking about was created. Most of Lastanosa's works were constructed in the ancient kingdom of Aragon, where he came from. He accompanied the King to the Courts in Monzon, his home town, in September 1563 and then to Barcelona´ s Courts the following year. According to the King´ s instructions, Lastanosa gave a report on the possibility of building a tower in the sea in Alfaques (Ebro river mouth). This matter was described in "The Twenty-One Books…" and is also an evidence of his authorship. Working as an hydraulic engineer, he designed a project to carry on with the buildings of today's known Imperial Channel of Aragon, which had been started under the mandate of Charles V but it was not finished until after two centuries because of the Spanish Monarchy's financial troubles. Lastanosa was an expert in mills and he patented one of his own inventions which was moved by weights. But someone who tried to claim the invention brought an action against him.

This incident possibly explains the unfinished strange mill's weight that appears in "The Twenty-One Books…" According to the King's order, Lastanosa took part in compilation of a map of Spain by measuring some territories in Aragon, an area that he knew very well. Another scientific activity was his participation in the discussion about the position of the meridian which divided Spanish territories from those of Portugal. He contributed to editions of mathematics books in Spanish, such as one by Pérez de Moya, aimed at practical technicians. He also provided advise regarding Architecture and Engineering books, and the formation of the El Escorial library where he met Benito Arias Montano and became such good friends that while Lastanosa was in Amberes, Benito regularly sent him his salary.

Lastanosa was a member of the Erasmists and he approved the book printing of one of them, Brother Gonzalo de Illescas without his authorization this book would not have passed the censorship.

Pedro Juan de Lastanosa died in Madrid on 29 June 1575. An inventory of his goods was made and, consonant with his belief, there were no religious pictures or valuables. His library had 559 books, a great many considering the time. There were no books about religion, alchemy or other hermetic sciences. On the contrary, a lot of books of science, technique and architecture were found. All the books of the writers named in "The Twenty-One Books…" were there too, including the Alberti edition that we have mentioned before. But, the most important thing is that an unfinished hand-written version of the "devices" was found on his desk. Now, we will immediately see that this was the original from which several copies were made later, among them "The Twenty-One Books of Devices and Machines of Juanelo" (Pedro Juan de Lastanosa).

9 The Solution to the Enigmas

The first enigma of the manuscript is its authorship: it is easy to prove, throughout Pedro Juan de Lastanosa's biography, that he has all the characteristics of the author of "The Twenty-One Books…" Lastanosa is a native of the Cinca river in Monzon, marked by specialists as the linguistic region of the writer. This place is the most detailed area mentioned in the manuscript, and, despite the researches made by several Aragonese experts, there was nobody found in this area that would have the possibility of writing a book like this, except Pedro Juan de Lastanosa.

The book's author shows that he had travelled to different places in Europe and he also knew some Italian cities very well. The same as Lastanosa made: he was in Flanders, travelled from there to Milan and Naples, where he worked as a hydraulic engineer.

As we have said before, the document was written under the order of Philip II. Pedro Juan de Lastanosa worked under the service of this King in the subjects discussed in the manuscript and he was the chief responsible for this devices specialty. Indeed, he had the obligation of writing a book about this, as the other King's assistants were required to in their own fields.

The book's matter fits Lastanosa's experience in buildings and hydraulic devices. Specifically, the Aragonese studied mills and even patented a mill moved by weights that matches the one drawn in the manuscript, even the one that was made under particular circumstances. Very concrete works named in "The Twenty-One Books…" fit Lastanosa's participation such as the project of the tower in the sea in Alfaques de Tortosa.

Pedro Juan de Lastanosa had in his library all the writers quoted in the manuscript, especially the Italian edition of Alberti's book mentioned above. The documents he had written till then, whose originals were in his library too, belong with subjects included at "The Twenty-One Books…" A fact very clear if we see the document "Discussion about water in Serino", which although it is much shorter, contains the same issues about hydraulic engineering.

Because of all these reasons, we think that Pedro Juan de Lastanosa was the author of the original document, which was used as grounding for the manuscript afterwards known as "The Twenty-One Books of Devices and Machines of Juanelo". But the original wasn't divided in 21 chapters as it is named in the title, and it wasn't written by Juanelo. Since it was an unfinished book, it is possible that it hadn't a specific title then, but, if we remove the later added sentences "Twenty-one books" and "Machines of Juanelo" we simply have "of devices".

Indeed, in the inventory of Pedro Juan de Lastanosa's books made after his death, the scribe found an unfinished and unsigned document titled "of devices". Later, this document was divided into five volumes for the National Library of Madrid, and they have the same title in each secondary covers.

We have been on this Lastanosa manuscript's trail and we have obtained an interesting result:

It is the original document from which were made the copies that are kept today. This has enabled us to solve the enigma about what happened to the manuscript until it was deposited in the National Library of Madrid.

The evidences are clear, since it is certainly that Lastanosa's library, including the book called "of devices", was in the hands of the King thanks to an Italian merchant, Barbieri, who sold it to him. Nowadays, there are still several books of Pedro Juan de Lastanosa in the National Library (Pedro Juan de Lastanosa).

The copies and revisions of the document that we spoke of at the beginning were ordered to be made by the Court of Madrid. The royal Architect, Francisco de Mora, supervised the first copy and his nephew and successor, Juan Gómez de Mora, divided the document into five volumes and added the title pages we can see currently, which created the confusion with the authorship of Juanelo.

Successive royal architects, among them Teodoro de Ardemans, used the manuscript as a guide for their works (Teodoro de Ardemans 1724). Thus, the false Juanelo's book was actually a copy from Lastanosa's original document which was widely used till it was deposited in the Royal Library, today's National Library of Madrid. The other copies were spread over different places. So, we hope we have helped to dispel any doubts about the authorship of this Aragonese, who was undoubtedly Pedro Juan de Lastanosa.

10 As a Summary and Conclusion

Finally, it is necessary to summarize all we have said. Firstly, we have tried to clear some of the enigmas that the manuscript in the National Library of Madrid causes: the reason for the title given, why it was assigned to Juanelo Turriano, the reasons for the false covers where some characters of the seventeenth-century appear, such as John of Austria and Juan Gómez de Mora, the dates when the original was written, who ordered the document and what for.

After examining the text and the looked up documents we deduce that:

First. Between 1564 and 1575, an Aragonese writer, under Philip II's order, wrote documents about uses and applications of water, but it was neither unfinished nor unsigned. As we have seen, this author was Pedro Juan de Lastanosa, as it is proved with the inventory made of his library and desk.

Second. Between 1585 and 1610, the author died and because of the interest of the manuscript, it is decided to order in "books" or chapters and to copy them by scribes and draughtsmen, with the purpose of spreading it among the Court technicians.

Third. Between 1643 and 1647 new covers for one of the manuscript copies are made and the author is confused with Juanelo Turriano. The royal architect Juan Gómez de Mora made a new revision of the document, and, though he was devoted to Philip II's memory, he dedicated it to the powerful bastard brother's King, John of Austria. That is the current copy kept in the National Library of Madrid.

We spent the second part analysing the content of the manuscript from different points of view. The conclusion is that the writer was a great scientist, engineer and humanist who had taken into account specialists such as Vitruvius, Frontino, Plinio, Alberti, Labaco, Cataneo, Serlio or Viñola. He uses, above all, numerous examples from Alberti, from whom he had used a translation of Cosimo Bartoli (Florence, 1550) with commentaries and handmade drawings similar to "The Twenty-One Books…" It is interesting to observe the religious and ideological background that places the writer in the same line as the Spanish humanist Benito Arias Montano, who carried out the organization of the Library of El Escorial.

In the scientist aspect, we have analysed the author's knowledge of natural philosophy, mathematics, physics and mechanics, particularly fluid mechanics. The technical applications represent the most of the document: building materials, mechanisms, devices and engineering inventions, are some of the most important issues. However, the book is, above all, about "hydraulic architecture", precedent of those that would be written during the Enlightenment period in the eighteenth-century. Almost all the aspects related to water are detailed here, such as conductions, bridges and aqueducts, but, the chapters about mills are the ones that received a more original and longer development.

After compiling all this knowledge about the "unknown" author, we made a great effort to identify him. The matter was not easy and has been controversial, but we think we have found the solution. First of all, we have found the place where he came from, thanks to his language expressions and the many local mentions given in the book. These are the reasons why we know that the writer was from an area next to Monzon, an Aragonese town of the current province of Huesca, close to Calalunya. We have made an exhaustive documentary search among all the Aragonese who could have fulfilled the conditions for writing a book like this, and, among all the researched figures, we found only one: Pedro Juan de Lastanosa.

Almost nothing had been known about this scientist, engineer and humanist who was born in 1527 in Monzon; we had to reconstruct his biography, one of the most interesting in the technological Spain of the sixteenth-century. Pedro Juan de Lastanosa, after spending his youthful years in Aragon where he was brought up, he went to Italy where he worked in the hydraulic engineering field, and then he returned to Philip II's Court in 1563 as a devices engineer ("main devices engineer in the Kingdom") until his death in Madrid in 1576. He was a close friend of Arias Montano: they shared the same religious and philosophical ideas. He wrote several manuscripts about science, engineering and hydraulics that are conserved in the National Library of Madrid. In these documents some of the subjects that he would develop in "The Twenty-One Books…" have been discussed. As an engineer, he worked in important civil buildings such as the Imperial Channel of Aragon. In short, his profile coincides with the manuscript author of the National Library, and, we have also found evidences that Lastanosa worked in some of the hydraulic buildings mentioned in the document, such as the towers in the Sea of Alfaques de Tortosa. He was the inventor of the "devices" considered in the manuscripts as originals of the author, like a mill moved by weights among other examples.

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Bustamante, A., Marías, F.: "La révolution classique: de Vitruve à l'Escorial", Révue de l'Art, CNRS (1985), pp. 29–40

Concretamente en el libro de Teodoro de Ardemans, Fluencias de la tierra y cursosubterráneo de las aguas, Madrid (1724), se copian casi literalmente párrafos enteros y dibujos que estaban en "Los veintiún libros…". Para Ardemans, el autor del manuscrito era el digno de ser comparado a Vitruvio y a Alberti. (Specifically in the Teodoro de Ardemans' book, The earth's sources and underground water course, Madrid (1742), there are almost literally copied whole paragraphs and draws from "The twenty-one books…" According to Ardemans, the manuscript's writer was a person worthy of comparison with Vitruvio and Alberti)

Jerónimo Girava y Pedro Juan de Lastanosa, Los dos libros de Geometría Práctica…, (The two books of Practical Geometry…) Biblioteca Nacional de Madrid (National Library of Madrid), Manuscrito 9.437. N. García Tapia, Mª.I. Vicente Maroto, "Los dos Libros de Geometría Práctica de Fineo traducidos por Girava y ordenados por Lastanosa" ("The two books of Practical Geometry of Fineo translated by Girava and ordered by Lastanosa"), Asclepio, XLIII, 1, (1991), pp. 249–267

Frago Gracia, J.A., García-Diego, J.A.: Un autor aragonés para "Los veintiún libros y de lasmáquinas" (An Aragonese author for "The twenty-one books of devices") Zaragoza (1988)

García Tapia, N.: Ingeniería y Arquitectura en el Renacimiento Español (Engineering and Architecture in the Spanish Reinassance), Valladolid (1990) y De dios del fuego a la máquina de vapor (and From the god of fire until the steam engine). La introducción de la técnica en Hispanoamérica (The introduction to the Hispanic Technique), Valladolid (1992)

García Tapia, N.: Fuentes literarias de la antigüedad clásica en" "Los veintiún libros de losingenios…" ("Literary sources of the classical period in "The twenty-one books of devices…") Actas del X Congreso del CEHA, Madrid (1994), pp. 459–467

García-Diego, J.A., García Tapia, N.: Vida y técnica en el Renacimiento (Life and Technique in the Reinassance). El manuscrito de Francisco Lobato, vecino de Medina del Campo. Valladolid (1987)

Recogida en varios artículos y comentarios de (cited in several articles and commentaries by) García-Diego, Díaz Marta, Fernández Ordóñez, García Tapia y otros, en la Revista de Obras Públicas entre los años 1988 y 1989 (in the Public Works Magazine between 1988 and 1989)

Los avatares de la biblioteca de Pedro Juan de Lastanosa se encuentran recogidos en varios documentos y testamentos del Archivo Histórico de Madrid, que hemos recogido en el libro citado en la nota 1. (The avatars of Pedro Juan de Lastanosa's Library are collected in several documents and testaments in the Historical File of Madrid, in the book cited in note 1)

Mª. Isabel Vicente Maroto y Mariano Esteban Piñeiro, Aspectos de la Ciencia Aplicada en la España del Siglo de Oro (Applied Science Aspects in the Spanish Golden Century) Salamanca, 1991

Respecto de la labor de los científicos de la corte de Felipe II, consúltese el libro de Mª. I. Vicente Maroto y M. Esteban ya citado (Dealing with the scientists' work of Philip II Court, see the book by Mª. I. Vecente Maroto y M. Esteban above named)

Sobre la biografía de Pedro Juan de Lastanosa véase el libro citado en nota 1. (Related to Pedro Juan de Lastanosa's biography see the book in note 1)

Sobre los privilegios y patentes por invención, véase N. García Tapia, Patentes de invención españolas en el Siglo de Oro (Patents of Spanish inventions in the Golden Century), Madrid (1990)

Un libro de próxima aparición, titulado Historia de la Ciencia y de la Técnica en la Corona de Castilla, que hemos realizado entre varios autores especialistas de la historia de la ciencia y de la técnica española, cambiará sin duda esta concepción (An upcoming book titled History of Science and Technique in the Kingdom of Castilla). A work made by some writers, specialists in the Spanish history of the science and technique. A book that will change this meaning

Véase, por ejemplo, el libro de F. Checa Cremades, Felipe II. Mecenas de las Artes (Philip II. Patron of the Arts) Madrid (1993)

Historical Development of Paper Mills and Their Machines in South Latium During the Nineteenth Century

Michela Cigola and Marco Ceccarelli

Abstract The paper describes the industry of the papermaking in the vicinity of the Benedictine Abbey in Montecassino (Italy). The focus is mainly on the factories that were supplied by hydraulic energy that was available in that area. The historical analysis of the papermakers in the area begins with a factory that was established in the town of Sant'Elia Fiumerapido by abbey monks in 1516. The plant was chosen because it was provided with a water mill that made the Abbey's extensive 'scriptorium' independent of outside sources for the provision of suitable paper. Drawings of past plants at different scales have permitted us to analyze the historical and technical evolution of the papermaking in the specific area under the influence and supervision of the Montecassino Abbey. A specific analysis is carried out on the development of machines by observing their structure and operation, in conjunction with calling attention to recovering of the past needs for papermakers through the remains of their machinery.

1 Introduction

This paper reports results of a joint research activity between a team of architects at DART and a team of engineers at LARM who jointly studied the historical evolution of technical developments in the area of influence of the Benedectine Abbey in Montecassino.

The research started with a study of the Benedectine Montecassino Abbey itself, from which it was motivated to widen the investigations to include cultural and

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DOI 10.1007/978-94-007-1251-5_4,

technical development of the broader area of the South Latium. Beginning in the ancient past, Montecassino Abbey had been a unique hub and centre of spiritual, cultural, artistic, and industrial activity, and in several periods it was also a promoter and organizer of economical practices in the surrounding territory that became known as the “Land of Saint Benedict”.[1]

Investigation of the effect of cultural influence by the Abbey was oriented in several interesting directions, one of which was focused on a paper-making plant, in the town of Sant’Elia Fiumerapido, which had been established in 1516 to fulfil the needs of paper sheets for the laborious work of the Abbey scriptorium. Starting from this paper plant, the research interest was enlarged to other paper plants in the area with new attributes and goals, which are nevertheless linked to each other by historical evolution and comparison of their abilities and procedures (Gasparinetti 1956).

Attention was focused on the area of Cassino but with an extension to the Valley of Liri[2] where rivers were used to provide energy to paper mills. Since Antiquity, water flows of all types have been determinants for the structure and development of a territory. Any given river, considered as a water course that holds together an intricate system of production such as those that have always sprung up around waterways, provides an interesting possibility for interpretation of the many interconnected changes that have affected the countryside and settlements along its banks (De Seta 1983).

2 A Brief Account of History of Paper Making

Until the early nineteenth century, the raw materials used for papermaking consisted of linen and hemp rags, which were sorted into three categories – fine, medium and coarse – corresponding to the three grades of paper: fine writing paper, regular paper and wrapping paper. After sorting, the rags were washed for the first time and then set aside to macerate and ferment in stone or copper tanks or in wooden tubs, a process that lasted around 1 week.

Next, the rags were shredded twice to produce a pulp, which was then bleached with chloride of lime,[3] diluted to form a stock slurry, or “stuff”, as it was called,

[1] The Montecassino Abbey was founded by Saint Benedict in A.D. 529. It was considered one of the most important historical monuments of the European architecture until its destruction during World War II. It was rebuilt during the post-war period by reproducing the original structure from drawings and surveys of the past.

[2] The Liri is the largest river in the area under the influence of Montecassino Abbey that is known as the Land of Saint Benedict.

[3] Even when pure water was used, the pulp – and hence the paper – was not white, and a uniform bluish hue was imparted to it. For the papermaking industry, the discovery of chlorine’s bleaching properties towards the end of the eighteenth century was thus a revolutionary event.

and warmed. As this stock could not be kept for long periods without rotting, papermaking chiefly took place in cold weather.

Once the raw material had been prepared in this way, a rigid framework of wood covered by a fine metal mesh, called a mould,[4] was dipped in the stock and lifted, leaving the mould screen coated with a thin layer of pulp. This sheet was then turned over on a cloth called a felt. Another felt was laid over the sheet, and the process, called couching, was repeated to form a pile of interleaved sheets and felts known as a post. The post was placed under a screw press to squeeze out excess water, after which the sheets were separated from the felts and hung out to dry in the drying loft. This was followed by sizing, or in other words by dipping the paper in gelatin or glue to make it stronger and less absorbent, and by glazing or burnishing to make it easier to use (Gianni 1950–1951).

Until the nineteenth century was well advanced, then, preparing the stock was the only part of the papermaking process that was in any way mechanized, and even this relied, naturally, on water power. From dipping the mould to form sheets onwards, the entire process was carried out by hand. A number of fundamental advances for the paper industry came only in the second half of the 1800s: there can be no doubt that the first of these advances was the development of alternatives to the industry's traditional raw material. Thus, rags gave way to wood fibers produced either mechanically or through chemical-solvent processes that result in pure cellulose. The second step forward was the introduction of mechanization to the processes used to produce sheets of paper: pulp, instead of being strained through the mould to make a single sheet, could now be run through the *cylinder machine*[5] or the *continuous paper machine*.[6] The latter, however, were slow to gain ground, and as late as 1862 there were only 59 such machines in all of Italy. Handmade paper remained widespread, while machine-made paper continued to be an exception to the rule (Dell'Orefice 1984).

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[4] A pattern worked in silver wire can be attached to the mould. When the sheet is formed, the pulp settles in a thinner layer over the raised wire, producing an image that can only be seen when the paper is held up to the light: the watermark.

[5] Developed by the English inventor Joseph Bramah in 1806, this machine – also called a board machine or vat machine – consists of a wire covered cylinder that rotates partially submerged in a vat of dilute paper stock. Pulp fibers cling to the wire and are formed into a sheet on the cylinder as the water drains through it. The sheet is then automatically lifted from the wire by an endless felt, pressed and dried.

[6] In the procedure used by this continuous papermaking machine invented by the Frenchman Nicolas-Louis Robert in 1799, the watery pulp or stock is refined and conditioned before it enters the machine. From the machine's head box, the stock is spread onto an endless belt of wire mesh that moves horizontally, shaking from side to side as it passes over suction boxes that draw out the water from the stock. The paper is then compressed in a press section consisting of a series of rollers, dried by enormous dryer rolls, and wound on a reel.

3 On the Evolution of the Production Process

Traditional hand methods were used almost exclusively in the Papal States,[7] where mechanized methods were hardly ever employed, either to make paper or to process raw materials. The latter continued to be linen or hemp rags, which were in short supply.[8] Consequently, all of the Papal States' paper mills were quite modest in size. All of these problems were aggravated by the backwardness of the Papal government, which even in the mid-1800s still prohibited the use of Fourdrinier papermaking machines. As the nineteenth century proceeded, advances were limited to pulp preparation rather than to papermaking itself, as the introduction of stamping cylinders and Hollander beaters brought improved methods of processing rags and producing stock (Radice 1928).

In the Kingdom of Naples, the paper industry dates back to the eleventh century, if not before. It is likely that papermaking techniques were introduced and spread from Amalfi,[9] thanks to that city's far-flung trade connections. For many years, Amalfi dominated the paper market with a high quality product, but its failure to modernize production methods, coupled with growing demand for cheaper paper, eventually eroded Amalfi's monopoly. By the early years of the nineteenth century, all of the paper mills in the Kingdom of Naples were extremely outdated. Paper quality was poor, as production was still based on manual methods. On such a shaky footing, the Kingdom's paper industry was ill prepared to withstand the political upheavals that rocked the area between the late 1700s and the early 1800s. And as in the Papal States, problems in procuring raw materials helped undermine a situation that was nothing if not precarious (Milano 1965).

From Amalfi, papermaking spread along the coast and further inland, soon reaching the Liri Valley. The first paper mill in the area dates to 1516, and was founded in Sant'Elia by order of the Abbey of Montecassino.

Papermaking's introduction to the Liri valley was motivated by the area's rivers – the Liri, the Rapido, the Fibreno – which, swollen by their tributary streams and rivulets, provided ample supplies of pure water, essential for preparing the pulp, washing the rags, and powering the mills. All that remained for the valley's inhabitants was to assimilate the papermaking techniques pioneered in Amalfi and perfected in Fabriano.

Italy's papermaking industry languished in the 1800s, producing little and using antiquated methods. The reasons for this stagnation were two-fold in nature: economic and social.

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[7] Of the few machines in use, most were printers, while Hollander beaters were rare. Only three paper mills had vats (Archivio di Stato di Roma, Camerale II – CARTIERE (1775–1866) [envelope 1], 1850 – Statistics on paper mills in the Papal States). Also see: Balzani (1970).

[8] A flourishing trade – which often overstepped the bounds of strict legitimacy – grew up around rags: hemp, linen and wool (white or dyed).

[9] In the Middle Ages, the cities of Amalfi, Venice, Pisa and Genoa achieved prominence as maritime republics, i.e., small city-states whose economy was based on their naval power and sea trade.

The industry's economic problems sprang from a lack of capital, which hampered investments in equipment and meant that little money was available for developing new materials. From the social perspective, the low level of education then prevailing in Italy kept demand for books and newspapers – and hence paper consumption – from increasing. It is, in fact, indicative of culturally backward areas such as the Papal States and the Kingdom of Naples that handmade paper should have survived for so long before being ousted by mechanized processes.

Thus, precisely in the period (1830–1880) when the paper industry was growing by leaps and bounds in the rest of Europe, Italy's domestic paper production dwindled drastically. More than a decade from the unification of Italy was to pass before the transition from handmade to machine-made paper brought about a significant increase in output, south of the Alps as elsewhere.

Italy followed Europe's lead in beginning to make use of new raw materials such as wood pulp and cellulose.[10] These materials called for a radical rethinking of manufacturing techniques that not all producers were able to sustain. The industry's push to modernize was strongest in Northern Italy, where paper mills and resources were most plentiful and consumption was particularly high (Castagnari 1989).

The decline of Amalfi's paper mills in the mid-nineteenth century was offset by increasing production of machine-made paper in the Liri Valley's mills, which had mechanized rag processing as well as all stages of papermaking per se, even adopting the Fourdrinier machine. Starting from 1840, efforts to modernize production led the Liri area's paper producers to employ rag substitutes: plant materials such as wheat, barley and oat straw, corn fiber or poplar wood pulp (Paris 1983).

4 A Study of the Heritage of Architectonic Buildings of Paper Mills

From the early 1800s, the spread of new manufacturing methods obliged industrial settlements to adapt rapidly to the changing pace of production. These adaptations transformed the landscape, as factories expanded, canals and locks were built, and the many structures needed to harness water power for industrial use were erected.

Thanks to the geographic advantages afforded by its mountains and drainage patterns, the middle Liri valley in southern Lazio saw a resurgence of industrial activity in this period, when new or expanded woolen mills, filling mills, paper mills and so forth were set up to make use of the area's abundant water resources.

In the nineteenth century, the Liri and other waterways such as the Sacco, the Melfa and the Gari were the backbone of an entire system of production, channeling vital energy to the many water-powered machines lining their banks.

[10] Until this time, cellulose manufacturing had failed to make headway in Italy because of the high cost of production and the shortage of wood, coal and chemicals needed for processing.

Water rights, always a source of disputes in previous centuries, became particularly complex in the 1800s. Industry, intent on technological renewal, began to set new mechanisms for using water into motion that caused new and unforeseen problems. Where manufacturing activities could be located, and how they would be able to grow, depended on whether they could divert water from the river, either directly or through canals and pipelines for the more remote mills. In the middle Liri valley, this technological renewal spurred a rush to corner the best factory sites still available along the river, where frequent infringements of water rights set the old and new interests at odds. Not a few businessmen bought old grist mills and the surrounding land on the river, justifying their diversion of the water as a mere continuation of the rights acquired from the former owner – though using water for a grist mill and using it for an industry are two quite different things.

The changes in water law introduced during the Napoleonic period and carried over in the statute books of the post-unification Kingdom of Italy led to a veritable torrent of judicial and administrative action. Thus, a significant amount of documentation has come down to us concerning the disputes between competing businessmen that arose when an upriver factory diverted water – legally or otherwise – to the detriment of its downstream neighbor.

A large number of permits for structures built in order to divert Liri river water for industrial use in the last quarter of the nineteenth century are preserved in various archives in the area we are investigating.

In most cases, the text describing the details and terms of these permits is accompanied by documentary material presented in more or less standard form.

In many instances, this design documentation includes:

- A location plan, showing adjoining plots of land, the area of the watercourse concerned, and the factories involved in the diversion, as well as other factories in the immediate vicinity. Scale usually varies from 1:200 to 1:500, though a variety of other scales are also found, viz., 15 mm/10 m, and 1:667.
- Sectional views and detail drawings of diversion structures, generally in 1:100 scale.

Format is not uniform, but varies considerably; drawings and plans are generally on glossy fabric-backed paper, while paperboard is found more rarely in the Prefecture records of the period; all drawings are hand-tinted in watercolor.

Thus, water diversion applications, together with the reports submitted by experts appointed to resolve legal and administrative disputes, provide us with a wealth of maps, plans, topographic representations and drawings of all kinds that are of considerable historical interest. Even more importantly, they stand as an invaluable testimony to the changes that transformed the Liri valley, and to the type of representation used to depict this type of endeavor in the second half of the nineteenth century (Cigola 2001).

The approach used in our investigation of paper mills thus stemmed from our contact with documentary material of this kind.

As the first step in planning this approach, it was necessary to establish physical as well as conceptual limits to the scope of our investigation, or in other words to conduct a census of the paper mills once sited in the area on which we intended to focus our attention.

To do so, we prepared a chart showing the location of our paper mills, where the mills are listed in chronological order, i.e., by date of foundation, and identified by a location code. Naturally, the list is incomplete, as our investigation is still under way.

Immediately afterwards, we designed a catalogue card for use in recording and organizing our findings. This catalogue card features two sides, the first divided into two sections (top and bottom), and the second consisting of a single section (Figs. 1 and 2).

The first or front side of our catalogue card (Fig. 3a) is headed by a diagram showing the mill's position along the river from which it draws its power. This diagram will also be shown at the top of all annexes.

The body of the catalogue card is divided into two top and bottom sections. The top section is laid out in two columns, and lists information that provides the reader with an introduction to the paper mill in question, making it possible to identify the mill and determine its location. The bottom section lists the materials relating to the paper mill, divided between archival and bibliographic sources, which will likewise be recorded and cataloged.

The rear side (Fig. 3b) of the catalogue card is organized in the form of a historical register that makes it possible to place the paper mill in context, both as regards its own chronology and relative to the other paper mills under investigation and the development of the surrounding area.

Attached to the catalogue card is a series of annexes, one for each type of documentary material encountered in the course of the investigation. Given that much work remains to be done, it is likely that other types of graphic, cartographic and documentary records will turn up which will require us to design specific annex forms.

We thus present an example of a representative catalogue card, for which we assembled annexes and particularly significant documents taken from a number of cards in our collection. This is because our purpose here is to describe the investigation and classification method we have developed, rather than to present any particular catalogue card, however complete or exhaustive it may be (Cigola 2002).

- Photographic campaign (Fig. 4)
  This type of annex is an essential point of contact with the work in question, as it testifies to the paper mill's condition at the time of the investigation.
- Bibliographic source (Fig. 5)
  Naturally, our collection of materials also devotes ample space to bibliographic analysis (nor could it be otherwise, given the unparalleled assets of the Montecassino library). Consequently, the annexes also include bibliographic details. The subject of this annex is the volume from which the print shown above was taken: dedicated to the bishop of Sora, it extols the beauties of the bishopric, providing a profusion of information about the area and its many paper mills.

a

RECORD NO. P 1 BARTOLOMUCCI	AMASENO (river)	LIRI (river)	MELFA (river)	LE FORME (river)	RAPIDO (river)

Town: PICINISCO

Location: *Borgo Castellone*

Cartography no.: C.T.R.Latium sez. 391150 - 391110

Ownership: 1610 Ducale (?); 1826 Bartolomucci; 1872 Visocchi

Current ownership: private

Original name: *CARTIERA BARTOLOMUCCI*

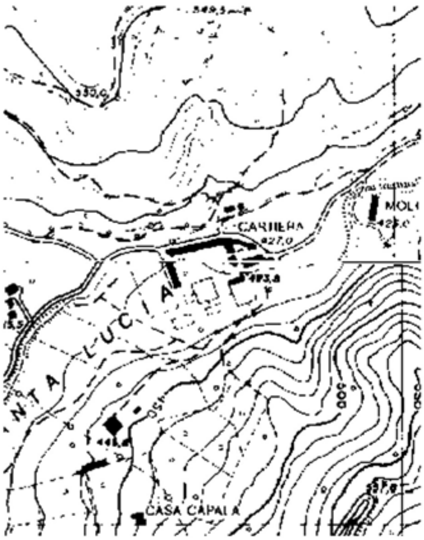
Current name: CARTIERA BARTOLOMUCCI

Designer: unknown

Date of construction: 1630 – 1820 ca.

Original destination: paper mill

Current destination: not in use and partially residence



Original production targets: in 1826-27 twenty types of papers; in 1833 several types of carton

Current production: nothing

DOCUMENTS IN ARCHIVES,:

- ASN/MI 2° inv, fasc. 568 2 june 1830, letter of Bartolomucci brothers to the king . (in Italian)
- ASC, Intendenza, fasc. 4, Sora, 13 november 1831, I sottindentende all'Intendente . (in Italian)
- ASN/MI, fasc. 590, Avellino, 17 march 1832, industrial plans for arts and crafts.. (in Italian)

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- MANCINI A., *The history of Atina*, II ed. Bologna 1994. (in Italian)

Note:

Fig. 1 Catalogue form: (**a**) data sheet. (**b**) notes on historical evolution

b

Historical notes:

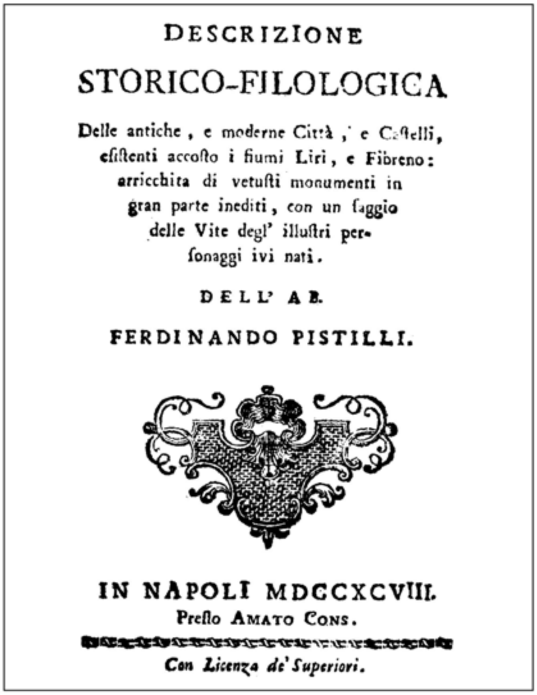
- **1630 ca.**, information on the a paper mill Picinisco as established by the duke of Alvito, Francesco Gallio (1613-1657) with a specific project
- **XIX sec, second quarter.** This paper mill is established similarly to the one in Fibreno, perhaps in the same building of the previous ducal one
- **1822 ante**, Lorenzo Montgolfier, from the family of the aerostat inventor became director of the paper mill
- **1826/27**, the brothers Antonio and Gaetano Bartolomucci build a three-floor building that was 130 palms long, 30 palms width, and 60 palms high. There was a smashing machine; 32 men and 32 women were employed; several types of paper were produced, namely Francia style paper for printing and writing, paper for drawings, and cardboard. A sales point was organized in a store (fondaco) in Naples. Accommodation rooms were also available for French employees who were used to train the local employees.
- **1828**, the brothers Bartolomucci asked the construction of a road from Picinisco to Atina, since the considerable distance from the exiting consular road required high transportation costs by using mules. They even insisted in the construction and finally the were the supporters of the Ministry for the road construction, as pointed out in [ASN/MI 2° inv, fasc. 568 2 june 1830, the borthers Bartolomucci to the king (in Italian)]
- **1829,** Giuseppe Bartolomucci and his brothers improved the paper mill installation by importing machines from France
- **1833,** they produce waterproof cardboard for the building roofs and solid cardboard as very hard papier-mâché [ASC, Intendenza, fasc. 4, Sora 13 novembre 1831, il sottindentende all'Intendente]
- **1834**, Lefebvre, owner of the paper mills in Fibreno and Carnello, together with Bartolomucci, owner of the paper mill in Picinisco, opposed to the purchase of a continuous operation machine by Luigi Lucibello, owner of a large paper mill in Amalfi [ASN/MI, fasc. 590, Avellino 17 marzo 1832, Stabilimenti industriale di arti e manifatture]
- **1850**, the paper mil was considered the best in the Kingdom of the Two Sicilies.
- **1861**, the paper mill became property of the brothers Bartolomucci
- **1863**, the paper mill became property of Gaetano Bartolomucci; the installation is for a paper production by laminators.
- **1872 ca.,** the paper mil became for half of the property of Visocchi, who owned the paper mill in Atina, that used wood smashing for paper cake
- **1876**, there were 90 employees
- **1890,** a new plant is build in Castellone with cooperation of Visocchi for producing wood-based paper cake, but it was not enough to supply the needs of the paper mill for the market demands.
- **1896**, there were 10 employees
- **1906, 29 October**, sale act of the half property by Bartolomucci in favour of the brothers Visocchi of Atina towards the ownership of land on which a hydroelectric plant could be established by using the water flow from Canneto near the falls of Castellone plant with the aim to provide electricity to railways
- **1984**, the paper mill is bought by privates who transform the building, including the mill area, in house flats
- **today**, it is a residence house with exception of the central part, which is under restoration.

Fig. 1 (continued)

RECORD NO. SEFR 1 LANNI	AMASENO (river)	LIRI (river)	MELFA (river)	LE FORME (river)	RAPIDO (river)

Fig. 2 Catalogue form: photo data sheet

RECORD NO. S 1 **E. COURRIER**	AMASENO (river)	**LIRI** (river)	MELFA (river)	LE FORME (river)	RAPIDO (river)



DESCRIZIONE
STORICO-FILOLOGICA
Delle antiche, e moderne Città, e Caſtelli,
eſiſtenti accoſto i fiumi Liri, e Fibreno:
arricchita di vetuſti monumenti in
gran parte inediti, con un ſaggio
delle Vite degl' illuſtri per-
ſonaggi ivi nati.
DELL' AB.
FERDINANDO PISTILLI.

IN NAPOLI MDCCXCVIII.
Preſſo AMATO CONS.
Con Licenza de' Superiori.

Book title:	*Historic-Philological description of antique and modern towns and castles that exist near the rivers Liri and Fibreno: as enriched by old monuments with usually unpublished information, with a treatise on the life of famous persons who there were born. (in Italian)*
Author:	Ferdinando Pistilli Abate
Book size:	15,5 x 21 (size of the anastatic edition)
Place and date of publication:	Napoli 1798.
Editor:	Amato Cons.
Content:	the volume that is written in Italian, is dedicated to mons. Agostino Colajanni, bishop of Sora; it describes all the urbanizations both small and large ones that were included in the territory of the bishopric and were located near Liri and Fibreno.
Library location:	Ed. Anastatica Arnaldo Forni Bologna 1977
Note:	

Fig. 3 Catalogue form: bibliography sheet

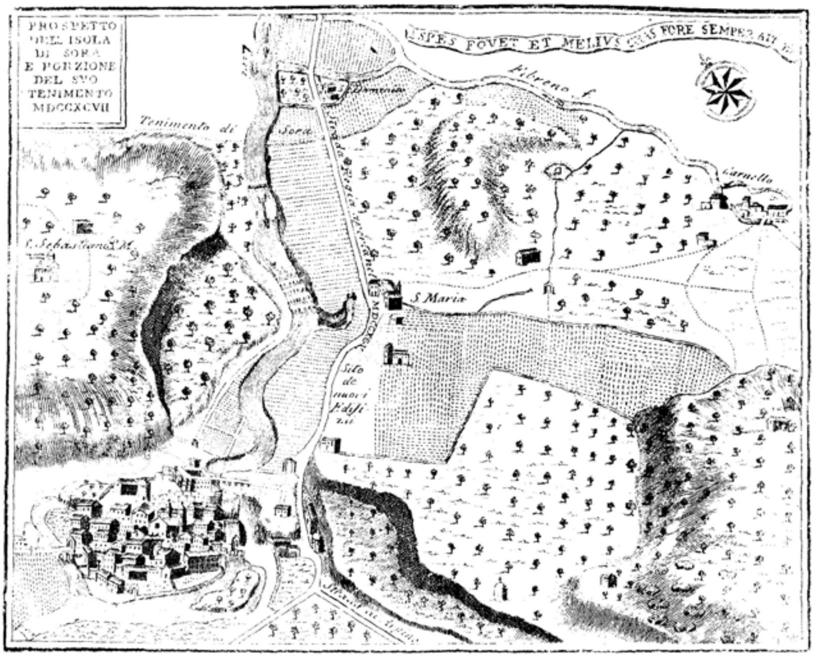
RECORD NO. C 1 CARNELLO	SACCO (river)	LIRI Fibreno (river)	RAPIDO (river)	MELFA (river)	GARIGLIANO (river)

Objetc/Title:	Plan with paper mills and mills along the rivers Liri and Fibreno
Author:	Unknown
Format:	none
Technique:	Aquarelle on parchment
Date:	XVII century
Legenda:	No
Graphic Scale:	No
Location:	Frosinone – State Archives
Archives coordinates:	Atti Demaniali b 65 fasc. 153

Note: *This is a typical representation of the 18 th century with a landscape that is drawn both with planimetry and prospective by using small hills and small forests with descriptive indications. The hydrography is very well depicted as well as the anthropoid elements like roads, houses, and small towns. In the other way the horography and usage of the terrain are not well indicated. Nevertheless, this is a representation with a clear will to describe the places with great details with emphasis on 'plans and paper mills along the rivers Liri and Fibreno' with an aim for a 'in nuce' design of industrial development of the area as it will happened in the next two centuries.*

Fig. 4 Catalogue form: archival data sheet

RECORD NO. I 1 COURRIER	AMASENO (river)	**LIRI (river)**	MELFA (river)	LE FORME (river)	RAPIDO (river)



Objetc/Title: *PROSPECT OF THE ILAND OF ILAND OF SORA AND PORTION OF ITS OWNERSHIP IN* 1797

Author: Unknown

Size: Size of anastatic editions : 19,5 x 15,5 cm

Technique: Incision

Date: 1797 – in Roman numbers

Legenda: No

Graphic Scale: Indicating the Rose of winds

Location: Ferdinando Pistilli, *Historical and philological description of antique and modern towns and castles existing along the rivers Liri and Fibreno*, Napoli 1798. (in Italian)
Ed. Anastatica Arnaldo Forni Bologna 1977

Figure/table no.: one table with no text

Note: *This is a very good graphical work with details of pseudo-prospectics of the towns Isola Liri and Carnello (on the top right) and of small groups of houses, and with characterization of several lands in which different cultivations are indicated. The limits of the town areas are indicated together with the roads and orography. Interesting are the indication of small hills with segmented lines that more or less dense as function of the altimetry. The written 'sito de' nuovi Edifici' gives and indication that the figure, although in this commemorative volume, was drawn for a project.*

Fig. 5 Catalogue form: bibliography illustration

- Archival document (Fig. 6)
  In addition to promoting an understanding of the geographical area and the buildings in it, this type of testimony is especially valuable for its role in identifying the types of graphic representation used for architecture, settlements and cultivated land: a question of particular importance in view of the nature of our study. This document refers to the Cartiera di Carnello, one of the oldest of the paper mills considered in our investigation. Here as in all of the annexes, information about the document's location as well as the type and method of representation it employs is provided beneath the reproduction.
- Bibliographic illustration (Fig. 7)
  Intended as a book illustration, this plate represents the same area, and reflects the same design concerns, as the preceding document. In addition to the physical changes that have taken place in the area in question (the two representations span a period of several decades), clear differences can be seen in the methods and graphic conventions used in representing buildings, settled areas, crops and landscape features.
- Drawings and surveys (Fig. 8)
  This section of annexes includes relatively recent engineering documents which make use of the representation techniques and standard graphic conventions introduced after the Industrial Revolution. This is a survey of the Cartiera Visocchi in Atina, conducted in 1945 to assess war damage to the structure.
- Period photographs (Fig. 9)
  The final section of annexes contains photographs that document the condition of the building in question at the time of earlier investigations. In this case, the paper mill depicted is the Paper mill Courrier in Isola Liri, and the photos document its condition in the year 1910/1911. The photos, in fact, show the third floor of the central section, which collapsed in January 1915 following an earthquake.

This investigation is far from complete: to date, we have collected data concerning around 15 historic paper mills, and are now compiling catalogue cards with their annexed graphic and documentary material from a variety of periods and sources.

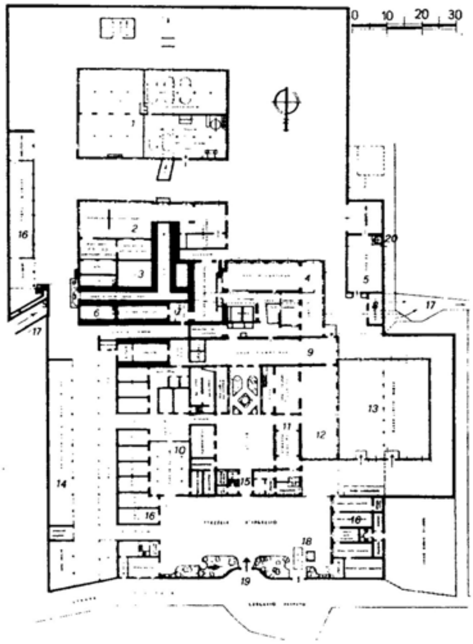
The ultimate goal is to preserve the historical record, ensuring that one of our area's greatest legacies is not squandered.

5 Machinery in the Papermills

The production of paper evolved as a function of materials for paper, but the production process also affected evolution of the improved machinery necessary to achieve larger production and better quality of paper products, mainly for writing and printing applications. Indeed, even before the Industrial Revolution the paper mill's manufacturing was achieved with well-developed industrial characteristics.

In this section a brief survey is discussed to illustrate the evolution of those machines for paper mills by using examples that are related to paper mills in South Latium but are also common with machinery used in Europe (Castagnari 2006).

RECORD NO. AT 1 VISOCCHI	AMASENO (river)	LIRI (river)	**MELFA** (river)	LE FORME (river)	RAPIDO (river)



Subject/title:	*PAPER MILL VISOCCHI – SURVEY OF 15 MAY 1945*
Author:	unknown
Technique:	Pen on drawing paper
Format:	none
Date:	1945
Legenda:	1. Stracceria - 2. Pasta legno - 3. Filtri - 4. Seconda Continua - 5. Caldaie - 6. Molazze - 7. Olandesi - 8. Trasformatori - 9. Prima Continua - 10. Officina - 11. Taglieria - 12. Calandre - 13. Allestimento - 14. Tettoie - 15. Uffici - 16. Depositi - 17. Canale - 18. Pesa - 19. Ingresso - 20. Fumaiolo
Graphic scale:	yes, but perhaps it was indicated successively
Location:	Armando Mancini *The history of Atina, collection of several documents.* 2 nd edition, Arnaldo Forni, Bologna, 1994. (in Italian)
Figure/table n.:	Fig. 1 pag. 1220

Note: *This document is relatively recent and therefore it is done by using techniques for representation and standards, which are near to the current ones. The representation, that was very probably figured out just after the second World War, has the aim to evaluate the damages that the paper mill suffered because mined by Germans after it was abandoned. Although there is the date of May 1945, the representation emphasizes on some elements (like the garden in the internal court) with drawing signs that were obsolete for the time of that date.*

Fig. 6 Catalogue form: drawings and survey

RECORD NO. I 1 COURRIER	AMASENO (river)	LIRI (river)	MELFA (river)	LE FORME (river)	RAPIDO (river)

Subject/title: *PAPER MILL COURRIER - ISOLA LIRI*

Author: Unknown

Technique: Black and whit photograph

Date: 1910 about

Location: AA.VV., *Industrial changes in the middle Liri valley in modern and contemporaneous times*, Isola del Liri 1988. (in Italian)

Figure/table n.: Figure n. 9

Note: *in the photo is shown the third floor of the central body of the building that was destroyed by an earthquake in January 1915.*

Fig. 7 Catalogue form: archival photos a

Fig. 8 (**a**) Machines in paper mills in Europe in sixteenth century by Hartman S. (**b**) Machines in paper mills in Europe in the sixteenth century by Dard Hunter

b

Fig. 8 (continued)

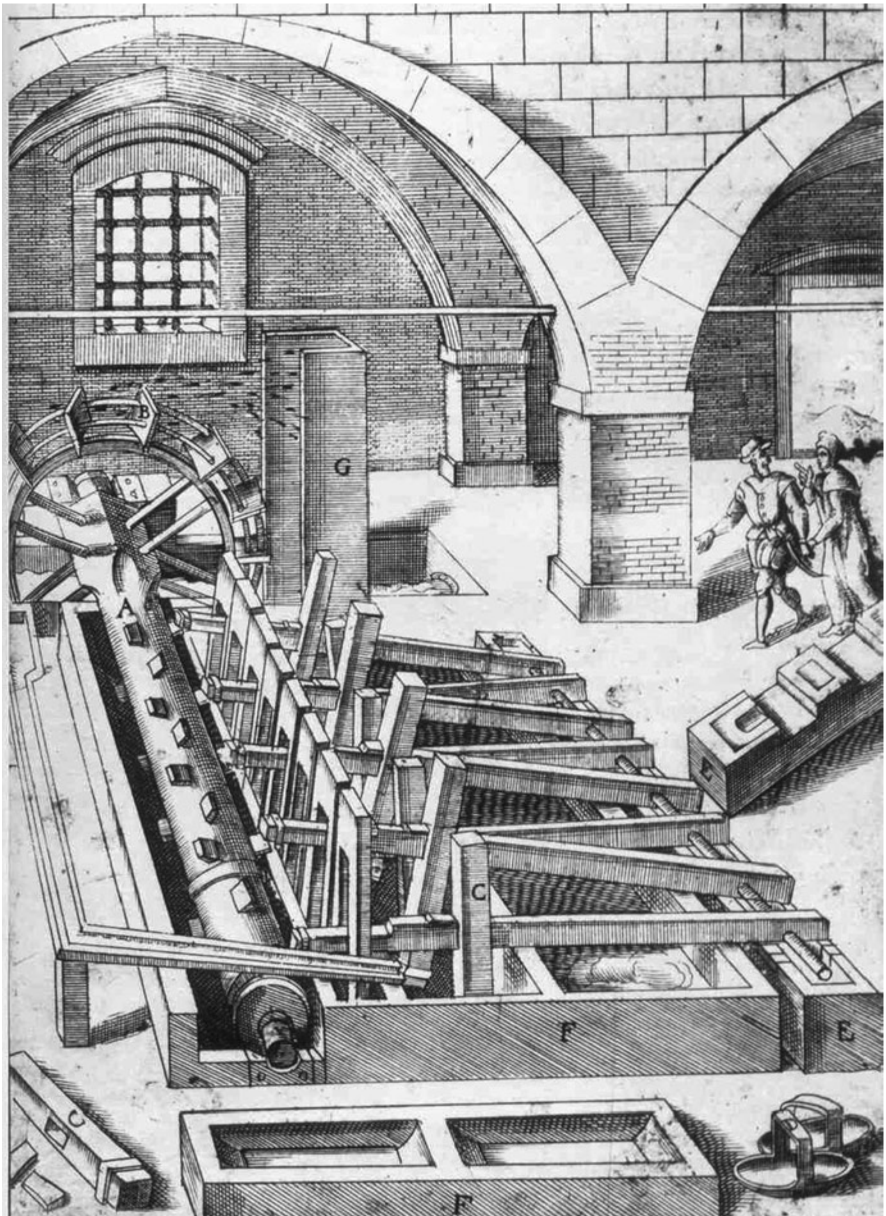


Fig. 9 Smashing and mixing machine for paper mass, by Agostino Ramelli in 1588

Usually the historical evolution of paper making is studied in terms of products and paper mills as frames and environments of the related activity. Thus, our main attention is addressed to the contributions of owners and managers or even technicians, but in terms of plant developments, both in studies of the history of papermaking, as for example in (Emery 1978a, b), or in studies of technical evolution, as for example in (Forti 1974).

At the beginning, papermaking was developed with a process that was essentially manual, in the form that is illustrated in Fig. 8. Those illustrations show a process that was quite common and well known in the sixteenth century so that there was no more need to keep it secret and therefore it was published in the first handbooks on machinery. Typical machines for papermaking are shown as a necessary complement to human labour, yet fundamental for paper production.

In particular, in both scenarios in Fig. 8 the prominence of human labour is stressed by focusing the scene on the actions of human operations. Nevertheless, machines are indicated in the background as a part that is essential both for the process and the paper mill's environment. Thus, in both Fig. 8a, b a machine with alternating hammers is shown as necessary to prepare the paper mass cake for the papermaking. In Fig. 8a even a press is clearly depicted with a large actuating screw to stress the size of the required mechanical power in that step of papermaking. The alternating hammers machine is presented in both pictures in the background with details of mechanical design of the actuating geared rotor. In addition, in Fig. 8b a flywheel is indicated on the right of the rotor. The machine is fully described since also a hydraulic turbine as motor is indicated as viewed from outside the windows. It was a fundamental power source for the continuous operation of the machine.

Similarly, in Fig. 8b at the bottom of the geared rotor a large gear is shown as coupled with a geared portion of the rotor as needed to regulate the velocity to proper values for the alternating hammers from the input axle from the power source (that is a hydraulic turbine, but not shown).

We note that in this case the machine is located in a separate room, probably with the aim of isolating the machine for safety purposes of human operations and even to limit noise in the working area.

Nevertheless, the process of papermaking is emphasized as a function of manual operation with proper frame tools, which emphasize the centrality of human labour in both scenes. This is because the operation to obtain a proper paper mass cake is considered the central part of the process as a function of a proper distribution and composition of the first paper product with direct human actions.

The importance of those machines is nevertheless clear as shown also in Fig. 9 where the view is focused only on the machine with alternating hammers. Indeed, in this figure the size is remarkable as compared with the humans who are shown in the drawing.

The aim of the alternative hammers consists in smashing and mixing the paper mass cake to a proper level for the next manual operations.

It is remarkable that the solution to simplifying the mechanical assembly, i.e. by hydraulic turbine with its axle as a geared rotor, also obtained a more compact machine. It is quite certain that those machines were used also in the paper mills in South Latium, which were already considered as reference models for papermaking all around Europe, as pointed out in (Castagnari 2006).

The mixing machines evolved towards solutions with more sophistication with the aim of obtaining better features in terms of operation simplicity, compactness, and automation. Examples are shown in Fig. 10 in which in 1629 in his machine handbook, Giovanni Branca refers to experiences and machinery of the State of Vatican in the surroundings of Rome (which includes South Latium). In particular, the machine in Fig. 10b is interesting for the mechanism design and human-machine interaction for regulating the mixing operation. Linkages are used also to obtain a continuous movement thanks to a large flywheel on the top of the machine. In Fig. 10b the machine is made of essential parts for the smashing action but with a fully automatic operation by using alternating piston/hammers that are moved by a gear rotor section (which is nevertheless not fully explained).

In Fig. 11, machines are depicted as standard solutions in the Encyclopédie at the end of the eighteenth century. Those standard machines include previous ones such as for mixing, pressing, and frame deposition of the paper mass cake. In the eighteenth century paper mill environment those machines were installed with a better location and increased efficiency for a better exploitation of the machine operation. However, those machines were designed still with the same structure and operation principles of the past.

Unfortunately, from the remains of paper mills in plant structures in South Latium it is not evident that those machines were yet used in that area at the end of the eighteenth century. In general, the pre-industrial machines were made of perishable materials, mainly of wood. In addition, they were destroyed when substituted with other more powerful machines in the nineteenth century when machines for industrial production were built with metallic components. At that time, machinery was not considered of interest for cultural heritage and very rarely were they preserved for a technical historical background, and therefore they were not preserved at all.

The practice of destroying machinery when old or surpassed by new machines has been increased with the machine evolution during the Industrial Revolution and it is somehow still persistent today with modern machines.

This is why there are not remains of machines of nineteenth century from paper mills in South Latium, but only from the twentieth century. A relevant source of information on past machinery is the photos archives such as the one that shows machines that were used before the Second World War, as reported in Figs. 12–16 (Mancini 2007). In those photos the industrial developments and achievements for papermaking are shown in enterprises of South Latium, namely Cartiera di S. Elia (in S. Elia Fiumerapido); Cartiera di Carnello, Cartiera Sorvillo, Cartiera E. Courrier (in Sora); Cartiera Bartolomucci (in Picinisco); Cartiera dell'Anitrella (in Monte Giovanni Campano); Cartiera di Sora, Cartiera del Fibreno, Cartiera Courier, Cartiera Boimond, Cartiera Viscogliosi, Cartiera Costantini, Cartiere Meridionali (in Isola Liri); Cartiera Pelagalli (in Aquino), Cartiera Visocchi (in Atina); Cartiera Tersigni (in Fontana Liri).

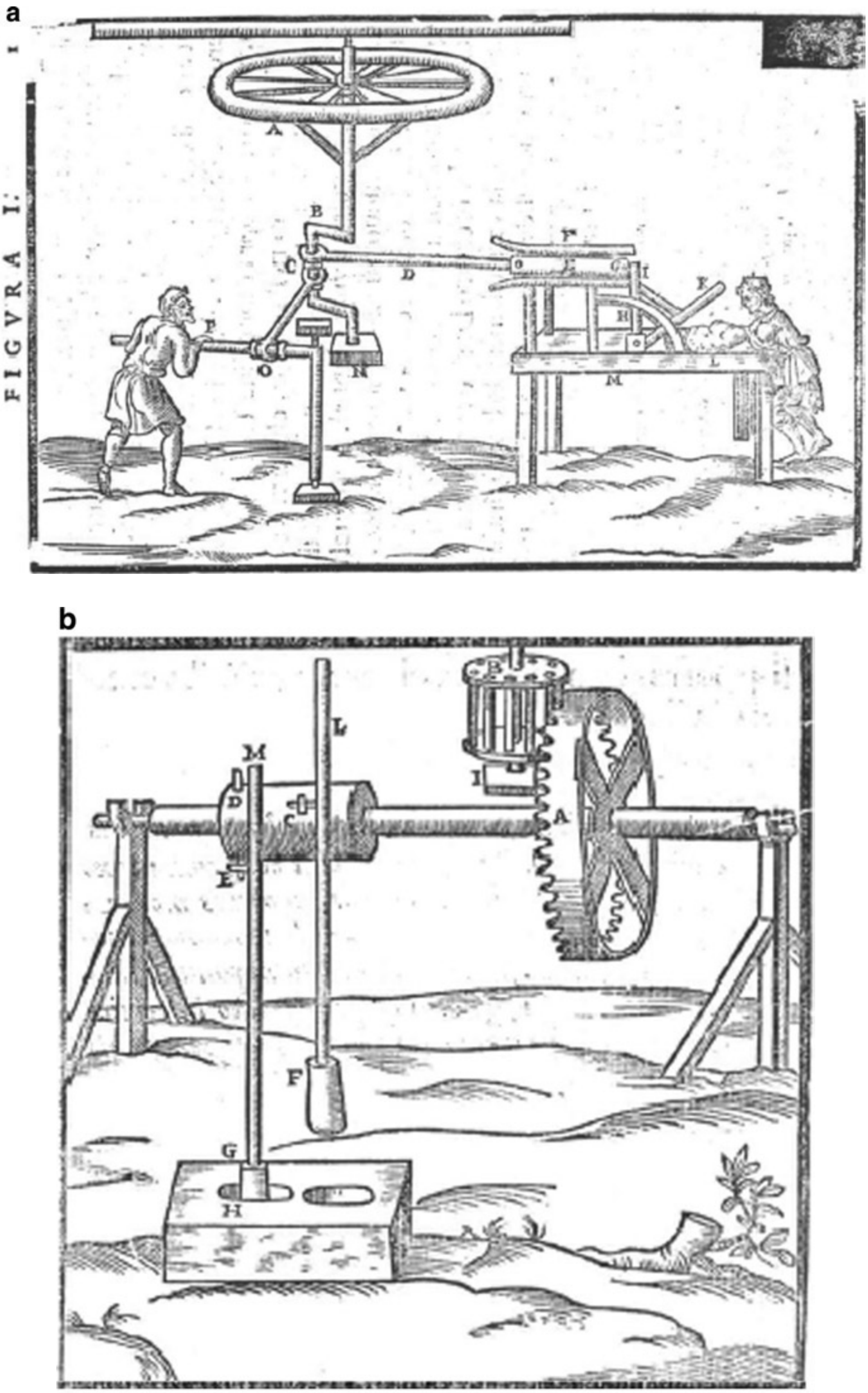


Fig. 10 Papermaking machines by Giovanni Branca in 1629: (**a**) a regulated mixing linkage machine. (**b**) an automatic smashing machine

The machinery in Figs. 12–16 show the high level of automation in all phases of papermaking for the massive production that was reached just before the Second World War. In fact, each production phase is characterized and equipped with a specific machine for a specific operation by using a specific machine design. We note that those machines do not need a hydraulic power source but the process still needs a lot of water for the material production in mixing the paper mass cake. It is also remarkable that those machines in Figs. 12–16 can be considered industrial

a

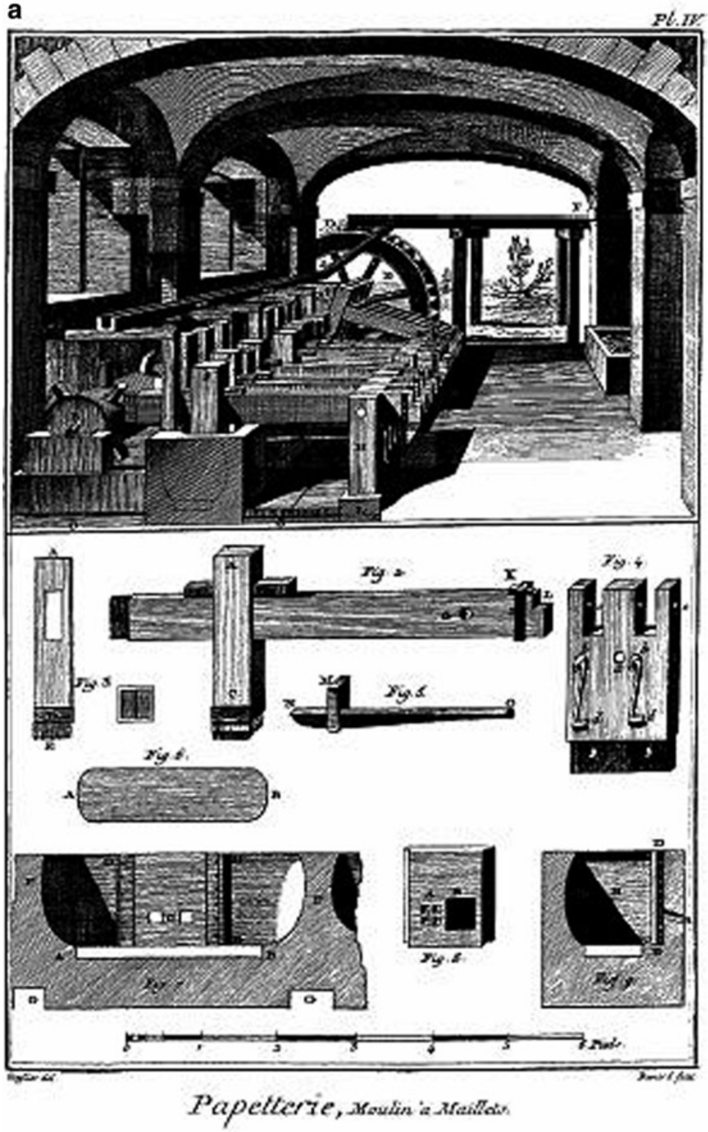


Fig. 11 (**a**) Paper mills and their machines in the collection "Papetterie" by D'Alembert J.B. and Diderot D. in the Encyclopédie in 1751–1772

b

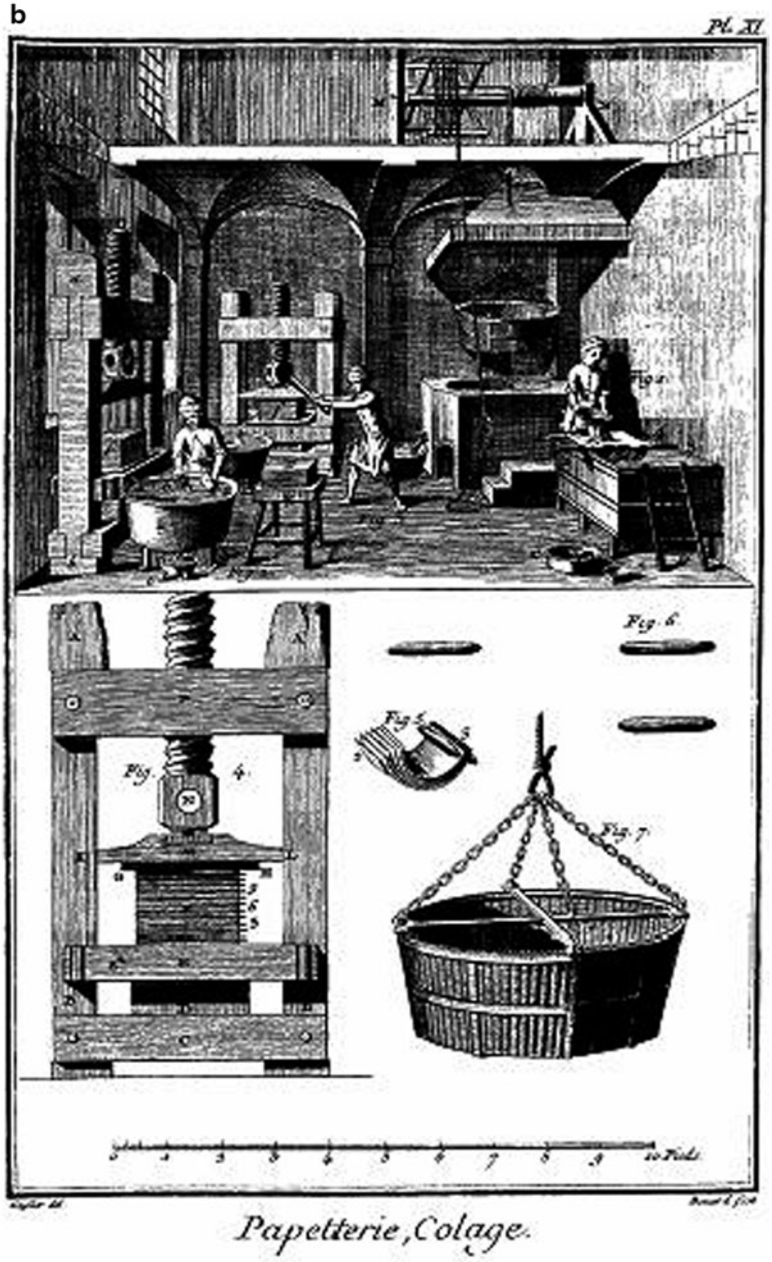


Fig. 11 (continued)

machines as designed and built with components that are in common with other industrial machines for other applications. Nevertheless, specific details and adjustments made them specific for the papermaking process and thus as machines for the papermaking industry.

Fig. 12 Smashing machine in the paper mill Fibreno in Isola del Liri (Mancini 2007)

This aspect was due to, but also motivated by, an industrialization of the paper mills both in terms of technical functionality and enterprise activity.

In Figs. 12–16, it is evident the transformation of paper mills into industries for massive production is evident, although in some cases still with goals of high-quality products. The machines were designed to be used by operators who do not add anything manual in the papermaking process and do not even touch the paper mass as it evolves into paper. The machines are the central part of the process of papermaking.

The evolution of machines for papermaking is an interesting case of industrial archaeology that aims to understand the aspects that have motivated and affected technical development, but also to preserve past solutions that can be used not only as a simple memory of past technology but reconsideration of their successful functional in the design of future modern machines.

In addition, there is also a real need to understand machine design and operation from industrial artifacts.

Figures 17 and 18 are illustrative examples of situations in remains of paper mills in South Latium where plant structures have been abandoned still with machinery inside. In Fig. 17 the building structures have been abandoned with machinery in a still proper installation. It is the usual layout of nineteenth century plants where the power source for the machines was located outside or elsewhere far away from the room of production with human operators. The power was transmitted to several machines with a unique axle that was connected with different mechanical transmissions as depending on the distance and power need. In Fig. 17 are observable remains of a pulley for belt transmissions.

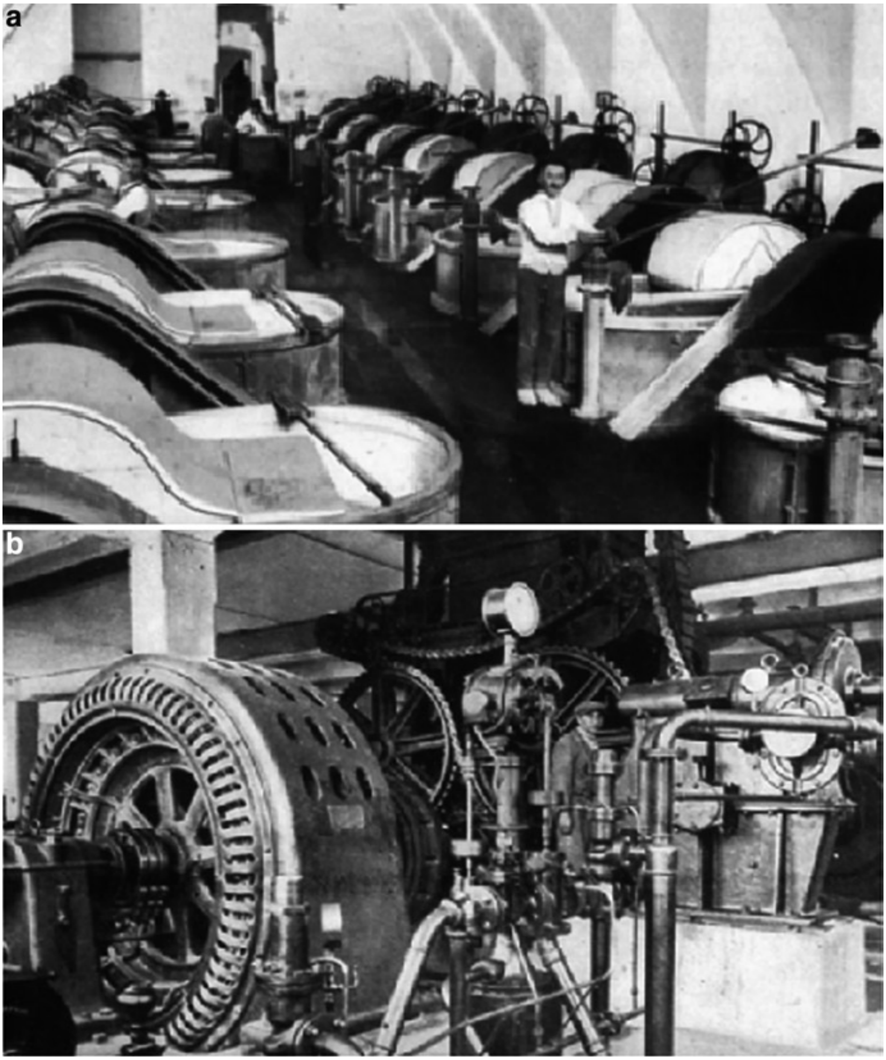


Fig. 13 Smashing machine in the paper mill Cartiera del Liri in Isola del Liri (Mancini 2007): (**a**) Dutch pile for unthreading clothes; (**b**) continuous mechanical smashing machine

In Figs. 18 and 19 a collection of abandoned machines is shown with their remains as found in several paper mills in South Latium.

A restoration and understanding of their design and operation could be useful for better interpretation of the historical evolution of the process of papermaking and its machinery as focused on the specific developments in the area or even at each specific paper mill enterprise.

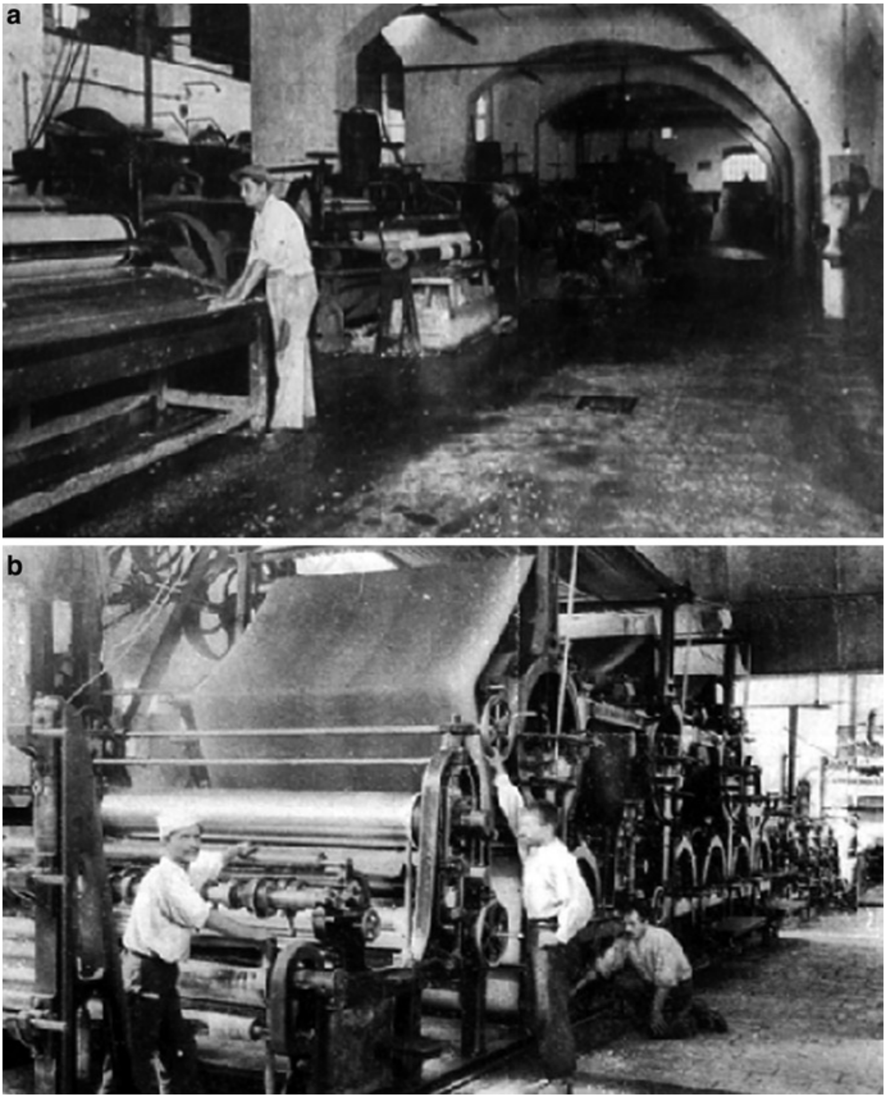


Fig. 14 Machines in the paper mill Cartiera del Liri in Isola del Liri (Mancini 2007): (**a**) press for compacting paper mass; (**b**) continuous laminatory for paper drying

Fig. 15 Machines in the paper mill Cartiera del Liri in Isola del Liri (Mancini 2007): (**a**) packing machine; (**b**) cutting machine

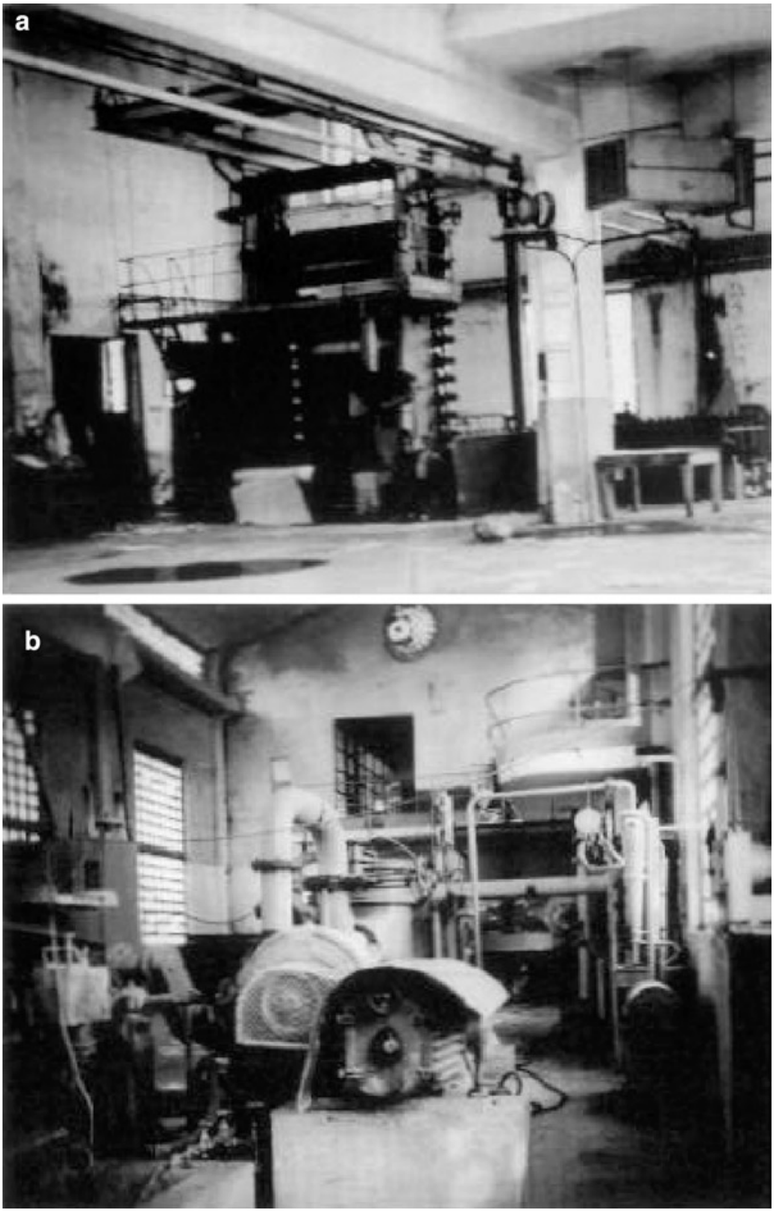


Fig. 16 Machines in the paper mill Cartiera Visocchi in Atina (Mancini 2007): (**a**) abandoned machine for paper mass; (**b**) power station of the plant

Fig. 17 Room and machinery as abandoned in the paper mill in Sant'Elia Fiumerapido

6 Conclusions

In this paper we have presented the historical development of the papermaking plants in the surroundings of the Montecassino Abbey with a specific attention paid to those that used hydraulic energy. The historical analysis starts from the paper watermill that was established in 1516 in the town of Sant'Elia Fiumerapido by the Abbey monks with the aim of providing suitable paper sheets for their scriptorium activity. The study of these plants was carried out by using documents and drawings at several scales that have permitted us to track the historical evolution of the structures and papermaking process in the area of the South Latium.

Results have identified and characterized the peculiarities of the plant architectures and production process as motivated and supervised by the monks of the Montecassino Abbey. A first technical development was achieved with characteristics of excellence that nevertheless decreased over time, attaining a minimum during the Industrial Revolution. Similarly, machinery was developed with successful ingenuity that gave prominence to the papermaking process of the area. Those machines have been examined and their historical evolution has been tracked to identify sources for Industrial Archaeology both in recovering the machine remains and to inform future activity on understanding their design and operation.

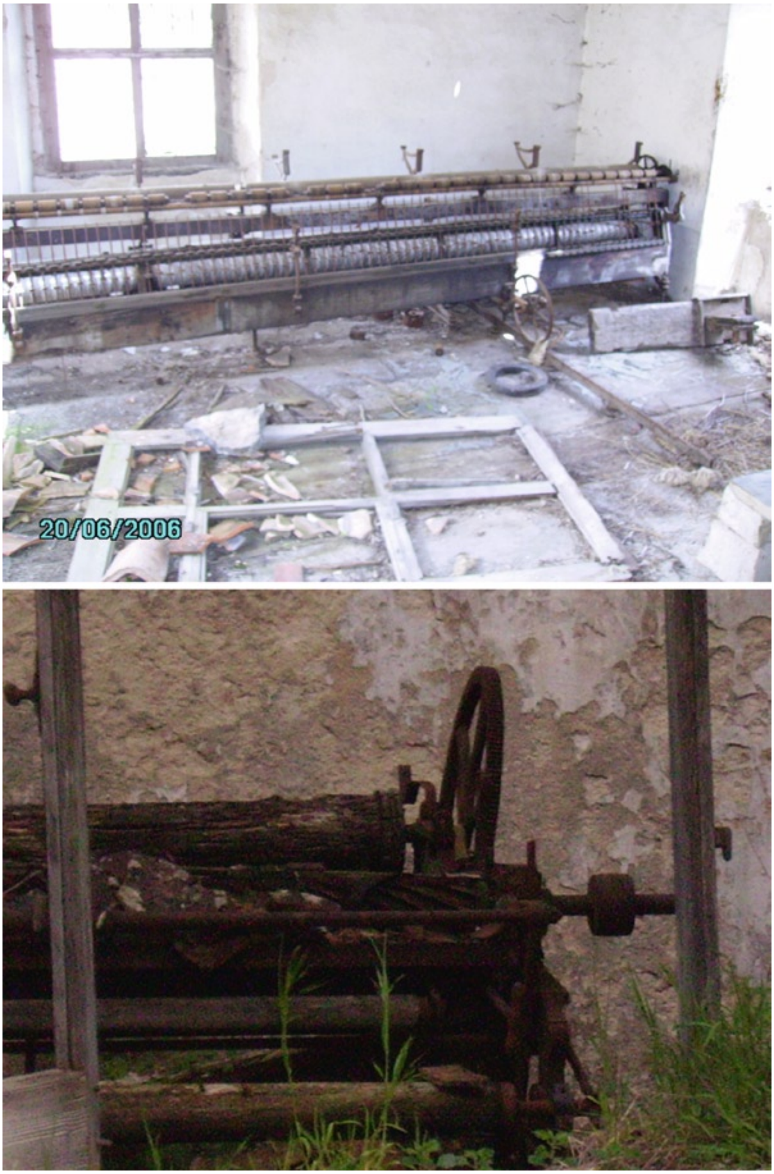


Fig. 18 Remains of machines of difficult interpretation as abandoned in the paper mills in Atina

Fig. 19 Remains of machines of difficult interpretation as abandoned in the paper mills in Sant'Elia Fiumerapido and Isola del Liri

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A Virtual Reconstruction of a Wave-Powered Flour Mill from 1801

Manuel L. Membrilla, Francesc X. Villasevil, Dolores López, Josep M. Monguet, and Joaquim Marquès

Abstract Around 1801, Francisco Terrés i Serra designed and developed a sustainable wave-powered flour mill in Vilanova i la Geltrú, a town located on the Mediterranean coast south of Barcelona, Spain. The mill, which was located on the seashore, consisted of a system of paddles driven by waves that provided the energy necessary to pump sea water to a gathering pond located at a height of 5 m above sea level. This water was then fed to a wooden waterwheel that, via a lantern wheel, turned two sets of millstones in the upper room of the mill where the flour was ground.

The mill is now located more than 50 m from the water line due to the sedimentation of the coastline caused by the construction of nearby breakwater walls. Only a small part of the building is still standing, however, and there are no traces of the original hydropower or pumping systems.

Using information gathered by the historian Francisco Conde and original plans of the mill obtained from the Navy Command in Barcelona, we created a virtual reconstruction of the flour mill complex and its hydraulic components and a 3D simulation of how the mill operated.

Keywords Digital modeling • Virtual simulation • Sustainable technology • Industrial heritage

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J.M. de la Portilla and M. Ceccarelli (eds.), *History of Machines for Heritage and Engineering Development*, History of Mechanism and Machine Science 14,
DOI 10.1007/978-94-007-1251-5_5,

1 Historical Background

The coastal town of Vilanova i la Geltrú, located on the Mediterranean coast south of Barcelona, Spain is home to the remains of an original wave-driven flour mill designed and developed by Francisco Terrés i Serra, a carpenter specialised in the construction of water pumping systems for mines and hydraulic machinery for mills and other water-powered applications. Terrés was from a small town, Sant Martí de Riudeperes, in inland Catalonia and we do not know what brought him to Vilanova i la Geltrú in the late eighteenth century, or what became of him in later years. It is likely, however, that, after witnessing the closure of many river mills and the rising price of flour as the result of drought conditions, our inventor decided to apply his knowledge to create a mill that was not dependent on river flows.

The earliest reference to the flour mill dates back to November 1798, in a letter written by the Captain General of the Principality of Catalonia and the *Real Acuerdo* (a supreme governing authority) to the City Council of Barcelona [1]. Attached to the letter was a copy of a document written by Terrés a few days earlier. The builder claimed to have conceived a system that would use wave energy to move a water-wheel. He highlighted the advantages of a system that would not be affected by changes in river flows and requested funds to pay for its construction (Fig. 1).

1.1 Steps for Construction

We know that there are numerous historical sources that we have not been able to locate since the correspondence held by the National Historical Archives in Madrid

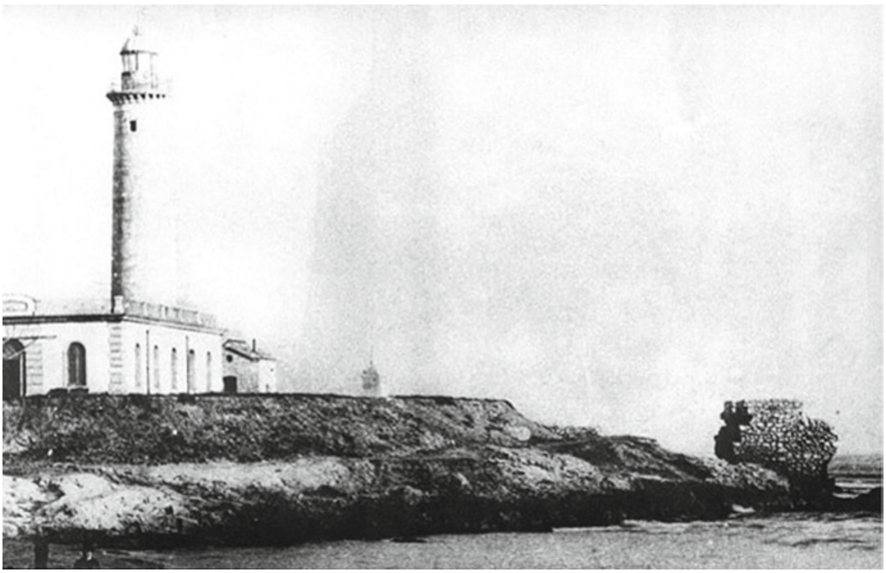

Fig. 1 Remains of the mill at the beginning of the twentieth century

(which has not yet been analyzed in depth) contains a comment by Terrés that his invention may have been copied by foreigners and a request for the government to look into the matter and lend its support. Neither have we been able to locate the drawings and description of the improvements the inventor made after experimenting with the initial construction.

From the documentation consulted, we can assume that Terrés was willing to take responsibility for the costs associated with building the mill but was of the opinion that such a costly venture would not be worth doing if it could then be copied by all and sundry. We can therefore presume that he decided to negotiate with the government to secure a patent that would provide for him and his heirs.

1.2 Possible Operational Problems

We know that the mill was operating at some point because a description of the mill published in the newspaper *El Diario de Barcelona* in August 1801 mentioned that "very white cakes" had been produced thanks to the mill [2]. We can also deduce, however, that the mill had limited effectiveness because there is little or no mention of it in the years that followed and also because Terrés had urgently attempted to raise money to make improvements. The mill was perhaps overly dependent on the sea waves to ensure adequate force and direction of thrust. While excessive force might have broken certain parts, inadequate force would not have generated the power needed by the pistons to pump up the water required to move the waterwheel. It is known that waves rarely impact the coast perpendicular, a fact that would have seriously compromised the performance of the pumps, and consequently, of the mill. Another equally serious problem that the builder undoubtedly had to face was rusting from seawater. To prevent rapid deterioration throughout the mill, the parts would have needed constant protection, which would have been both costly and time-consuming.

Finally, we believe that Terrés cannot fail to have heard about the construction of Spain's first steam engine in Barcelona, news of which was published in 1804. Early prototypes had already been in use in Europe for several decades but because of their strategic importance, details were zealously guarded by national governments. It is likely that our inventor knew little or nothing about the use of new steam-powered mills throughout Europe. This was also the case with many other inventions, whose fate we know little of.

Just 2 years after Terrés started struggling to obtain funds to improve his mill, the famous inventor and doctor Francesc Santpons together with industrialist Jacint Ramon set to work with a group of specialist craftsmen to create a reduced-scale prototype of a steam engine. Surely the reports of their work would have spread the news of the enormous power and productivity associated with steam-powered machines abroad. Added to his problems with money, the unpredictable force of the sea, and rusting parts, this news probably dealt a great moral blow to our modest inventor.

The art of invention has changed over the centuries, with teams of scientists working with skilled operators and the backing of investors having replaced the inventor-craftsman, who took care of practically everything. Another important change is that to-scale prototypes are now built to minimise costs and control possible losses should the invention fail.

1.3 Current Situation

The mill was in all likelihood abandoned because of its lack of productivity and also probably because Terrés failed to raise the money he needed to make much-needed improvements. We can only presume that the most delicate parts of the complex, i.e., those that needed constant maintenance such as mobile or metal parts, were probably eroded by the sea and that the materials used to build the sections of the mill that housed the millstone and the waterwheel were used in nearby constructions. The surrounding landscape would also have changed with time, first with the construction of Vilanova's first lighthouse, in 1866, later with the completion of the first phase of the port, and later still, with the building of the current lighthouse, which began operating on May 1, 1905. Electricity was also brought to the town between 1813 and 1896 [3]. Later changes included the building of the first villas in the area and the railway station in 1926. The change that would have had the greatest impact on the mill, however, was undoubtedly the construction of the current port [4]. The breakwater, which was started in the first construction phase and still stands today, led to the build-up of large amounts of sand on the shoreline, forming what is now the beach in front of the lighthouse and burying much of the original mill complex (Fig. 2).

Fig. 2 Remains of the mill as it is today

In 1975, repair work was begun to support the remains of the existing structure. The holes in the walls were repaired and the floor of the gathering pond was covered with a cement slab to prevent the rains from collapsing what had been the most solid part of this complex for the best part of two centuries [5].

2 Virtual Reconstruction of the Flour Mill

2.1 Description of the Mill, Parts and Nomenclature

Obrador (milling room): The workplace of the miller. This would have contained the millstones and mechanisms necessary for producing flour. The Spanish term *obrador* is still used nowadays to describe a baker's workplace.

Gathering pond: Pond used to collect the water raised by the pumps to power the waterwheel.

Pump room: Part of the mill housing the pumps. It was located below sea level, with the base of the pumps submerged in water to permit the suction of water. The side walls of this room are visible in some old photographs.

Waterwheel axle support: The description of the flour mill mentions a pillar in the centre of the room under the milling room, which, in conjunction with a similar support on the side wall, bore the weight of the wheel.

Architectural components: The architectural remains that are still visible on the beach in front of the lighthouse correspond to the building that housed the gathering pond. The pond has also been preserved, together with certain features such as two holes through which water was supplied to the wheel below. There are two holes as Terrés initially intended to drive two wheels.

Millstone: Circular stone with a hole in the centre through which the grain to be ground was fed. These stones usually had a spiral groove to help channel out the ground flour. The careful grinding and balancing of millstones was crucial to the process and required an expert hand. The stones were changed quite frequently due to the amount of abrasion they were subject to.

Hopper: Receptacle with an opening in the bottom through which the grain was dropped onto the millstone. These hoppers included a mechanism that allowed the controlled feeding of grain to prevent blockages.

Lantern wheel: Wheel responsible for transmitting the power from the rotating waterwheel to the millstone.

Waterwheel: A wooden wheel with enclosures formed by blades—called buckets—arranged around the wheel to hold water. The weight of the water in the buckets on one side produced the torque needed to turn the wheel, the movement of which was aided by the kinetic energy generated by the water striking the blades.

The wheel was also fitted with teeth to transmit the movement of the wheel to the lantern wheel.

Tentering (grinding adjustment) system: A wedge system that acted on a wooden plank supporting the axle of the lantern wheel to adjust the gap between the millstones to produce exactly the grade of flour required. The addition or removal of wedges changed the angle of the plank and with this the height of the millstones, which were supported by the axle of the lantern wheel.

Rocker arms: Attached to the tie beams at one end and to an axle at their centre point, these arms transmitted the swinging movement from the tie beams to the connecting rods, thus enabling the pumping of water.

Tie beams: Two parallel beams attached at either end to axles that were attached to rocker arms and pendulums. Their purpose was to transmit the movement of the pendulums to the rocker arms.

Pendulums: The paddles that received the dashing of the waves. Because they were supported by an overhead axle, the movement of the waves produced a swinging movement similar to that of the pendulums. Firmly attached to the top of the pendulums was an arm that stretched perpendicularly backwards. The top of this arm was, in turn, attached to the tie beams.

Connecting rods: These are the metal bars that connected each piston to the rocker arms. They are not exactly connecting rods, however, because they did not convert linear movements into rotary movements. A more correct term, perhaps, would be thrusters.

Pump: A metal cylinder with a piston inside and two valves, one to pump up the water and another to prevent it from returning when the piston was activated.

Elevators: Tubes connected to the pumps to carry the water up to the level of the gathering pond.

Races: Troughs for channelling the water lifted by the pumps to the gathering pond.

All of these mechanisms were designed to harness the force of the waves to power the mill, as follows. The waves hit against the pendulums, causing them to swing. This swinging, or rocking, movement was then transmitted to the pumps through the tie beams and the rocker arms, which replicated the movement of the pendulums. The pumps lifted the water, whose potential energy was used to channel it to the waterwheel, causing it to turn. The movement of the wheel was then transmitted to the millstone via a lantern wheel. Logically, the process is more clearly depicted in the video we have created [6, 7].

2.2 Justification of the Virtual Model

In our 3D modeling of the mill, the main objective was to provide as clear a picture as possible of how the mill harnessed the power of the waves to operate the

Fig. 3 Virtual reconstruction of the flour mill

millstone and produce flour. This is primarily a visual work and we strived to provide an as realistic a recreation as possible given the information available and the technical limitations of the equipment used.

On analysing all the documentation collected, it soon became clear that we would be unable to produce an exact replica of the original mill as it was in 1801. To create our model, we had to make many assumptions and decide on many major and minor details, particularly with relation to the appearance of the original building (Fig. 3).

The starting point was to define the criteria that would guide our decision-making according to the reliability of the information we had. In certain cases, we had to decide on the order in which these criteria should be applied, depending on the information available regarding specific details and related circumstances [8, 9].

The criteria used to govern our decisions are listed below, in order of reliability. The section that follows provides further details on each point.

- Observation and measurement of the existing remains
- Study of old photographs
- Analysis of original plans containing details of the system used to pump up water to the gathering pond
- Description of the layout and mode of operation of the complex made by an eyewitness in 1801
- Deductions made on the basis of known dimensions, information about the machinery used in other mills, and technical requirements that the mill would have had to comply with to operate
- Non-technical aspects such as construction costs and criteria related to creating a simple model that showed how the mill worked

2.3 Observation and Measurement of the Existing Remains

On analyzing the remains of the mill, we obtained numerous measurements and information about the general size and orientation of the complex. We also obtained many ideas about the position of the mechanical parts of the installation.

Although the remains did not initially appear to provide much information about how the mill actually worked, they actually contained numerous features that helped us to interpret some of the documents consulted (Fig. 4).

Although the mill remains are obviously the most reliable source of information, the gradual deterioration of the building over the course of the years has destroyed certain features and made others difficult to interpret. For example, we were unable to determine whether the different wall thicknesses observed was part of the original design or simply a result of the passage of time (Figs. 5 and 6).

We were also unable to find a satisfactory explanation for the presence of two symmetrical cavities under the arch. Another feature observed was a possible smooth plaster finish on the brick arches.

For the virtual reconstruction of the mill, we decided to create an exposed brick finish, in keeping with the building's current appearance.

We also simplified other aspects. For example, when constructing the walls, we ensured that these were fully upright and parallel to each other, even though this was not exactly the case in the original building.

Fig. 4 Current remains. Centre building with the gathering pond

Fig. 5 Current remains. Symmetrical cavities

Fig. 6 Current remains. Wall with arch

2.4 Study of Old Photographs

We had several photographs dating from the early nineteenth century to the 1970s. Most of the photographs had been taken before the construction of the breakwater which had led to the formation of the beach in front of the lighthouse (Fig. 7).

a

b

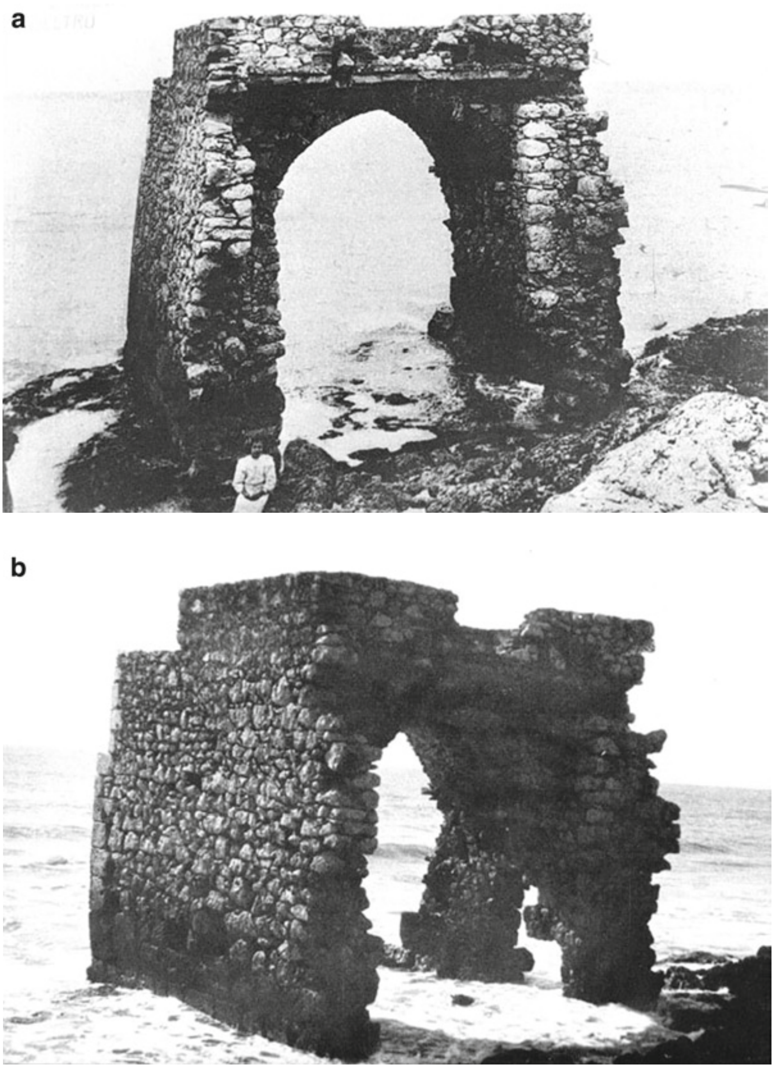

Fig. 7 (**a**) Original location. Walls with a projection extending seawards. (**b**) Original location. Walls with a projection extending seawards

The most important details obtained from these photos were the shape, dimensions, and finish on the walls that extended seawards from the pond building and formed the room that housed the pumps.

We were also able to calculate the height from sea level to the pond by estimating the distance from a group of rocks next to the current remains to the rocks visible in a photograph but that are now buried under the sand.

Another important detail observed in these old photographs was a projection on the walls of the pump room. We believe that this acted as a support for the crossbeam that held the posts supporting the axle of the pendulums.

Finally, we were able to see the position of the mill complex with respect to the sea and to gain an idea of what the surrounding landscape looked like.

2.5 Analysis of Original Building Plans

The only plans we located for the building were actually the most interesting ones as they described the innovative aspect of this mill. The plans featured a floor plan, elevations, and a cross-section of the wave-powered pumping system. Unfortunately, these plans contained general measurements only. They had been hand drawn and were missing crucial measurements such as the diameter of the pumps or the exact length of the pendulums, tie-beams, or rocker arms. They did, however, provide a rather good idea of how the mill worked [10].

It is probably no coincidence that the only plans found were those that had been created by the inventor to justify the viability of the project. Flour mills had been around for some time and required few technical explanations, but Terrés' mill was different in that it was going to harness the force of the waves rather than traditional sources of power such as a river current or waterfall, or even the potential energy provided by tidal flow. Our inventor had to provide a convincing account of how he intended to harness this power to run a flour mill.

As we had no information on the dimensions of the pumping system used, we started by entering approximate measurements based on the relative sizes shown in the diagram. Using these measurements, we calculated the approximate amount of water that the system would have been able to pump up to the pond, presuming that the waves would have moved the pendulums from one extreme to the other and that the pumps had a piston diameter of 20 cm. (These suppositions were necessary as calculating wave force is a complex process beyond the scope of this study. Neither did it make sense to base our calculations on the size of the pendulums or other components as we had no exact measurements for these either.)

The initial results obtained from the measurements entered into the model led to our changing the length of the pendulums to achieve a longer stroke length for the piston and to thus increase the amount of water that could be pumped.

It should be noted that an in situ description of the mill provided by an inhabitant of Vilanova in 1801 shows that the builder was not faithful to the plans in at least three aspects, marked with asterisks below (Figs. 8 and 9).

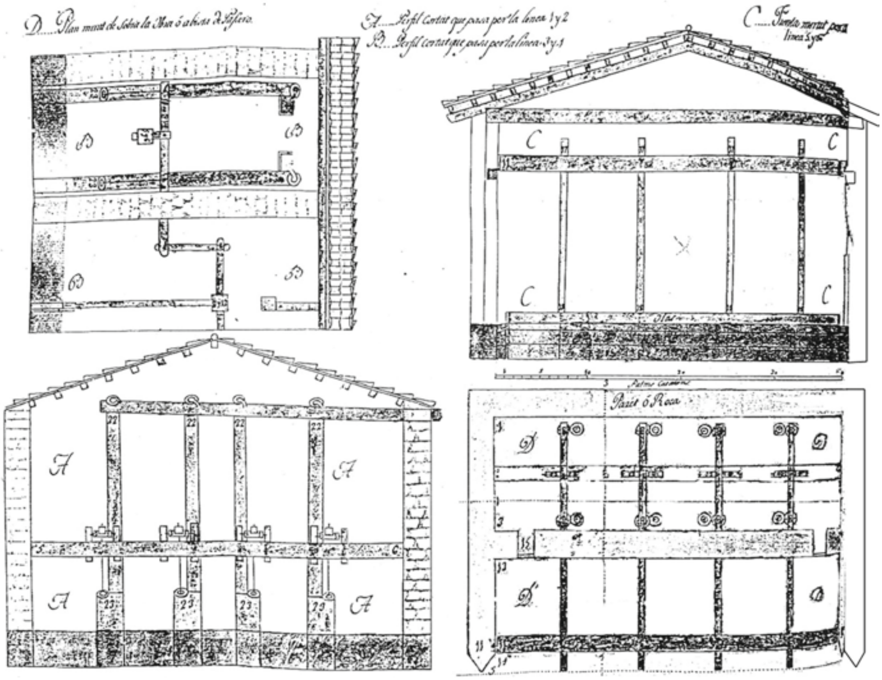

Fig. 8 Original construction plans for the flour mill

Fig. 9 Virtual reconstruction of the mill: original appearance and location

2.6 Eyewitness Description of the Mill

The eyewitness description of the mill provided, without a doubt, the greatest insight into how the mill operated. This description was found in an article published in the *Diario de Barcelona* on August 9 and 10, 1801 (issues 221 and 222) (Annex B).

The article had been written by an observer who described to a friend the layout and operating mode of this unusual mill. He only mentioned a few estimated measurements, but they proved crucial to our gaining an idea of the layout of the different parts that made up the complex.

The article also provided other vital details, detailed below.

- The existence of three pendulums instead of the one specified in the plans.
  It appears that Terrés decided to divide the original pendulum into three pendulums of equal length. From the layout shown in the diagram, it would seem logical that the pendulums on either extreme would have powered two pumps each and that the middle pendulum would have powered the other two sets of two pumps.
- The means by which the pendulums were attached to the rest of the building.

  "*From the sides of the building facing the sea emerge two wooden posts or large beams that support an axle from which three pendulums hang in an oblong fashion…*"

  We had to imagine the form and length of these beams as well as the means by which they were attached to the building.

  We calculated the height of the front wall, behind the pendulums, from the estimated measurements provided by the eyewitness, and imagined that it would be the same width as that of the side walls. The walls were probably thicker towards the bottom of the structure but we did not reflect this in the model to simplify matters.
- Roofless pump room.
  Terrés' original plan had been to operate two waterwheels and four sets of millstones.

  "*Because this wheel has teeth on both sides, it can, by itself, move two lantern wheels,…*"

  The waterwheel in the model has teeth on both sides but we omitted other details. Because of the size of the wheel, its axle and spokes would have featured reinforcements that were not shown in the drawing. We can thus assume that the wheel had more wooden components than those shown. Nonetheless, we considered that such details were not crucial to understanding how the mill operated and would have considerably increased the computation power needed to create the final model.
- The layout of the milling room above the waterwheel.
- The vaulted walls around the wheel and the axle support mechanisms.
- Estimated sizes.
- Terrés' intention to make improvements.

"… *it seems as if the inventor of the machine intends to increase the number of pumps or to place the existing pumps in a better location, using resources that he has not mentioned, and also, possibly to make the best possible use of the pendulums, by continually changing their position, to align them with the different directions of the waves of the sea.*"

- A general idea of the layout and operating mode of the mill.
- The fact that the mill actually worked at some point.

"… *whose result has provided us with very good flour for kneading and eating very white cakes.*"

The first difference with respect to the plans is the position of the pendulums and specifically the means by which these were attached to each other at the bottom, via paddles that absorbed the dashing of the waves. The plans featured just one pendulum, whereas the description mentioned three.

This change was probably made for technical reasons. Waves do not normally impact the coastline perpendicularly and would not move the pendulums uniformly across the structure. Furthermore, considerable force would have been required to move the pendulums, causing stress to the wooden structure from the moment the wave impacted one side to the time it reached the other. The longer the pendulum, the greater the stress and the greater the risk of damage or detachment.

The simplest way of reducing this stress would have been to divide the total length into several shorter lengths (Fig. 10).

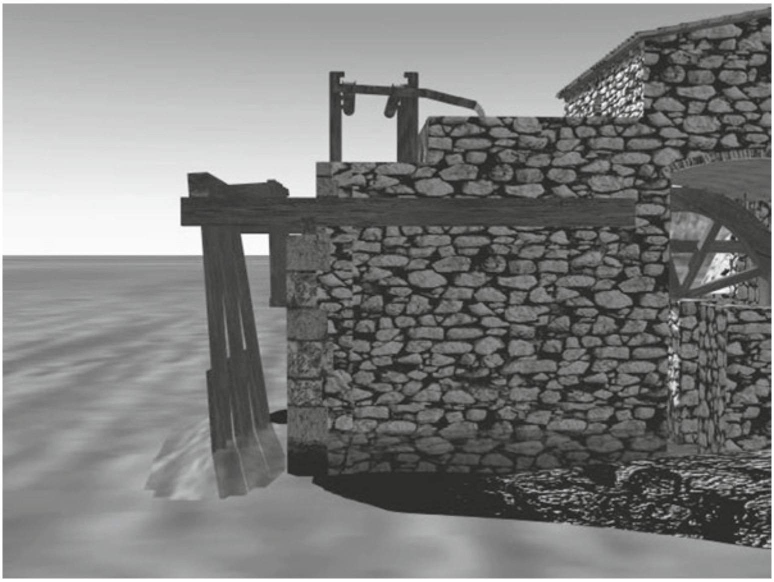

Fig. 10 Note the lag between the different pendulums and the stress of the mechanism working as a single pendulum

A better but more complicated and costly solution would have been to angle the pendulums according to the direction of the waves. This would also have improved the performance of the pumps as the pendulums would have received the maximum force of each wave. This theory is supported by the fact that the newspaper article mentioned the inventor's intention of improving performance by adding a system that would angle the entire structure towards the direction of the waves so that these would impact the pendulums perpendicularly.

In the actual construction, the axle of the pendulums was supported by two beams that projected from the sides of the building rather than being enclosed by walls and a roof. This change would have saved on materials and building costs by eliminating the need to extend the walls out to sea.

The eyewitness made no mention of a roof over the pump room, even though there was a double-sloped roof in the diagram. This change might also have been made to cut costs.

2.7 Deductions

Apart from the information obtained from the newspaper description, we were unable to locate any documents that shed light on the true dimensions, location, and shape of the remaining parts of the mechanical system. To calculate the diameter of the waterwheel, we analysed the distance between the holes that supplied the water to move the wheel and took into account the estimated diameter of 6 m mentioned by our eyewitness. Because this seemed excessive, we finally decided on a diameter of 5 m as this would have been the largest diameter that would have allowed the wheel to turn freely (Fig. 11).

We calculated the width of the waterwheel using known dimensions for other wheels with similar diameters. We found that these measurements varied greatly and that there was no set pattern for the relationship between wheel diameter and width. The sizes were calculated according to the amount of water available or the speed with which this was to be supplied to the wheel. In our case, the wheel had to be sufficiently wide to accommodate the eventual installation of four sets of mill wheels. For our calculations, we had to take into account the distance between the two water supply holes.

This space, measured in situ, was where two of the sets of mill wheels were to be located. Furthermore, the wheel had to be wide enough to allow it to collect all the water that fell from the holes, which were 31 cm wide. We finally decided on a wheel width of 50 cm.

Using the dimensions calculated for the wheel and the distance between the two water supply holes, we were able to estimate the maximum diameter of the two centre millstones and, by extension, that of the other two. To further improve the accuracy of our estimations, we assumed that the original building would have been as wide as the remains and that the miller would have had to have enough space to pass between each set of millstones. We therefore decided on a diameter of 80 cm

Fig. 11 Note the holes in the wall of the pond room prepared for two waterwheels. From the information available, only one wheel and one set of millstone were installed

for each millstone. This gave us the initial information we needed to calculate the axle of the lantern wheel and its radius.

When the above measurements had been entered in the model, we saw that the diameter of the waterwheel was very large compared to that of the lantern wheel and would have caused the millstone to turn at a speed of six revolutions per minute. Because this speed was excessive, we changed the measurements and created as wide a diameter as possible for the lantern wheel, and thus reduced the speed with which the millstone would have turned. The final diameter of the lantern wheel was set at 32 cm.

2.8 Decisions

The form of the central part of the building (the gathering pond room) and the walls of the pump room were determined on the basis of the photographs we had. As far as the rest of the building was concerned, however, we had to imagine many aspects and take certain decisions that could easily have gone another way [11]. Our first assumption was that the width of the milling room would have been identical to that of the rest of the building given the fact that the walls of the pond room extended out towards the back. As far as the length was concerned, we assumed that it would have been proportional to the width and sufficient to house, in our case, four sets of millstones and the corresponding machinery.

In the description published in 1801, our eyewitness mentioned that the room housing the waterwheel was "*surrounded by vaulted walls*". We interpreted this information freely and continued the curve of the vault, which started in the gathering pond room, towards the back and joined it to a perpendicular curve on the back wall. Given the form in which this curve began and taking into account the shape of the typical Catalan brick arch of the time, we decided to maintain the symmetry and finish the curve in the same way as it began (Fig. 12).

Probably to create an attractive building design and economise on construction material, Terrés had decided to leave the side and rear walls open, such that the waterwheel could be seen from the outside. Accordingly, we built half-height side walls, which served as a support for the waterwheel axle, just as our eyewitness had reported in his newspaper report (Figs. 13 and 14).

Because the milling room was the part of the complex for which we had the least information, we had to imagine what it might have been like. We decided that it would have been as wide as the rest of the building and large enough to house four sets of millstones and corresponding equipment.

To simplify matters, we decided to create a roof sloping down towards the gathering pond. We added three small windows and a door leading out to the back, which was accessed by a small wooden ladder.

With the exception of the back wall, which was provided with a thickness of 75 cm, the other three walls were made identical to those of the rest of the building (thickness of 50 cm).

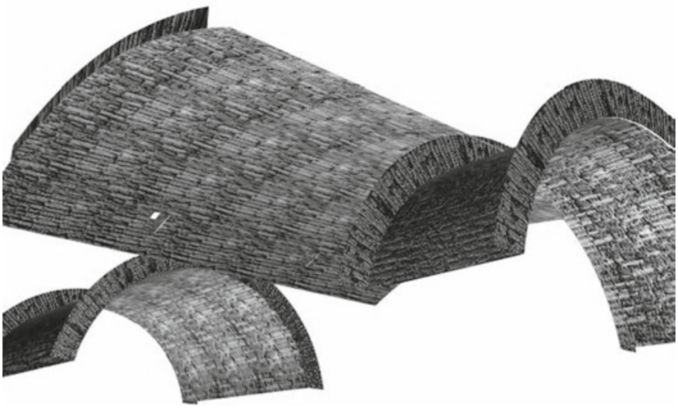

Fig. 12 Close-up of the vaults from the model

Fig. 13 Close-up of the milling room

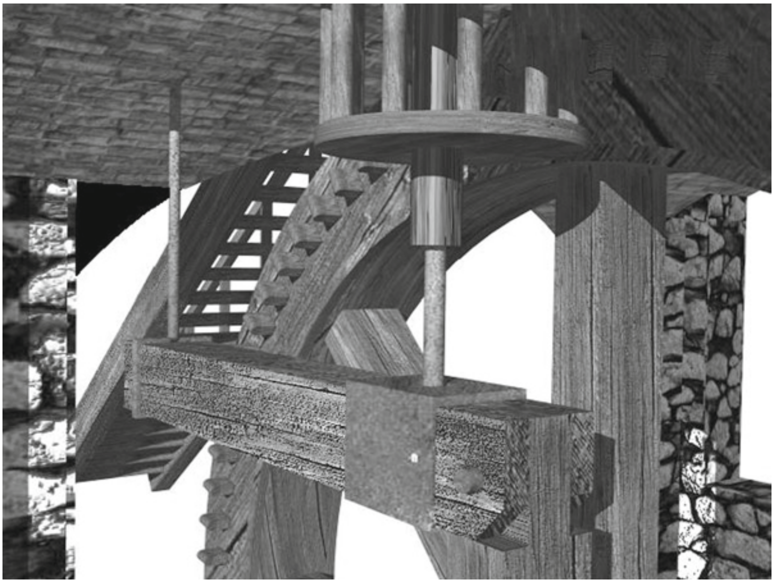

Fig. 14 Close-up of the waterwheel and transmission system

3 Conclusions

3.1 2D Drawings. Digitalization of 3D Models

Once we had defined the size and position of all the components of the model, we drew a 2D diagram which we then used to correctly enter the coordinates for all the elements in the 3D model.

3.2 Exportation of 2D and 3D Drawings to a Virtual Simulation Program

All the components were added to a virtual simulation program in small groups until the complete model of the mill had been created. Numerous changes were also made following importation.

3.3 Creation of Maps and Textures

The components of the mill were classified according to the material with which they had been made in the original mill. In the case of wood, which was the most common material used, we created a family of mobile components and another of fixed ones. Mapping is the process of applying a material to each object or component.

3.4 Scene Creation

Once we had prepared the maps and textures, we used the materials editor to select a standard format and other personalised formats. These were given names and applied to the maps selected for each component. Once placed over the object, they were rendered to check that the orientation, proportion, and final result were correct.

3.5 Animation and Generation of Videos

To animate the mobile parts of the mill, we had to carefully define the movements of each component and synchronise them correctly.

As explained above, the video contains various sequences that have been put together. This permitted the application of certain effects such as the blending of images in the final edit. All the rendered images were compressed in order to view them once they had been created. For the final scenes, however, it would have been better to have compressed these images in the post-production stage to prevent the loss of image quality that occurred in certain cases.

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3D Modelling and Animation Study of the Industrial Heritage Wonders

Jose Maria de la Portilla de la Nuez and Jose Maria de la Portilla Fernández

Abstract The paper describes the process of creating a virtual representation of some of the drawings made by the famous engineer and genius Agustin de Betancourt y Molina (Fig. 1). The latest technologies were used to recreate some of the engineering designs he painted with extreme detail to be part of a documentary directed by Desiree Hernandez Hormiga. No real physical simulation was intended, just an artistic interpretation of the environment, while maintaining a very approximate animation of such models.

Everything will be covered from gathering the right material to the study of movement and the correct approach at animating the wonders.

1 Introduction

When approaching such a task of bringing to life the ideas of another man, be he a genius or a madman, one must always feel humble and act carefully. The project that fell into my hands was a very exciting and intriguing task, to recreate three drawings made by Agustin de Betancourt y Molina. This notable man was one of the most influential and acclaimed engineers of his time. Working for the crown of Spain, gathering covert intelligence on the revolutionary steam engine, becoming a legend in Russia… The story of this man was truly fascinating. The more research I made, the more I realized that not only was Betancourt a great engineer, but a great artist too. His drawings had a beautiful finish, but also an extreme attention to detail. This attention to detail would prove later on very valuable.

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Fig. 1 A painting of Agustin de Betancourt y Molina (1758–1824)

2 Betancourt and His Works

For the purposes of this article, three industrial wonders have been chosen from thousands of ideas and paintings created by Betancourt.

The first one was the design of a Watt's steam engine with double-action (Fig. 2). The story behind this painting was truly fascinating. In 1789, Betancourt traveled to England, to meet the famous inventor James Watt. He was kindly received by the inventor, but he was shown everything except what Agustin was really there for, the steam engine. Disappointed, Betancourt went back to London. Still determined to see the engine, he contacted a friend and went to Albion Mills, at Blackfriars, where one of those engines had been recently placed. What is fascinating is that being able to only partially see the engine, at a certain distance, and only a glance, was enough for Betancourt to understand the mechanics behind the new steam engine of double-action. Once he went back to France, he started with the drawings. Not happy with what is probably one of the first examples of industrial espionage, Betancourt allied with the Périer brothers, and in less than a year, 1790, they constructed the first steam engine of double-action on the continent. This was truly a history-changing episode, as we do not know what would have happened if England had been the only country to control the steam engine. The reaction from England was not long in coming, and Watt wrote to Boulton, recommending that he be wary of foreigners. The knowledge of the steam engine grew

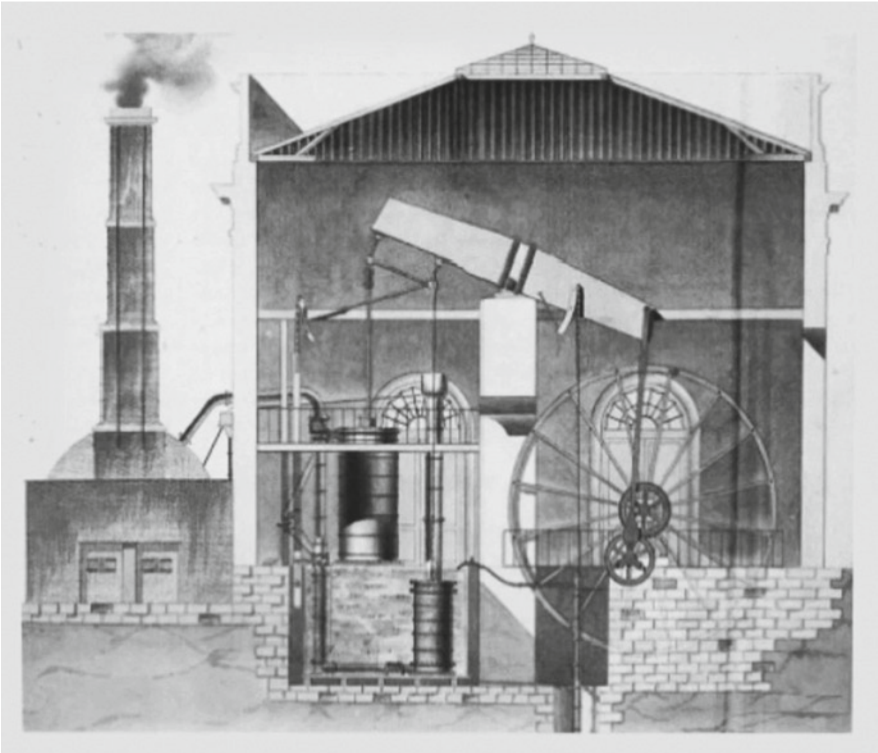

Fig. 2 A painting of the steam engine of double-effect (1789)

rapidly throughout Europe, affecting the complex phenomenon called the Industrial Revolution. The story can be found in Prony´s "Nouvelle Architecture hydraulyque" (I, page 572).

The second wonder that was selected was a water mill, designed to grind flints (Fig. 3). This was a very creative design, and it stands out from the rest because the mill could change the position of the waterwheel depending on the river flow, and the height of the water. The waterwheel was on top of two floating wooden devices, which could change its vertical position depending on how much water the river carried. The design was published in "An 18th century engineer's sketch book. William Reynolds book". Another sketch of this same mill can be found in Saint Petersburg, in the State University. There is no proof that the actual mill was ever constructed, still the design is made up from numerous paintings, in which Betancourt describes carefully how to make one of these marvels.

The third and last engineering wonder was the Kronstadt dredger (Fig. 4). The story behind this design is also full of anecdotes. In 1791, soon after taking part in study of the steam engine of double-action, Betancourt tried to design what would eventually be a steam-powered dredger. Taking the designs from the German

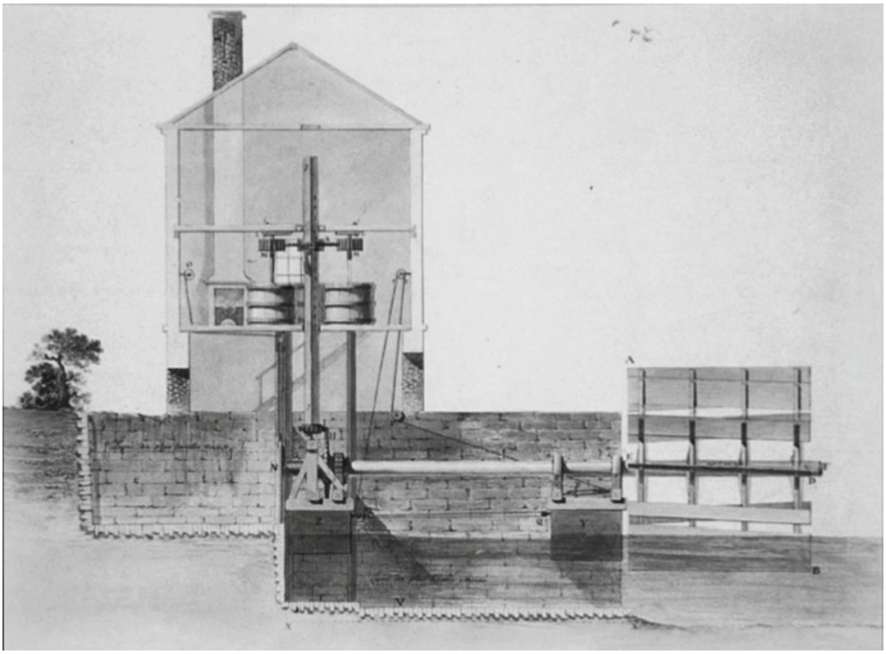

Fig. 3 A painting of the floating water mill

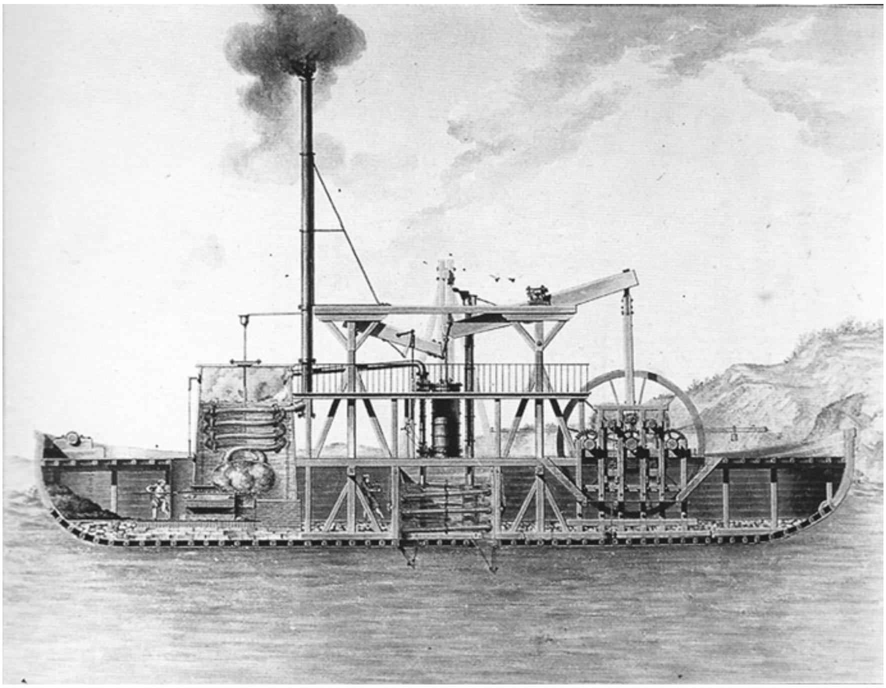

Fig. 4 A painting of the Kronstadt dredger (1810)

engineer Meyer, who invented the dredger powered by beasts, Betancourt penciled the steam engine dredger of double effect. The Spanish navy, pleading that the machine was too powerful, dismissed his pioneering design. This dredger was never constructed in Spain; Betancourt had to wait 18 years to see his vision come true. It was when he lived in Russia that he saw the opportunity of creating this steam dredger. Kronstadt was an island on the Finnish gulf of great strategic importance. It defended the city of Saint Petersburg from the seaside. In 1810, Agustin was given the task of making this steam dredger, using the best part of a year. It was finished in August 1811. In September of that same year Betancourt tried it and retouched some areas and in August 1812 the dredger arrived in Kronstadt. It worked full time until 1820, a year in which they made some repairs. Apart from this dredger, Betancourt designed another one of smaller proportions for cleaning the basin of the River Neva.

After considering which engineering marvels where going to be recreated in a virtual environment, the next step was to do some "geographical" research. If the task was to recreate these machines in the best possible manner, it was equally important to place these marvels in the right location. Photographs from different places were used as reference material to get an approximate idea of what was needed for the backgrounds, and what other elements the machines would be interacting with. In the example of the water mill and the dredger, it was clear that a correct river environment was required. How this was done will be discussed in the Post-Production section.

3 Modelling in 3D

The program chosen for the 3D modelling and animation of Betancourt's drawings was Autodesk Maya. Maya is an industry-standard software used in countless films and games. Having a large number of tools at our disposal, we concluded that Maya was the right choice for the task.

At the beginning polygonal modelling was used to outline the drawing's main features. A polygonal mesh is made from line segments that connect points in 3D space, called vertices (Fig. 5).

The vast majority of 3D models today are built as textured polygonal models, because they are flexible and because computers can render them so quickly. However, polygons are planar and can only approximate curved surfaces using many polygons. Most of the time these polygons will be triangular, being a complete mayhem to control, especially when modelling and texturing. The key here was to keep all faces of the model in quads (name given to a face with four vertices). The vast majority of the models were created with simple cubes, which then would be shaped using a technique called box modelling. This technique is used in 3D modelling to create complex shapes using simple cubes. There are two basic operations that make up this technique. Extrude is the main tool for this operation, it lets you take a face from the surface of a model, and elongate its position with newly created faces at its sides (Fig. 6).

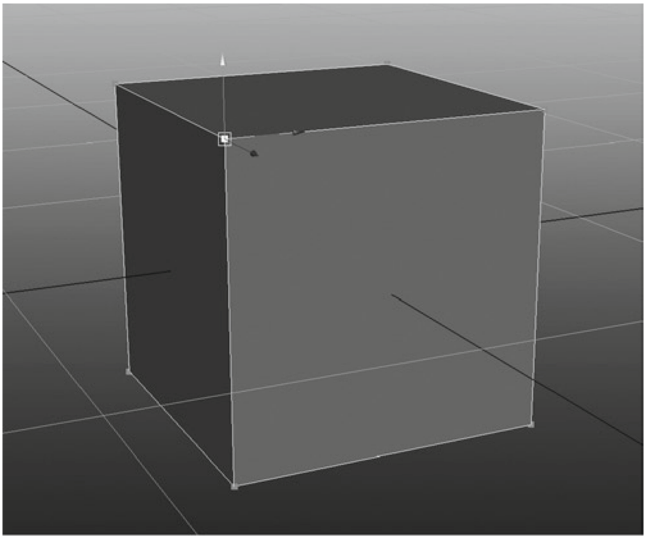

Fig. 5 A polygonal model showing the vertices, edges and faces

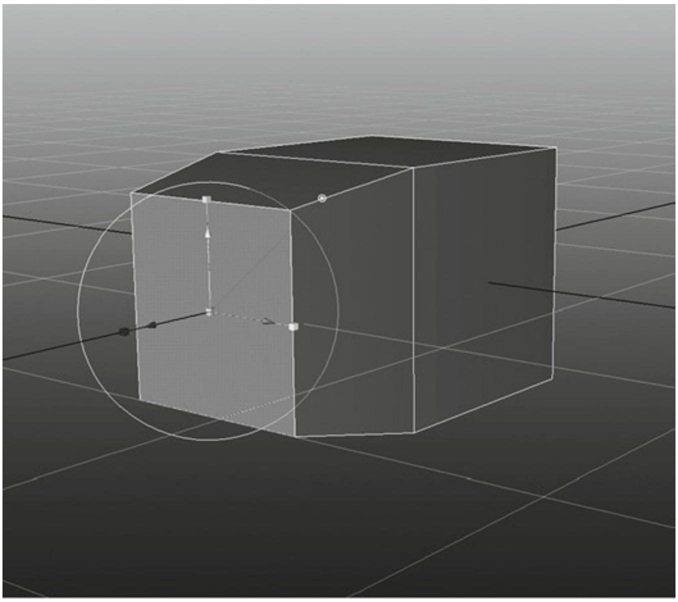

Fig. 6 The extrude operation with a slight scale difference

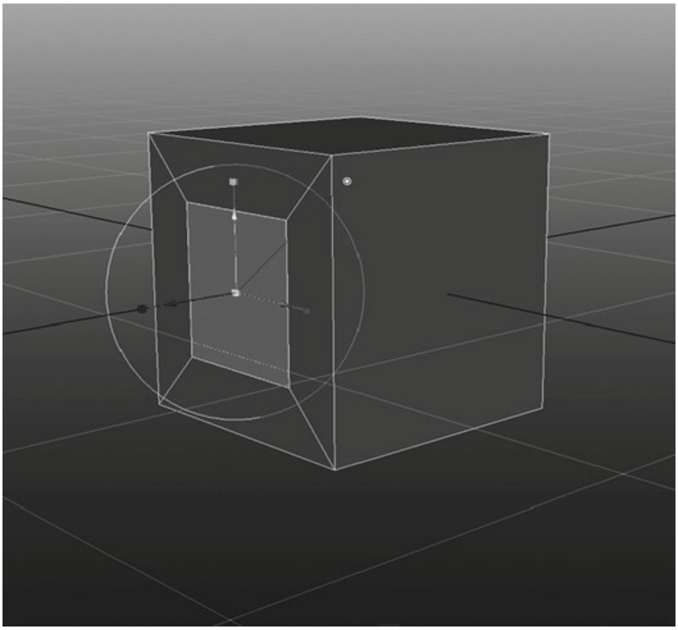

Fig. 7 The inner extrude operation

The next tool could be described as an "Inner Extrude" (Fig. 7).

This technique is quite similar to the extrude operation, except that the face chosen is now made smaller, creating new faces to the sides to fill in the area of the original face.

With these two basic operations you can model almost anything, you only need practice and expertise to master box modelling. The reason why many designers use it to create organic shapes is that, later on, one can apply a smoothing function to the mesh, creating curves where edges used to be.

Thanks to the extreme detail of Agustin de Betancourt's paintings, the modelling was quite simple. The only consideration about modelling came when creating the different tubes and chimneys of the models. NURBS modelling was used to create all tube-shaped objects (Fig. 8). NURBS stands for Non-Uniform Rational Basis Spline; it is basically a mathematical model, commonly used in computer graphics for generating and representing curves and surfaces, that offers great flexibility and precision for handling both analytic and freeform shapes. Thanks to this technique, the accuracy of the modelling was doubled, due to the flexibility of the control vertex points of the mesh.

It was agreed early in the production stage that the models would represent only Agustin's machines. No extra modelling was needed, epecially the characters that would appear if there was a need to show any human interaction with the machines. The other elements such as background or water would be created using post-production programs such as After Effects.

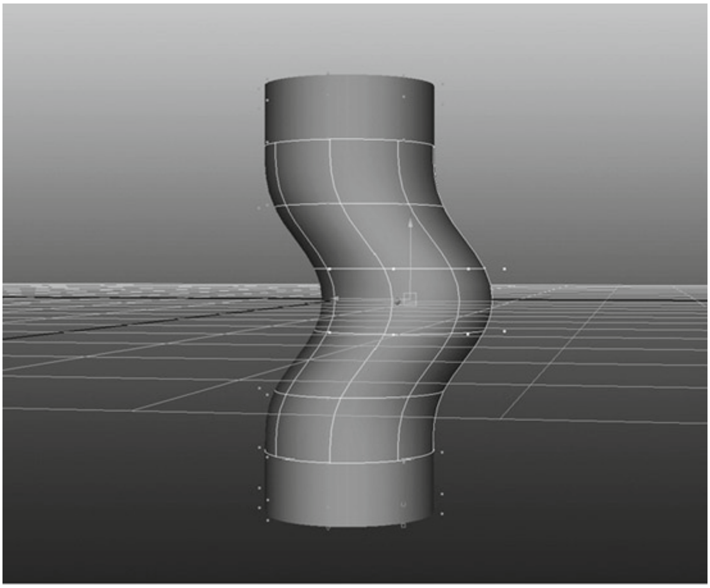

Fig. 8 NURBS being modified and returning a smooth surface

4 Applying Textures

It is a healthy habit to texture your models immediately after modelling them. The main reason is that if animation has been applied before the texturing process, "dancing textures" could appear, making the animation look strange and unprofessional. These so-called "dancing textures" are simply wrong interpretations of the UV points that are wrapped around the surface of an object in order to tell the 3D program where to show what part of the 2D texture.

Straight photographs were taken of all textures and processed first in Photoshop. A lot of research was required to find materials similar to those that would have been used during that period of time. Especially, woods and metals were used and a few concrete and dirt materials.

In any attempt to create professional looking textures, you need to have different parameters that will create what is called a material, or shader. These parameters will usually be the colour, bump map, displacement map, reflection, refraction, and a long list of others. In the case of recreating materials such as wood and metal, only the colour map, bump map, displacement map, reflection (on metal), and specularity (also metal) were used. Different files feed all these parameters. For example, the colour map is fed by a coloured photograph or composition. The rest of the maps are black and white images. The greyscale of the maps is translated to a range of values. Usually blacks are low values and whites are high values. The easiest way of illustrating this is probably using the reflection map as an example.

The areas of the map that are white will be reflective and all areas with black will be opaque, while all grey areas will be partially reflective, depending on the amount of black or white that the grey might have. A great tip for anyone who is looking to get a good bump map from a photograph is to use the red channel as the bump map. Colour channels in photographic programs are represented in a greyscale. So the famous RGB (Red, Green, and Blue), are actually greyscale maps that tell the program the amount of red, green or blue that must be applied to a certain area according to the same criteria as the other maps, using the greyscale as a scale of values.

A usual practice in the 3D profession is to "dirt-up" your models. This practice became quite renowned after the first 3D models looked too clean, or perfect. One of the goals of a good 3D artist is to try and mimic as best as possible the real world. Most of the time when doing research the 3D artist tends to look for the imperfections of the real world, since this does not occur in a computer environment. Textures are a crucial part of getting this realistic aspect of the scene.

Once the textures were chosen, the next stage was to set out the UV mapping. UV mapping could be explained as a 3D modelling process of making a 2D image representing a 3D model (Fig. 9). The map transforms the 3D object onto an image known as a texture map. In contrast to "X", "Y" and "Z", which are the coordinates for the original 3D object in the modelling space, "U" and "V" are the coordinates of the transformed object. This creates the effect of painting the image onto the surface of the 3D object. This task was quite simple, as most of the modelling was made out of extruded boxes: being all polygons it is easy to access the UV points throughout the UV editor.

Even so, the key to getting a successful UV map is to know how to project the map to the surface. There are different methods of wrapping the texture on to the object. These operations usually employ geometric shapes, such as square, cylinder, planar, or spherical projections (ideal for planets and beach balls!). There is also an

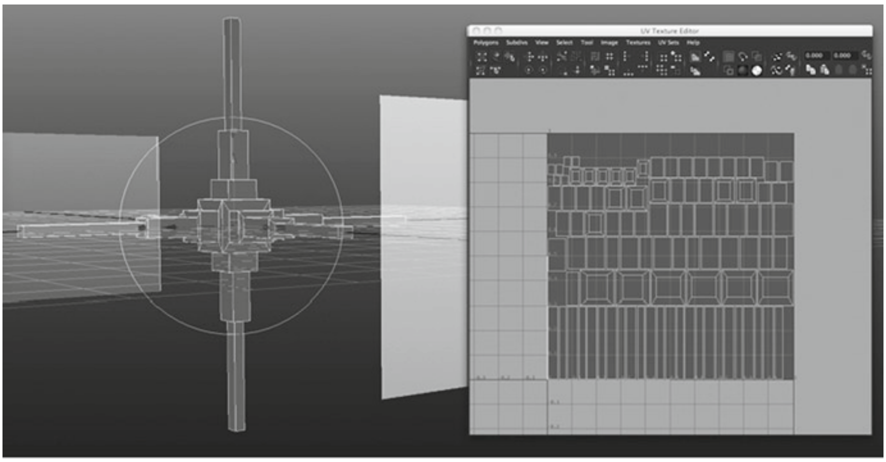

Fig. 9 UV mapping example

automatic way of making the UV texture: basically it takes every single face, and lays each one next to another. The problem with this procedure is that it creates very unpredictable UV maps, as adjoining faces from the chosen shape are usually not projected next to each other, so to paint or position different types of graphics on that map is not sufficiently coherent. Ideally, you want to use one of the geometric projections mentioned above, and then manually reconstruct the shape of the object so it is recognizable when you attempt to lay down the textures.

Some of the shadows were baked to lower rendering times, as there was a tight schedule. Baking shadows is a process by which the renderer calculates where the shadows will be cast to a surface, and then apply this information to literally become part of that surface. This translates to literally painting the shadows on the actual texture. This is a great choice for obvious reasons, but only if you are completely sure that the light's position, direction and intensity are correct. The main reason to gain speed by baking shadows is that the renderer overrides any calculation having to do with the trigonometry of the angles of light being cast and hence creating shadows. This operation is usually the part that takes longer to render, especially if you use Final Gathering.

5 Animation

This was by far the most exciting and inspiring part of the whole process. Long sleepless nights were spent to try to figure out how all these machines could be animated in an efficient way, while keeping some sort of realism. At the beginning the task seemed to be quite simple, as no accurate simulation was needed. But the animations had to look "believable", which actually made it much harder than planned.

There is something about motion that the human eye can pick up quite easily. Its astonishing to see how one tries to animate a scene following the right "scientific" way and after seeing a quick render, the eye tells you its not right. I found the hardest task was to fool the mind of the viewer into seeing the animation as something natural. Actually, the whole purpose was to make the viewer see the animation but not necessarily take too much notice of it, letting the mind discover the shapes and textures of the models.

The first approach was made through traditional key frame animation. A key frame in animation and filmmaking is a drawing that defines the starting and ending points of any smooth transition. They are called "frames" because their position in time is measured in frames on a strip of film. A sequence of keyframes defines which movement the spectator will see, whereas the position of the keyframes on the film, video or animation defines the timing of the movement. Because only two or three keyframes over the span of a second do not create the illusion of movement, the remaining frames are filled with in-betweens (Fig. 10).

Soon this technique proved to be very tedious and the animation seemed too "mechanical". Every element had to be animated separately, which made the process far too slow.

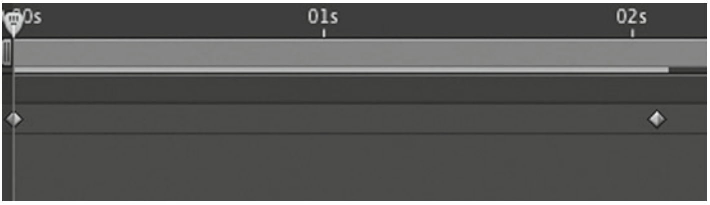

Fig. 10 Visual representation of keyframes

Fig. 11 Set driven key window

The next technique that was tried was to use set-driven keys. In Maya, set-driven keys are keys that link the attributes at their new values (Fig. 11). You can link the attributes with as many keys as necessary. The default interpolation between the keys is linear. To fine-tune the relationship between the driver attribute and driven attribute, use the Graph Editor. The Graph Editor is like the Holy Grail for any animator. In this procedure you see a visual representation of movement described by curves. The steeper the curve is, the faster the values will change, while the more horizontal the line is, the slower those values will change. This technique is extremely interesting, and it involves certain mathematical equations to link parameters from one object to another. In theory the setting up of the animated scene takes quite a long time, but once everything is linked properly, it should be quite easy to see the results.

Still this second technique turned out to be very unpredictable. The animations lacked naturalness and some of the parameters did not match up, as one would have wanted them to do. The main problem resided in the rotational axis of the wheels (all three designs had some sort of wheels). Linking values that feed rotations with values that come from vertical movement proved to be quite hard to match.

Finally, and after a lot of thought about the animation technique, I decided to use the same technique used for characters: skeletal animation. Skeletal animation is a technique in computer animation, particularly in the animation of vertebrates, in which a character is represented in two parts: a surface representation used to draw the character (called the skin) and a hierarchical set of bones used for animation only (called the skeleton) (Fig. 12).

Bones will be created to form the skeleton, and thus the skeleton would deform the skin. Now it is crucial that the rotational axis of the skeleton is set properly at the start of the creation of the animated system. That means that all bones should have the x, y, and z-axis facing the same way, as if not, the animation would end up being chaotic and unpredictable. In this case the skin would be the parts of the engine. Now the reason why I did not try this technique before was because to do so, the model needs to have the right perfect proportions and the location of joints need to be extremely precise.

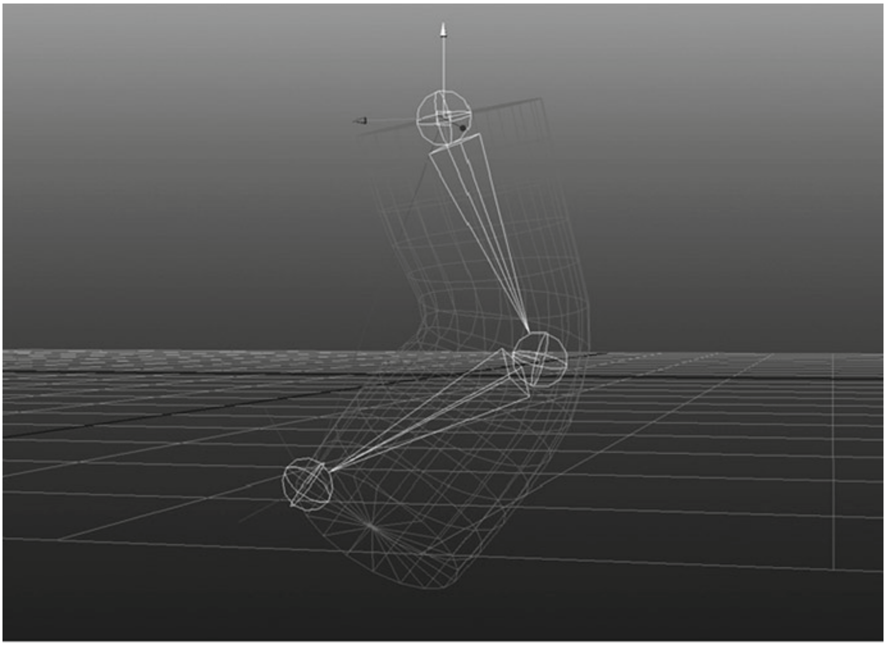

Fig. 12 A set of bones with inverse kinematics and skinning

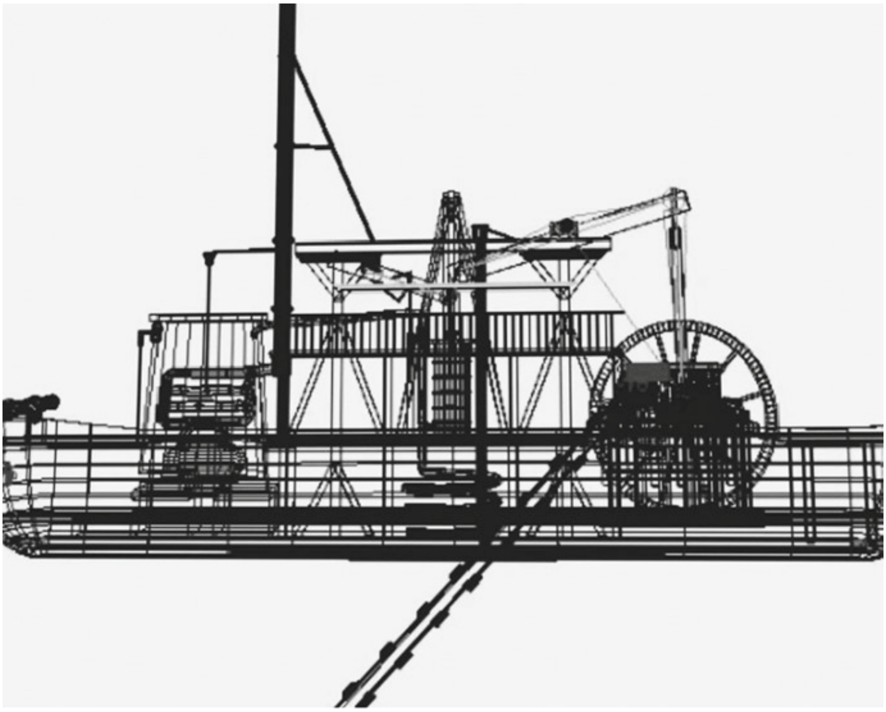

Fig. 13 A schematic view of the complex bone system or “rig”

Never before had I tried to animate an inanimate object with this technique. Following to the millimetre the drawings of Agustin to create the model, and having laid out an extremely complex bone and joint system with multiple hierarchies and constraints, I witnessed a miracle (Fig. 13).

In the end, only one parameter was animated with several key frames, and the whole system behaved accordingly, giving it an amazing feel of realism and naturalness to the motion. After a lot of research on how the steam engines would behave, I found myself with an animation, that was extremely close to being hyper-realistic. The only reason for such success was the incredible drawings of Agustin de Betancourt y Molina. His drawings were so perfect that, when it came to recreate them, they worked exactly as intended. This kind of experience humbled my perception of artistry. This man, centuries ago, was able to draw something that was computer-calculation accurate!

Once the technique was polished and the skeleton system was perfected, the animations took much less time than had been expected. The days lost in trying out different techniques were regained once again by the genius of Agustin. Everyday that I worked on his projects I felt closer to him.

Once the animations were finished, it only remained to light the scene and take it to post-production.

6 Lighting and Rendering

After all the process of animating the models in an accurate way, the final step was to light the scenes and render the files.

Lighting was approached in the most accurate way. Mental Ray was used to light the scene with an accurate Physical Sun and Physical Sky and applying Final Gathering. Mental Ray is a production-quality rendering application developed by Mental Images (Berlin, Germany). Nvidia bought Mental Images in December 2007. As the name implies, it supports ray tracing to generate images. In computer graphics, ray tracing is a technique for generating an image by tracing the path of light through pixels in an image plane and simulating the effects of its encounters with virtual objects. The technique is capable of producing a very high degree of visual realism, usually higher than that of typical scan line rendering methods, but at a greater computational cost. This makes ray tracing best suited for applications where the image can be rendered slowly ahead of time, such as in still images and film and television special effects, and more poorly suited for real-time applications like computer games where speed is critical. Ray tracing is capable of simulating a wide variety of optical effects, such as reflection and refraction, scattering, and chromatic aberration (Fig. 14).

A classic problem in computer graphics is lighting a scene solely through indirect light, like from a sky, or other "environment" light from an acquired HDRI or similar. High dynamic range imaging (HDRI or just HDR) is a set of techniques that allows a greater dynamic range of luminance between the lightest and darkest areas of an image than standard digital imaging techniques or photographic methods. This wider dynamic range allows HDR images to more accurately represent the wide range of intensity levels found in real scenes, ranging from direct sunlight to faint starlight. This is accomplished in Mental Ray using Final Gathering (henceforth

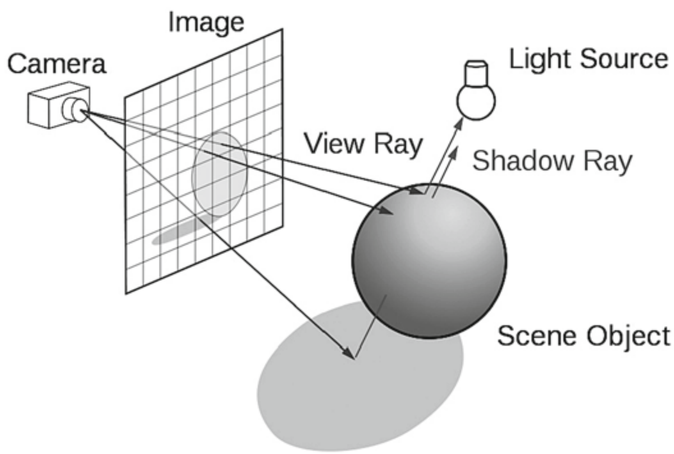

Fig. 14 Explanation of how Ray Trace works

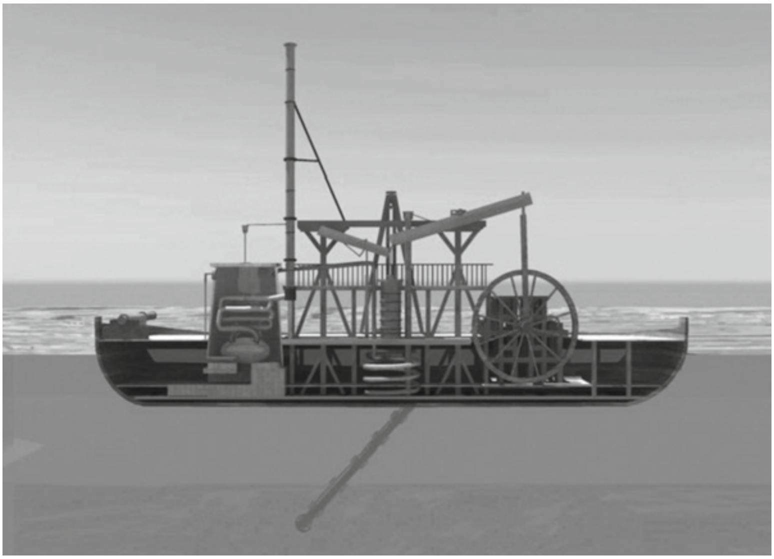

Fig. 15 Frame rendered with Final Gathering

abbreviated as FG), and is done by tracing a large number of “FG rays” to see which hit the environment (or other lit surfaces). Since this is a large number of rays, the results are cached (for performance) at FG points and the result is interpolated, “smoothing” the result. This all works very well when there is a lot of fairly uniform light that is “seen” by the FG rays. In general, FG gives the best result when the light levels in a scene are fairly uniform; it works well to illuminate an outdoors scene by the sky (most FG rays “see” the sky), and it works well to bounce secondary light in a room in which most surfaces are lit by direct lights (most FG rays “see” some already-lit surface) (Fig. 15). Notice the areas that are exposed to the sun directly and the areas inside the boat.

These tools let you light the scene with one single light that would act as the sun, plus a sky to create second lighting algorithms. This technique is very interesting, since it actually calculates the amount of light that bounces off the surfaces and thus lightens other parts of the scene or model. In a nutshell, it recreates real light behaviour.

This technique is very processor intensive, and also increases the rendering times, but since all the background would be added in post-production it was the best choice to render these scenes in the most photorealistic way.

After doing some test renders, some cameras were added to the scenes and animated accordingly so as to have enough shots for the editing in the documentary. The camera had smooth movements, to recreate a cinematic feeling to the shots. The advantage of 3D programs is that you can literally place the camera wherever you want on the scene, with no physical constraints. This is why some of the shots had extreme close-ups, in places that would have been unthinkable to do with a real camera. Once the test renders were done and the motion of the camera and objects was approved, every single camera was rendered separately. Final Gathering was quite slow, and the average time for a frame to render was around 4 min. Taking to account that every second has 25 frames (PAL system was being used), you probably have a pretty good idea of the very long time it took.

The rendering output was set to TIF sequences to obtain a clean alpha channel that later on would be vital for the post-production process. There is a need right about now for a discussion of which formats to use when exporting your work in 3D. PNGs are a great choice for this kind of sequences especially if there is not much available space on your hard-drive. A PNG is basically a TIF but much more compressed. The key advantage of a PNG sequence is that it occupies less space on your hard-drive and that it also has transparency information, crucial for the next stage, post-production.

The rendering should be done in different passes, which implies that every visual effect, such as diffusion, the lights and their shadows, the reflection of refraction of the scene, etc. should be stored separately. The idea is to gain power later on in the post-production process.

My most crucial advice would be to keep control of all the files in separated folders, naming everything very carefully, as later on the task is to take all those rendered sequences and amalgamate them.

7 Post-production

Once the rendering was finished, all image sequences were imported into After Effects (Fig. 16).

Now all that remained to be done was to create the scene on which these drawings would appear. Research was done to determine what kind of geographical and

Fig. 16 After effects workspace

architectural elements could be used to give some sort of credibility for the animation. Photoshop was used to isolate the elements from photographs for later use in the background of the image. In the end, the backgrounds for each animation were a collage of multiple photographs that where positioned, scaled, and colour corrected in order to obtain a decent landscape. Also the rendering passes were imported into the program and placed in layers. The key to successful composition is to use the right blending modes to mix the layers.

Blend modes in digital image editing are used to determine how two layers are blended into each other. The default blend mode in most applications is simply to hide the lower layer with whatever is present in the top layer. However, as each pixel has a numerical representation, a large number of ways to blend two layers is possible. The currently most common numerical representation of colours is the one used in RGB (red, green, blue) images, where three numbers (x, y, z) can take values between 0 and 255, each of them indicating how much red, green and blue the pixel contains. This means for example that (255, 0, 0) is intense red and (0, 0, 255) is pure blue. There are other colour models, which have other number representations. For the purpose of blend modes, the principles are very similar for different colour models, even though not all blend modes can be applied with all colour models. These objects and render passes are placed in layers inside the composition program (Fig. 17).

After all preliminary positioning and blending was finished, the integration of the different elements was made through primary and secondary colour correction. Primary colour correction affects the whole image utilizing control over intensities of red, green, blue, gamma (midtones), shadows (blacks) and highlights (whites). Secondary correction brings about alterations in luminance, saturation and hue in six colours (red, green, blue, cyan, magenta, yellow). The main objective of secondary controls is to adjust values within a narrow range while having a minimum effect on the remainder of the colour spectrum. Using digital grading, objects and colour ranges within the scene can be isolated with precision and adjusted. Colour tints can be manipulated and visual treatments pushed to extremes not physically

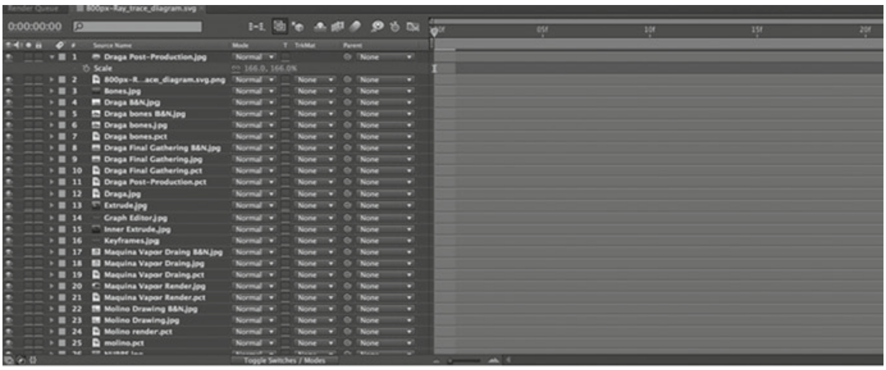

Fig. 17 Stacked layers with all the rendered passes

possible with laboratory processing. Special digital filters and effects can also be applied to the images. It was vital to match the shadows and highlights of the background with the foreground. Now this is probably one of the most difficult aspects of any compositing workflow. Making objects match. After using levels and curves to match the three channels (RGB), some more elements were added to create an atmosphere.

Also matching the film grain was a crucial part in making the shot work. Film grain or granularity is the random optical texture of processed photographic film due to the presence of small grains of a metallic silver developed from silver halide that have received enough photons. There are multiple effects that let you match the grain of different footage, but there is one in particular that works very well. That is “Match Grain” in After Effects. The reason it is so powerful is because you can actually change the amount of grain in every individual colour channel (RGB), obtaining the highest quality results.

After everything was in place particle systems were used to create smoke, fire and water splashes (Fig. 18).

The term particle system refers to a computer graphics technique to simulate certain fuzzy phenomena, which are otherwise very hard to reproduce with conventional rendering techniques. Examples of such phenomena that are commonly replicated using particle systems include fire, explosions, smoke, moving water, sparks, falling leaves, clouds, fog, snow, dust, meteor tails, hair, fur, grass, or abstract visual effects like glowing trails, magic spells, etc.

Once all the elements were added together and blended with each other using colour correction techniques, there was nothing left to do except to render the final clips and edit them into the documentary. The rendering time of these clips will take much less time, since the complex 3D calculations have been translated to pictures. In the end one ends up with something like this (Fig. 19).

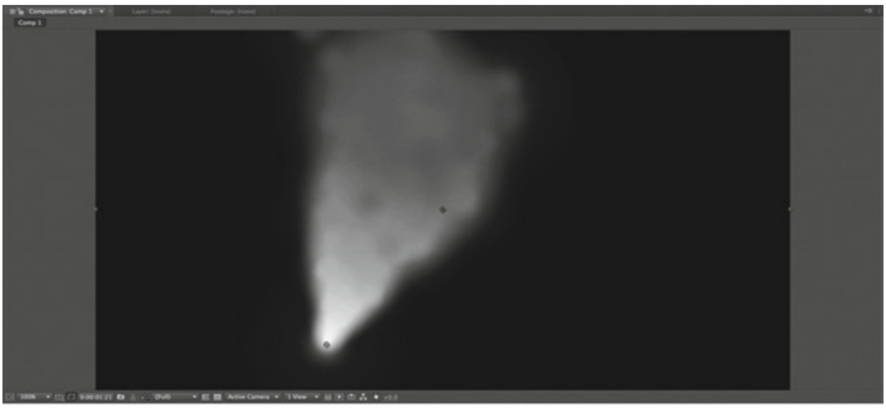

Fig. 18 Particle system as a smoke effect

Fig. 19 Final frame of all the elements in place

8 Conclusion

Working on this project made me realize the educational potential of this kind of animation. Once the tedious modeling and texture have been finished, being able to animate cameras from any angle, gives you the opportunity to watch the machine from points of view that in a normal world would be impossible. You can place cameras inside the machine to illustrate in a more visual way a complex interaction of pieces that otherwise would have needed to be explained with large, confusing diagrams. Once the model has been finished, you can modify as many times as you want the animations, giving you a limitless amount of possibilities in order to create educational content.

Times are changing, and education should change with the times. With these kinds of tools you can enhance the learning experience of students, helping in the understanding of different types of engineering concepts.

You also have the historical factor, as you can recreate very precisely engineering wonders lost in time, giving everyone the opportunity to have a look at the past, and understand better how those engineering wonders worked.

The next step would be to create a website where all these animations would be hosted, so that anyone could access thousands of years of knowledge. It would then be easy to create dynamic historical timelines of different machines, showing how the technology has evolved in the last thousands of years. For example, we could see the evolution of power through the usage of beasts, to the steam engine, to modern engines.

Making this proposed project into reality would lead to an incredible amount of information that would be accessible to anyone, anywhere in the world. It would be a great way to reach to potential engineers, to show them how engineering evolves, and to suggest where it could evolve to.

Fig. 20 Steam engine of double-action

Fig. 21 Water mill with floating waterwheel

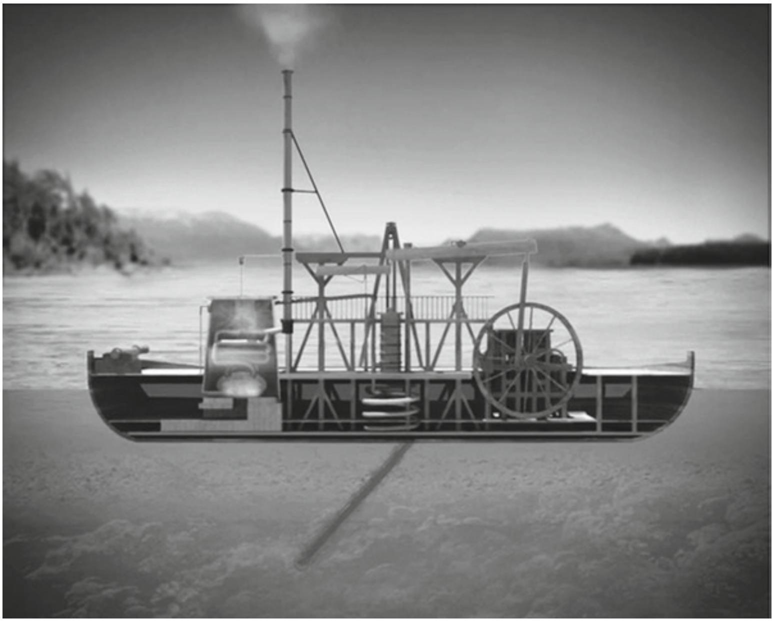

Fig. 22 The Kronstadt dredger

This not only implies a fantastic resource of information for future students, but also a source of inspiration. At the end of the day, the word engineering comes from the Latin word "ingenium", which can also be translated as "wit" or "to create", and is very similar to ingenious.

This project proved to be an incredible experience that steered my professional career in a direction I did not anticipate, and allowed me to discover a whole new avenue for creating animations based on engineering wonders.

These are the final results of the process described in this article (Figs. 20–22).

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New Model of the Hydraulic Machine Known as *El Artificio De Juanelo*

Xavier Jufre Garcia

Abstract There is proof of the existence in the sixteenth century of exceptional mechanical works, considered in many cases the principal European hydraulic infrastructures of the Renaissance, the water machines of Toledo, designed and built by Juanelo Turriano. The first of the two machines that existed began functioning in 1569, the second in 1581, and were finally disassembled in 1640.

It was never known exactly what the machine looked like because no diagrams were saved, only some indirect descriptions.

The project presented in this paper is a new model that fills in the gaps of the existing theories, without removing itself from the content of the historical texts.

1 Introduction

With the arrival of the Renaissance at the end of the fifteenth and beginning of the sixteenth century, Europe experienced an important technological advance in an environment that was practically undeveloped. Their appeared a group of engineers with very diverse knowledge and interests (the most illustrious of all was Leonardo da Vinci 1453–1519), who published a new kind of literature, referred to as "the theater of machines", that showed their technical knowledge, and from the ideas presented there designed machines of all kinds. Especially important were hydraulic machines that were of great importance in areas of strategic development (mining, metallurgy, public works, agricultural irrigation, elaborate gardens…). Probably the most well-known of these devices were the lift at Augsburg (1548), the pumps of London along the shore of the Thames (1582) and the Samaritaine of Paris (1608). And emerging among these great works were the Water Machines of Toledo, work by Juanelo Turriano (1500–1585, engineer and royal clock maker under the

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orders of Charles V and later his son Phillip II), considered the principal hydraulic infrastructure of the Renaissance, for its features and singular design, which gave great fame to its designer.

The Water Machines of Toledo were two practically identical units (the old one in 1569 and the new one in 1581); each of them transported 17,000 l of water daily from the Tagus River to the Alcazar of the city. Each machine was a group of interconnected parts, forming a non-pressure, hydraulic lift system that spread along a route of 306 m, overcoming a total drop of 90 m high (a lift not achieved until the construction of the machine by Marly in 1682, used to bring water from the Seine River to the gardens of Versailles). Although very famous at the time (there are numerous citations of the machines in the literature from the main writers of the Spanish golden age), in 1605 the old machine no longer worked, in 1624 the new machine was temporarily stopped, and both were totally dismantled in 1639, leaving only the buildings that held the machines during their operation. Unfortunately, the life of Juanelo Turriano was more troubled than the demise of his machines; he died at 85 in extreme poverty caused by not receiving payment for the construction of the machines.

2 Existing Documentation

2.1 Blueprints and Layouts

On the operation of the hydraulic machinery of Toledo, that transported water from the Tagus River to the Alcazar, there are no notes, drawings or lithography. This fact is not strange, because Juanelo personally financed and directed the works, so he did not have to give extensive explanations to third parties, evaluating the results independently of the machinery used.

The difficulty in the conception of the machine, plus its location inside the buildings, did not facilitate the opportunity of third parties to precisely describe it in blueprints and layouts. An example cited Jehan Lhermite, who was part of the royal court from 1597 to 1602, and published “Le passetemps de Jehan Lhermite, depuis son voyage d’Espagne”, where it says:

“Although it is a very admirable thing, as I said, I have described that I could never obtain a project or fair representation of this machine to satisfy my desire to present a live image that could visually please my readers, and even if human comprehension and intellect could understand what it is, it is highly difficult to comprehend the machine, industry and invention of this machine without seeing a representation. Therefore, I worked hard to obtain a fair image, but I still have not been able to get anything, and also my numerous requests were made in vain to Juan Baptisto Monnegro, architect of the king, presiding in the mentioned palace, that is the person who governed, who did not stop persuading me at all times to dissuade me of my efforts […] he wrote a brief note that he sent me saying basically that to understand well and explain thoroughly the mystery of this machine it would first be necessary to make a book full of different representations and that later still, to give an even more vivid intelligence of it, it would be necessary to create various wood models, given that – he wrote me- there is no man in the world capable of comprehending this machine by just a single representation".

It would be necessary to use the descriptions, lacking blueprints, that have been conserved until today, in order to create a model of the machine.

2.2 Conserved Descriptions

It is important to mention that at the beginning of the seventeenth century, more than 15 years after the death of Juanelo, modifications were tested on the machines, basically on its sections that were closest to the Tagus. In 1605, Francisco de Pisa wrote in his "Description of the Imperial City of Toledo":

"It is true that this machine and aqueduct need continuous repair, and much cost to perpetuate or maintain. Later, in the year 1604, a certain decision was made which improved and facilitated this machine and aqueduct".

In 1598, the maintenance of the machines fell to Juan Fernández del Castillo. Around 1600, numerous faults appeared from the complicated solution that, together with imperfections generated by growth of the Tagus River and the difficulty of conception of the operation of the machine, provoked a definitive shut down of the old machine, and Juan Fernández del Castillo decided to propose to the king and the city of Toledo, the design of a new machine based principally on Tesibius pumps.

He carried out trials in the sections closest to the shoreline that were finished and put into operation in 1602.

Phillip III authorized construction of the machine by Juan Fernández del Castillo in 1606, and ordered the disassembly of Juanelo's old machine to take advantage of the reusable material in the construction of the new proposal. The machine by Juan Fernández del Castillo was made outdoors and attached to the buildings that protected the machines of Juanelo, being exposed to the weather and visible without obstacles.

It is probable that travelers, chroniclers, bystanders… who visited the machines in the seventeenth century, observed the machine by Juan Fernández del Castillo, because it was not enclosed in buildings, but were placed up against the wall of the machines of Juanelo, outdoors. This fact informs all descriptions prior to 1604, in particular all those dated in the sixteenth century.

Therefore all the existing documentation referring to the machines of Juanelo should be grouped in at least two large blocks where we will place the two most relevant texts (Table 1).

Table 1 Blocks of documentation referring to the machines of Juanelo

Block	Main description
Documentation prior to 1604	Description by Ambrosio de Morales (1575)
Documentation after 1604	Description by Manuel Severim (1604)

3 The Existing Models

Specifically, five investigators have dedicated large amounts of time to the study of the machines of Juanelo, obtaining solid conclusions that have allowed them to formulate diverse theories, they are:

1. Model by Mr. Luís de la Escosura y Morrogh: "The machine of Juanelo and the bridge of Julius Cesar". Reports from the Royal Academy of Natural, Physical and Applied Sciences of Madrid. (Madrid. 1888). Volume XIII, part 2.
2. Model by Theodor Beck: "Juanelo Turriano (1500–1585)". Beitrage zur Geschicht. (Berlin 1899)
3. Model by Dr. Ladislao Reti, (called the model of towers with oscillating spoon: "The Machine of Juanelo". J. Porres. Re-edition of: "Conference given by doctor Ladislao Reti at the University of Los Angeles pronounced in the Casa de Cultura of Toledo on June 15, 1967, in an act organized jointly by the Patron of the Casa de la Cultura, the Royal Academy of Fine Arts and Historical Science of Toledo and the Provincial Institute of Toledan Investigations and Studies". Revista

Table 2 Key points that a machine model should fulfill

Key point	Description
1	Should be based on the Valturio stairs.
2	It can not be a simple machine; its conception is intrinsically complex.
3	The complexity of the machine is founded on arithmetic, needing for its design, numerous calculations.
4	The elements that transport water should pause in order to carry out the transfer, while the rest of the machine remains in motion. Water will not be transferred during the periods of elevation. The transfer is careful, without spillage.
5	The machine is made up of a large number of parts; many of them are small and have to be greased often, which indicates the existence of relative movements between parts in motion, and the appearance of friction.
6	The physical and structural conception of the machine is a balanced ensemble. It looks to minimize friction so that the necessary energy is as close as possible, only that required for the elevation of the water.
7	The machine is a continuous unit. It never mentions "towers" in the inventory of the officials of the Alcazar, nor in the description by Ambrosio de Morales.
8	The spoons are grouped two by two, joined by a pipe, with strange stems, that look like handles. Ambrosio de Morales estimates that a machine has 1500 spoons.
9	The machine should be able to adapt to different slopes of the land, without difficulty.
10	The transfer of the water between spoons has to follow the cadence specified in the description by Ambrosio de Morales: "The two vessels of a pipe are sometimes empty, while both sides have a full vessel, and the pipe that empties out completely later has a full vessel, and always between two full ones is a pipe with two empty vessels."

Estudios Toledanos, 6th century, Vol. 47, year 1987. An evolution of this model is the works by Nicolás García Tapia: "Technology and Supremacy". Nivola libros y ediciones, S.L. (Tres Cantos, 2002), "Engineering and Architecture in the Spanish Renaissance". Series: History and society, num. 11. University of Valladolid-Caja de ahorros of Salamanca (Valladolid, 1990).

4. Model by J.L. Peces Ventas: Constructor of models and investigator of the water machine. There is extensive information on the Internet. (Toledo, where he resided).

The models by Mr. Luís de la Escosura and Theodor Beck, according to the current bibliography, are dismissed for not being able to overcome the steep slopes of the land along the machine's route, and that by J.L. Peces Ventas is frequently cataloged as improbable.

The current bibliography uses in its descriptions the theory of the "Towers with Oscillating Spoons" model, most likely due to the entity of its postulant, Dr. Ladislao Reti, a great investigator of Leonardo da Vinci, whom the National Library commissioned to prepare the edition of the codex Madrid I and II. In any case, several doubts about its feasibility have been suggested by recent investigators, especially Mr. J.L. Peces Ventas, and Mr. Ángel Moreno Santiago, author of the book "Juanelo and his machine. Anthology", edited in 2006 (Figs. 1–6).

Fig. 1 Detail of the Arroyo Palomeque plan seventeenth cent

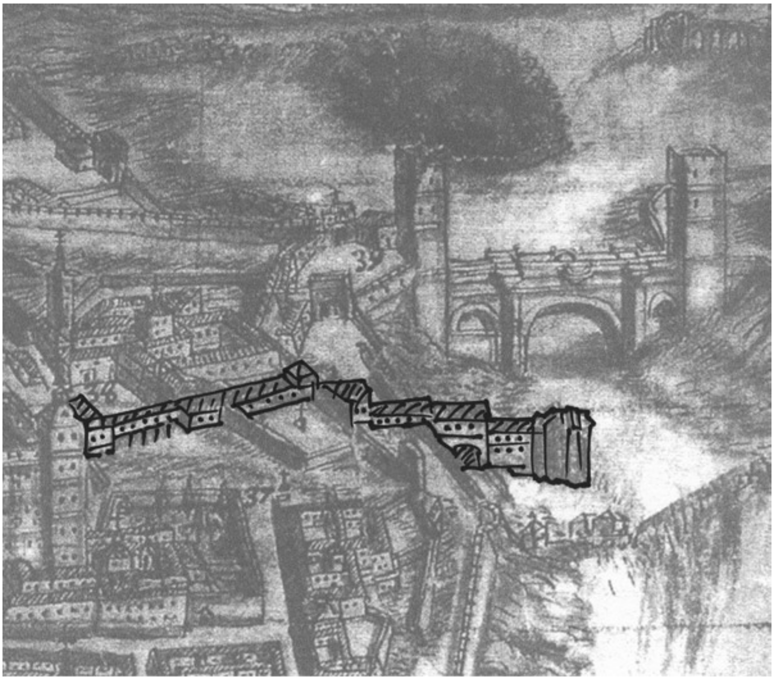


Fig. 2 Detail of the Arroyo Palomeque plan seventeenth cent. Artificio buildings highlighted

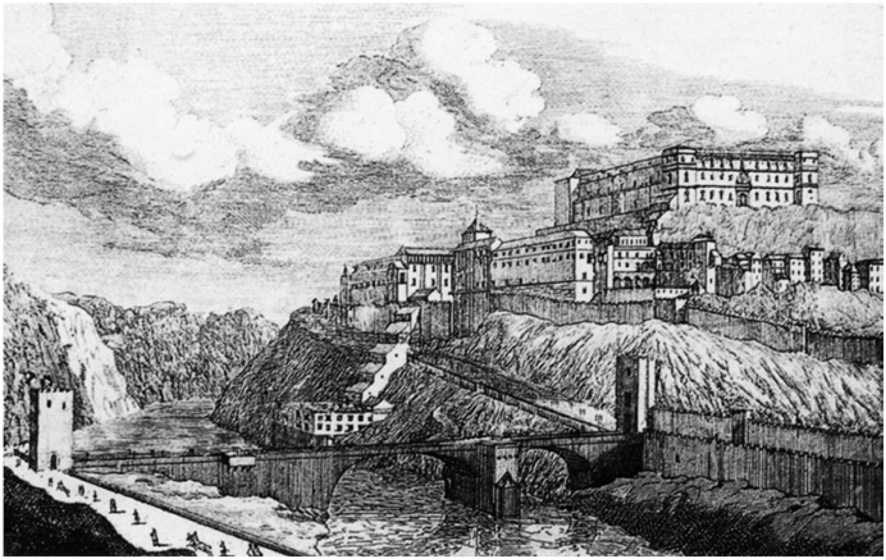


Fig. 3 Toledo engraving 1650

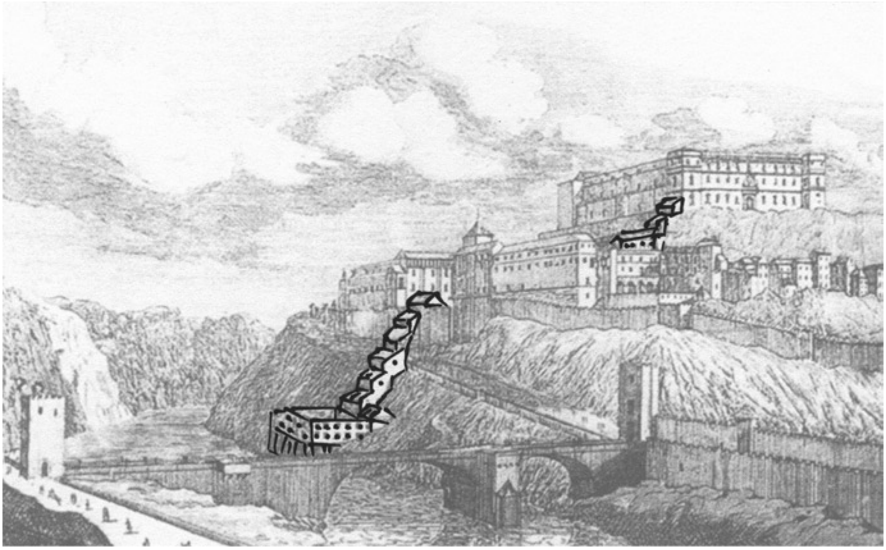


Fig. 4 Toledo engraving 1650. Artificio buildings highlighted

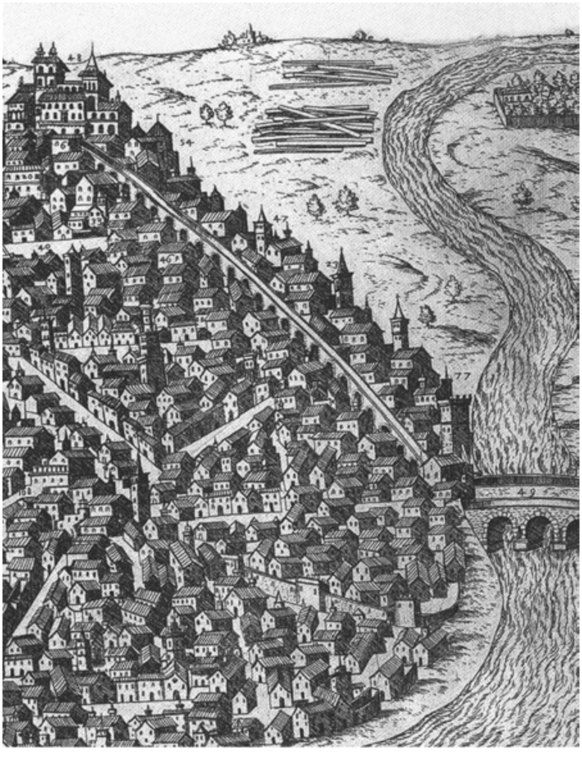


Fig. 5 Detail of the Giacomo Lauro plan 1642. Artificio represented in two parallel lines

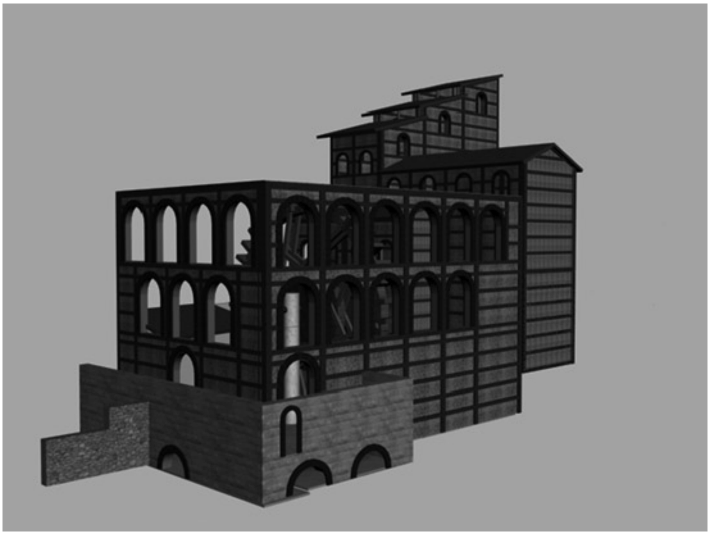


Fig. 6 Computer reconstruction of the stretch next to the river

4 Key Points that a Theory Should Fulfill

Analyzing historical documents, we identified the principal points that a theory of the machines of Juanelo should fulfill, and among all of them selected the ten principal ones, to be used to evaluate the degree of fulfillment of each one of the existing models, and to decide which of them better fits the conserved descriptions.

4.1 Description by Ambrosio de Morales

Among all the existing descriptions, none deserves more attention than that developed by Ambrosio de Morales, published in 1575, "The Antiques of the cities of Spain. Those named in the chronicle with the verifications of their locations and antique names." Ambrosio de Morales, chronicler of King Phillip II, was a cultured person and used to capturing events with the maximum accuracy possible, and also nephew to the famous humanist Fernán Pérez de Oliva, educated in the universities of Salamanca, Alcalá, Rome and Paris, who was in charge of technical development in the kingdom of Castilla.

But even more important is that Ambrosio de Morales was a friend of Juanelo, who personally showed him the model prior to the construction of the machine and, later on, the first machine finished and operating.

4.2 Description by Manuel Severim

Referring to the description of Manuel Severim in 1604, who, at the age of 21, wrote "Peregrinaçao de Baltasar de Faria Severim, Chantre de Evora, ao Mosterio de Guadalupe, no anno de 1604", held in the National Library of Lisbon, in which there appears a light drawing, that has recently been used to support the model of "towers with oscillating spoons" overall it appears to indicate that it is probably describing a modification introduced by Juan Fernández del Castillo on the shores the Tagus, surely in a trial phase. This fact is not completely strange, because the drawing contradicts the descriptions of the sixteenth century machine (Fig. 7).

Everything appears to indicate that a system of "towers with oscillating spoons" could only be found in the first section, to take up the water from the river, and that this was introduced after Juanelo's death.

The main contradictory points in the description by Manuel Severim are:

1. It observed that the tower took water directly from the river, when it is clearly known that the machine took it using a large wheel that then deposited it at the foot of the machine, various meters from the riverbed.
2. The description cited:
   "Only the first section of the machine is vertical and straight. After, it adapts to the slopes of the land, with its recesses, sometimes flatter, sometimes higher, all covered with wood and French roofing tiles, so as to warn one from the outside".

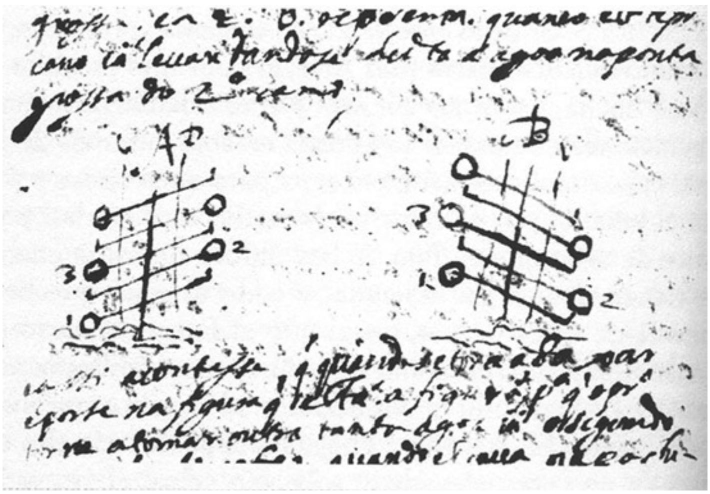


Fig. 7 Drawing by Manuel Severim

It has also been found that there are two dispositions, the initial and vertical, probably that displayed in the drawing by Manuel Severim, and that which adapted to the land, probably the original machine of Juanelo, consisting in a continuous machine located inside the existing buildings.

3. The word "tower" does not appear in the description by Ambrosio de Morales or in the inventory of the officials of the Alcazar when scrapping the machine, nor in any other description. If there was a tower with oscillating spoons, necessarily there would be specific reference to them. The maps of the city of Toledo which include the machines of Juanelo always show elements of continuous works, mostly staggered, but never discrete elements separated in towers.
4. In 1604, Juan Fernández del Castillo had already introduced modifications in sections near the river, attached to the outside walls of the buildings that safeguarded the machines of Juanelo, easily visible, and that Manuel Severim probably saw during the 4 days he was in Toledo.

4.3 Key Points that a Machine Theory Should Fulfill

A model that tries to reproduce the machine should respect the description of Ambrosio de Morales, take into consideration the official files (contracts between Juanelo, the king and the city of Toledo, assessments, lists of material for repairs, lists of material referring to the scrapping of the machine…) for its objectivity, and to evaluate all the remaining information, keeping in mind that the machine suffered modifications at the beginning of the seventeenth century.

Under these premises is a list of 10 key points that a machine model should fulfill, and that will be used to evaluate the known theories, as well as those next presented in this document.

Key points that a machine model should fulfill:

1. Should be based on the Valturio stairs.
2. It can not be a simple machine; its conception is intrinsically complex.
3. The complexity of the machine is founded on arithmetic, needing for its design, numerous calculations.
4. The elements that transport water should pause in order to carry out the transfer, while the rest of the machine remains in motion. Water will not be transferred during the periods of elevation. The transfer is careful, without spillage.
5. The machine is made up of a large number of parts; many of them are small and have to be greased often, which indicates the existence of relative movements between parts in motion, and the appearance of friction.
6. The physical and structural conception of the machine is a balanced ensemble. It looks to minimize friction so that the necessary energy is as close as possible, only that required for the elevation of the water.

7. The machine is a continuous unit. It never mentions “towers” in the inventory of the officials of the Alcazar, nor in the description by Ambrosio de Morales.
8. The spoons are grouped two by two, joined by a pipe, with strange stems, that look like handles. Ambrosio de Morales estimates that a machine has 1500 spoons.
9. The machine should be able to adapt to different slopes of the land, without difficulty.
10. The transfer of the water between spoons has to follow the cadence specified in the description by Ambrosio de Morales: “The two vessels of a pipe are sometimes empty, while both sides have a full vessel, and the pipe that empties out completely later has a full vessel, and always between two full ones is a pipe with two empty vessels.”

5 New Model with Valturio Stairs

5.1 General Aspects

A water machine or machine also called a stair, because from a distance that is what it looks like, has four independent lifts of little spoons, called orders. These are paired, and each pair forms a channel or water lift. When the machine reached the Alcazar, it sprouted two water pipes, one corresponding to each channel, supplying a total of 16,320 l/day according to the assessments made in Toledo in 1585.

The water lifted 90 m high from the river to the Alcazar, alternating sections of steep slopes with other flatter ones, and route of approximately 306 m in length. The cross section and layout of the machines are known.

The water machine was a continuous element that transported the water at atmospheric pressure, covered completely and protected by a staggered construction that cleaned the water during its journey to the Alcazar, and sheltered it from the weather, and possible theft of valuable material like copper and brass.

The machine by Juanelo started at the shore of the river where a dam, of which today one can still see ruins, favored the small water fall that was indispensable for giving the force necessary to two hydraulic wheels that brought the water and power required by the machine.

5.2 Basic Construction Unit

A machine was the concatenation of water transportation units that linked together from the river to the Alcazar, of identical conception but with slight variations based on the slope that it had to overcome (Figs. 8 and 9).

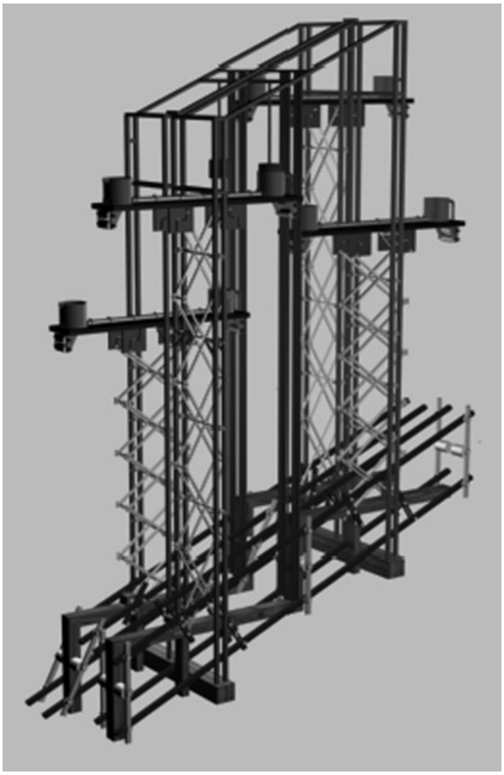


Fig. 8 Water transportation unit

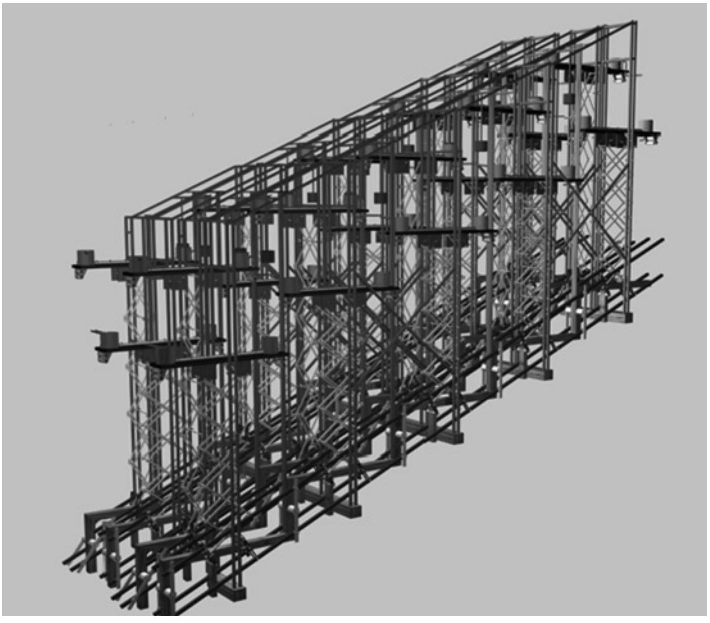
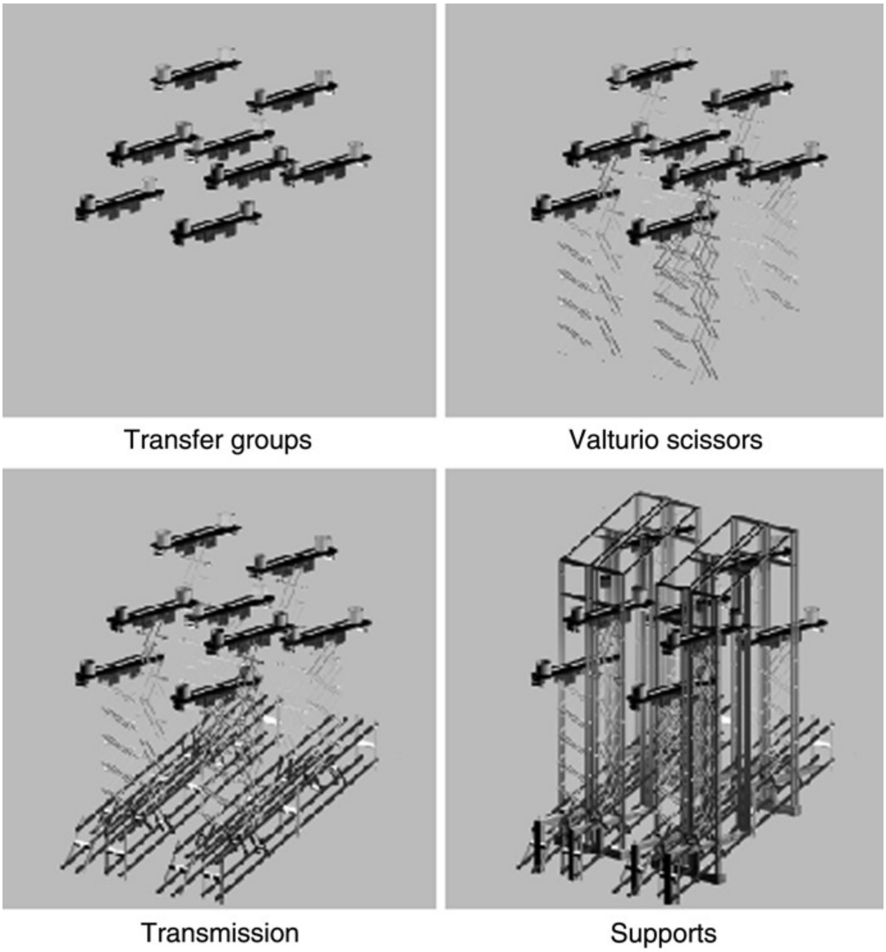


Fig. 9 Section of the machine

In a repetitive water transportation unit and therefore, in a machine, four large groups of parts can be identified:



The transfer groups carry out the exchange of water between spoons, allowing its movement upstream.
The Valturio scissors lift and drop the transfer groups cyclically.
The transmission transfers the energy obtained by the hydraulic wheel of the river to all the machine's elements.
The supports sustain and stabilize the other elements of the machine.

5.3 The Route of the Water

Each scissor (Valturio stair) lifts or descends two spoons joined by a brass pipe (transfer group).

When the scissors are extended and its transfer group at the highest part of its route, it pauses to deliver the water to the next transfer group that is at its lowest position, with its scissor retracted and paused.

Next, the cycle of movements continues, and the retracted scissors extend themselves and the extended one retracts in order to start the process for a new exchange of water between transfer groups.

In each exchange, the water advances along the machine moving up the ladder.

Due to the existence of two possible designs of actuators (elements that open and close the scissors), there are two equally valid hypotheses of how the water should circulate between the transfer groups of the different controls of the machine.

Hypothesis 1, Transfer in zigzag: The water flows between controls of a water channel.

Hypothesis 2, Transfer in a straight line: The water flows only through a control of a water channel.

Both transfer hypotheses fulfill the requirements of the referenced documentation, especially that referred to by Ambrosio de Morales:

"The two vessels of a pipe are sometimes empty, while both sides have a full vessel, and the pipe that empties out completely later has a full vessel, and always between two full ones is a pipe with two empty vessels the two vessels of a pipe. This is the sum of the machine."

5.4 The Water Transfer Groups

The advancement of the water loads is achieved thanks to the coordination of up and downward movements, of the multiple groups formed by two spoons and the pipe that join them (transfer groups).

Its principal characteristics, based on the existing documentation, are:

Total length of a transfer group: 160 cm
Total number of transfer groups in a machine: 768
Total number of spoons in a machine: 1,536
Volume of a spoon: 7.5–8 l
Cadence: 23 cycles/h – In each cycle, a transfer group carries out:

First movement: Moves to the highest point.
Second movement: At its highest point, it pauses and delivers the water to the next transfer group (extended Valturio scissor).

Third movement: It descends to the lowest point.
Fourth movement: At its lowest point, it pauses to receive water from the preceding transfer group (retracted Valturio scissor).

In addition to the two spoons and the pipe, the transfer groups also have a siphon, trackers and an overflow hole that are described in other sections. All these parts rest on a wood table called a shed that props up the entire group to stabilize it (Fig. 10).

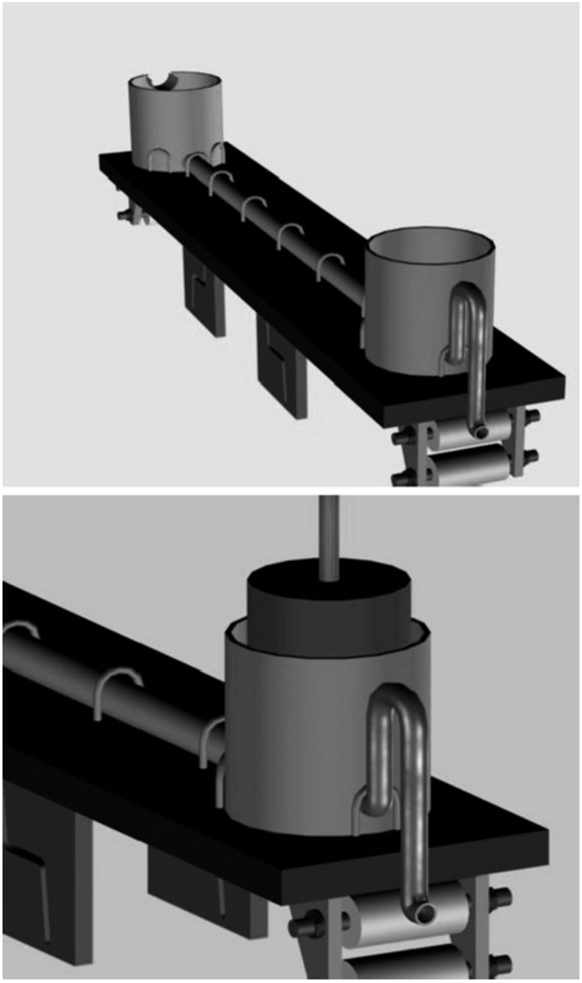


Fig. 10 Transfer group with spoon and siphon and spoon with siphon plus overflow hole

5.5 *The Upward and Downward Movement of the Transfer Groups*

Ambrosio de Morales narrates in his chronicles that the method to raise and lower the transfer groups is:

"The sum is to attach small pieces of wood crossed in the middle and on the ends in the Roberto Valturio manner; this is a machine for raising man to another level, although Juanelo has new qualities and subtleties."

In the 11th book "De Re militari" by Robertum Valturium, (Paris, 1483), page 259 includes a description on Valturio scissor by Valturio.

In the machine model presented, the Valturio stairs or scissors are made up of crisscrossed strips, whose feet move horizontally, opening or closing the scissor, provoking the upper plane where the transfer groups are located to raise or lower, always maintaining verticality.

All the scissors of the model are equal in dimension:

"l": longitude of the scissor strips = 700 mm
"n": number of blades or crosses of the scissor = 5 u.
"α": initial angle of the opening of the blades in their retracted position in relation to the horizontal plane. For any scissor along the route "α" = 40o, regardless of the slope of the land.

With these variables set, it is only necessary to estimate angle "β" of the final opening of each scissor in its raised position, which can be found based on each one of the slopes of the land that it must overcome because all the scissors along the route are identically built, and in their retracted position pause with the same initial angle "α". For example, in slopes of 20%, "β" will be 50o, allowing the lift of the transfer groups of each scissor 43 cm, which is the drop of the land between two transfer groups. In slopes of 40%, "β" will be 60o, allowing the lift of the transfer groups of each scissor 75 cm (Fig. 11).

5.6 *The Exchange of the Water*

Ambrosio de Morales describes that during the water transfer between the transfer groups of different scissors, there is a pause while the rest of the machine completes the cycle of repetitive movements. Once the water is exchanged, the transfer groups start up again and return to the machine's dynamics.

A solution is proposed that consists of a system made up of siphons, overflow holes and trackers, for the water exchange.

Rendering the siphon, an element that affects the speed of the water transfer, gives the following time tables (Table 3):

To clamp on the siphon, an overflow hole, a fixed and solid part of the machine's structure, is placed inside the transfer group's spoon with a siphon, causing a slight increase in the water level.

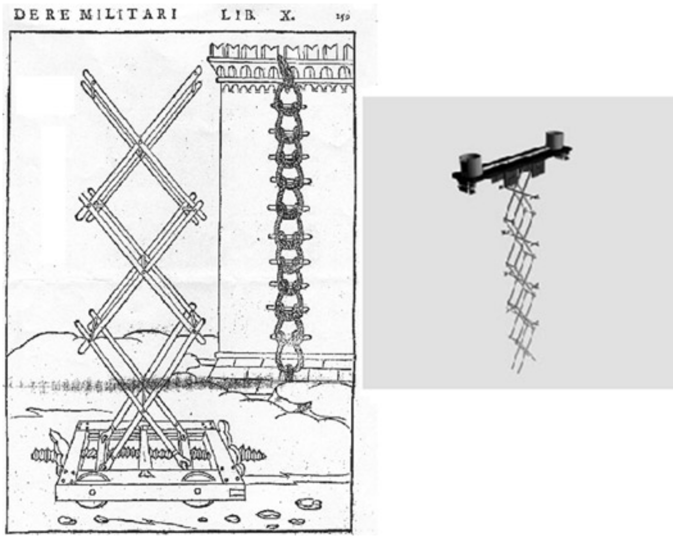


Fig. 11 Extended Valturio stair and scissor with transfer groups

Table 3 Total time of a complete transportation and transfer cycle

Movement	Time (s)
Receive water from the previous transfer group.	17
Pause of spoons and pipe group.	
Movement of the transfer group from their lowest to highest position.	61
Movement of spoons and pipe group.	
Deliver water to the next transfer group.	17
Pause of spoon and pipe group.	
Movement of the transfer group from their highest to lowest position.	61
Movement of spoon and pipe group.	
Total time.....	156

The trackers together with the feelers make up the equipment necessary to pause the transfer groups, when it receives or delivers water while the rest of the machine continues moving. There is the possibility of achieving a similar but less precise effect, using some type of elastic joint between the head of the scissors and the transfer group. This elastic joint would be the equivalent to a spring, although according to the technology of the time, a laminated element would adapt better, like the springs in the suspension of some of today's automobiles (Fig. 12).

When the feeler moves along the horizontal parts of the groove of the tracker, the transfer group raises or lowers together with the scissor. (The horizontal part of the groove absorbs the closure or opening of the ends of the scissors, when raising or lowering).

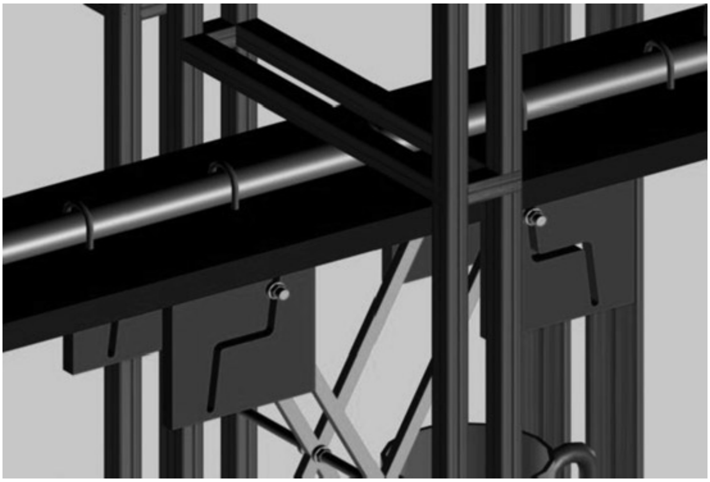


Fig. 12 Trackers and feelers

When the feeler moves along the vertical parts of the groove of the tracker, the transfer group remains immobile while the ends of the scissor raise or lower. (The vertical part of the groove absorbs the movement of the ends of the scissors).

5.7 Transmission and Actions

It is necessary to have a transmission that distributes the energy generated by the river's hydraulic motor wheel to each one of the bases of the scissors for the movement of the machine. This creates a transmission of strained braces (Fig. 13).

The transmission braces remain parallel thanks to the rockers.

The driver is the group of parts that acts as a connection between the transmission braces and the scissors. The most representative element of a driver is the actuator. There are two types of actuators, the rocker type and the blade type. The hypothesis of lineal water transfer uses rocker and blade type actuators. In the hypothesis of zigzag water transfer, only rocker type actuators are used.

The union between the center of the transmission rocker and the machine's bedplate is generally produced half-way up the bedplate, although for slight slopes, it is necessary to lift up the bedplate to avoid rockers that are too small (Fig. 14 and 15).

On the horizontal part of the bedplate, there are horizontal grooves that support the base of the Valturio scissors with a pin. When the scissors open or close the pin

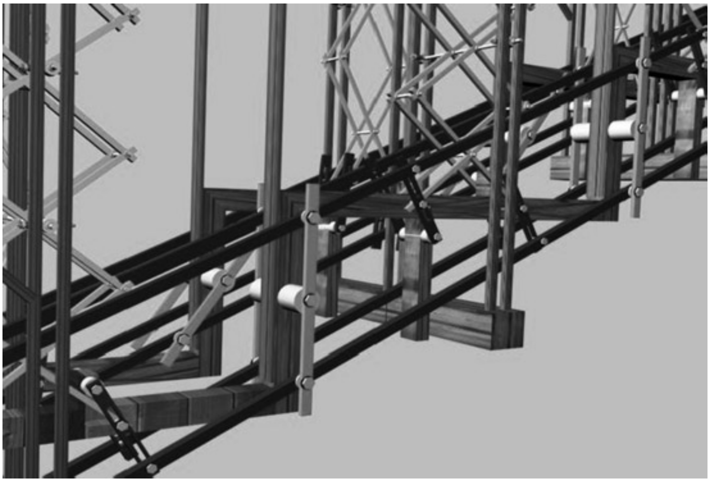


Fig. 13 Transmission of strained braces

slides inside this groove. The pin is the joining element between the scissor, the actuator and the bedplate.

It is necessary for the movement to reach the transmission brace, to the pins of the base of the scissors, making them open and close, but the transmission can not be directly joined to the base of the scissors, because depending on the slope of the land, the opening of the base can be different. The actuator is used as a mechanical part that allows the union between the transmission and the scissors, adapting and transforming the horizontal movement of the brace, in the horizontal movement necessary at the base of each scissor. When the transmission braces move, they also make a vertical movement that will be absorbed in the actuator's groove (Fig. 16).

For each slope of the land, the actuators dimensions, bedplate and actuators grooves, and the joint of the actuators to the bedplate should be calculated.

To characterize the machine model presented, the essential parameter of rotation of the rockers of the transmission is set for its back and forth movement, estimated at 35o. With this value defined, the longitudinal movements of the transmission brace can be calculated for any type of slope, and all the characteristics of the actuators, pins and grooves of the machine can be dimensioned, giving reasonable and mechanizable values.

If the water transfer is zigzag, all the actuators will be of rocker type. The water exchange is more difficult when jumping between orders and the symmetry of the machine is made as a group but not in each order. The rocker type actuators allow a better control of the movements of the base of the scissors, than the blade type actuators.

If the water transfer is lineal, the actuators are of the two types, rocker and blade. The water exchange is easier when not jumping between orders, and the symmetry

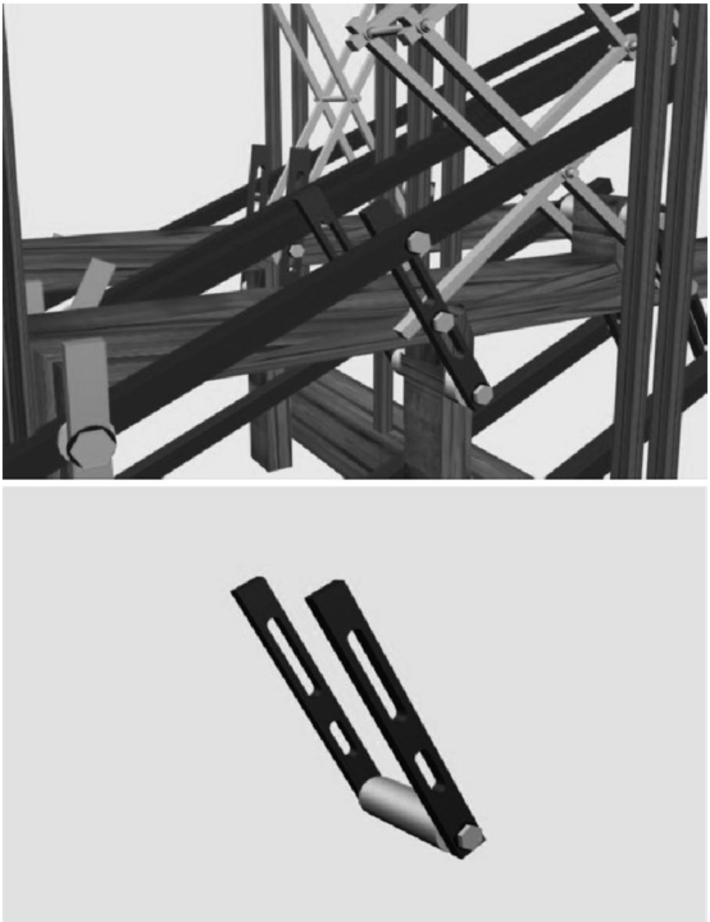


Fig. 14 Driver with rocker type actuator and rocker type actuator

and balance achieved is greater. The control of the movement of the base of the scissors is more complex for not being so precise.

5.8 Supports and Stability of the Group

Of vital importance are the balance and the symmetric distribution of efforts and tensions of the entire machine in order to obtain minimum friction and compensate weights, so that the energy necessary to move the entire group decreases. For this purpose, the model implements:

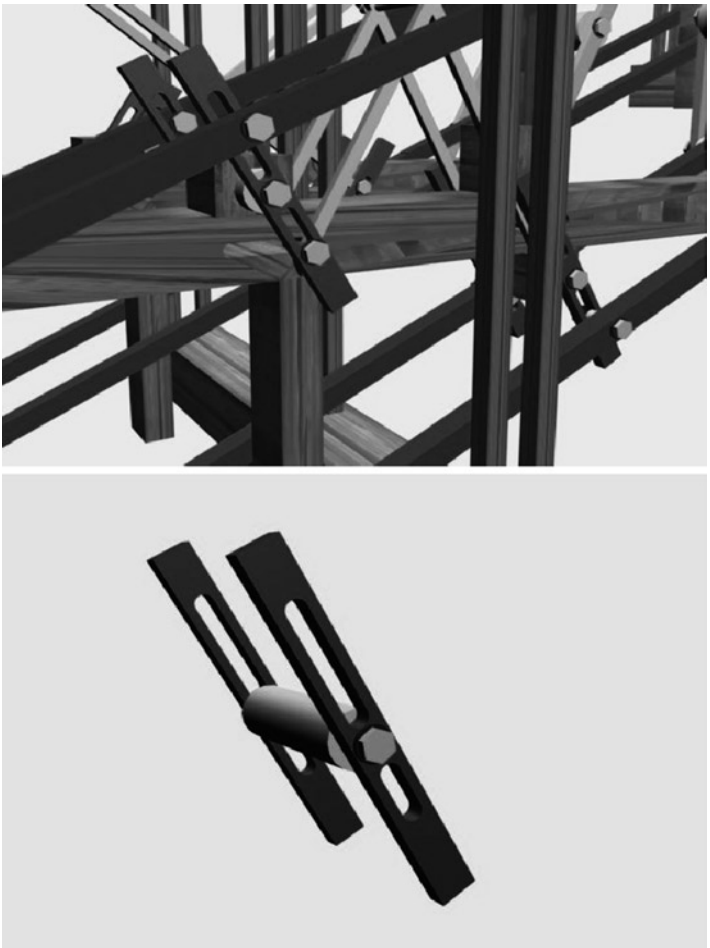


Fig. 15 Driver with blade type actuator and blade type actuator

1. The scissors are double, giving lateral stability, and are guided in their up and downward movements.
2. There is the possibility of the existence of two lines of transmission in each water order, so that each Valturio scissor would be moved on both sides.

For the whole machine to act as a robust and solid group, the structural elements are interconnected.

There are a large number of parts with friction between them, the correct greasing and continued maintenance of the machine is indispensable, as shown by the officials of the Alcazar in their documents:

> "…and ordinarily grease is used to oil the axles and springs and other things that move" (Fig. 17).

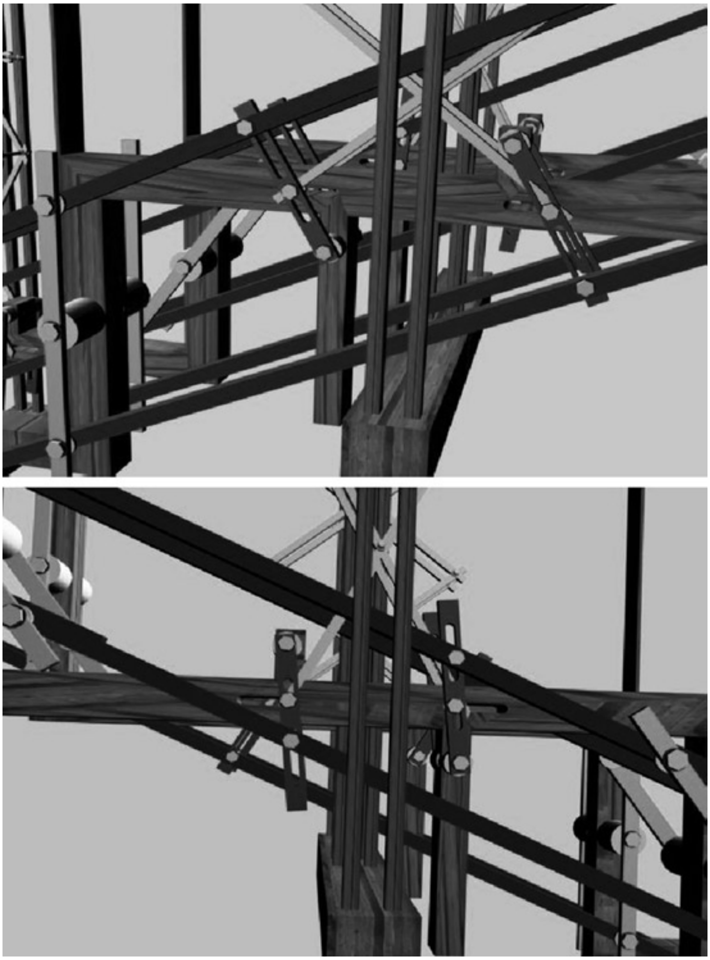


Fig. 16 Open scissor with rocker type actuator and closed scissor with rocker type actuator

6 Singularity and References of the Machine's Technology

The chronicle of Ambrosio de Morales makes it clear that the spirit of the machine resides in the difficulty existing in the design and calculation of the machines and its components, and in the ability of the entire machine moving in harmony, respecting the group's balance, the cadence of movements and the distribution of time, leaving behind of the purely mechanical conception typical of the period, making it a machine that was technically innovative and groundbreaking in its design, known throughout Europe.

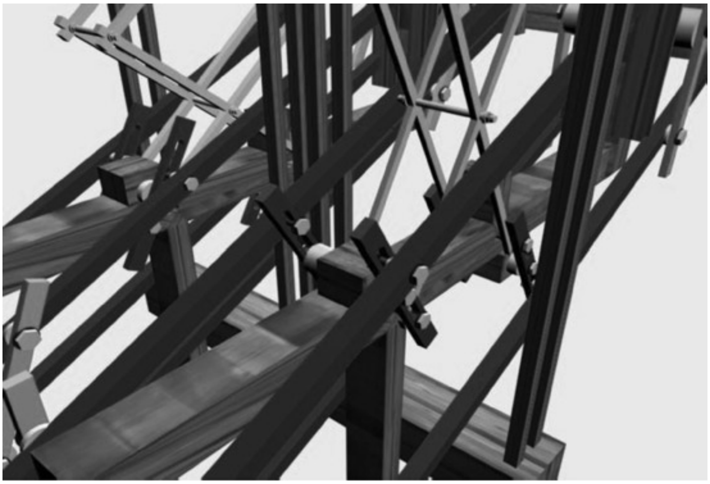


Fig. 17 Double transmission for double scissor

Surely this particular conception of the machine is the difficulty to overcome in trying to find references for its mechanical solutions in other machines, not being solved by consulting machines made by other contemporary engineers.

Finding similar mechanical solutions in other machines would support the feasibility of the Valturio stairs model. These references could be found in other machines built by Juanelo, but unfortunately none remain today.

With this perspective, the search was proposed for machines that although not made by Juanelo, he could have intervened in their creation or maintenance. Juanelo Turriano was a master Renaissance clockmaker, his mechanical solutions in the machines would make one think that they were inspired by clock making mechanisms (if they are not completely novel technical innovations), and not by hydraulic constructions.

Based on this premise, and knowing that Juanelo studied the Astrarium of Giovanni Di Dondi, which later inspired him to build emperor Charles V the "Big Clock", (the most complete and exact astronomical Renaissance clock known to man), and we can relate mechanical implementations of the machines with mechanical constructions used in the Astrarium.

The conclusions found show that Juanelo used his knowledge of clock making to create the Water Machines of Toledo, especially for the movements between parts. This provoked a design of water machines, totally different from those known for transfer and elevation of water and, at the same time, required that the designer have a very solid mathematical base, for the necessary calculations.

7 Three-Dimensional Computer Simulation

To visualize the proposal model of the Juanelo machine with Valturio stairs, it has been reproduced in computer animation to scale and in 3 dimensions. It also reproduces the operation of the Mercury dial of the Astrarium, in fast mode, to observe the related movements between parts.

You can find the images and animations at: www.artificiodejuanelo.org (Fig. 18).

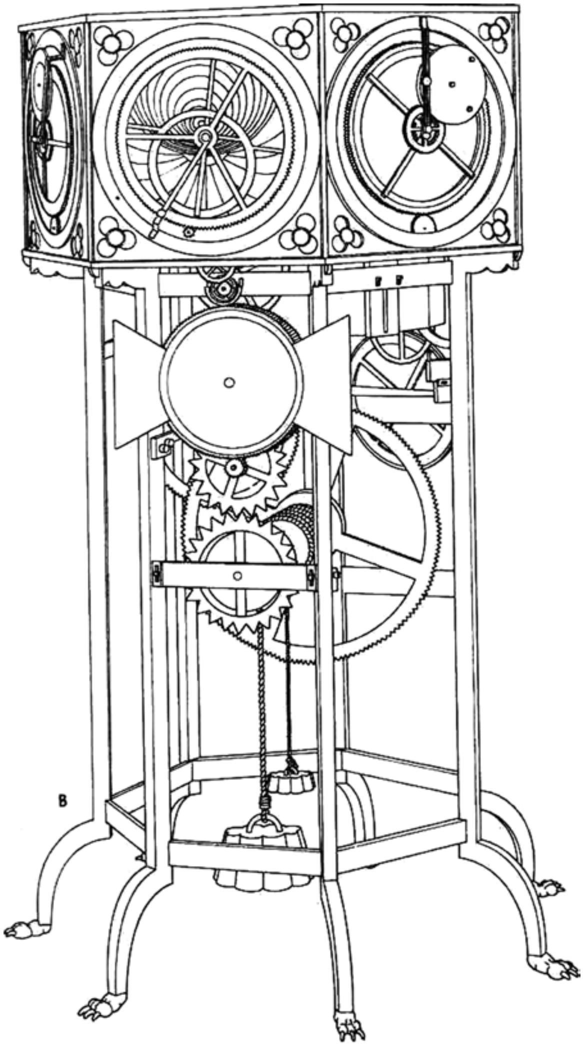


Fig. 18 Astrarium and virtual reconstruction of its Mercury dial

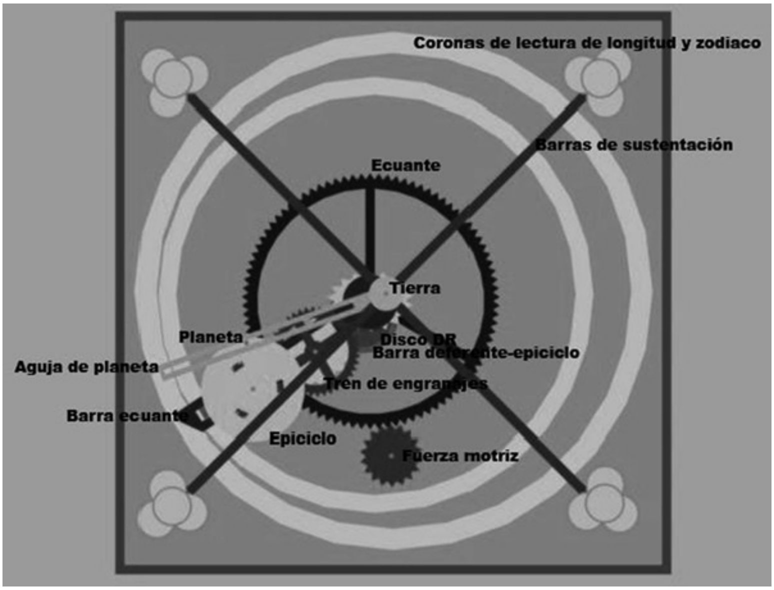


Fig. 18 (continued)

Table 4 Evaluation of the degree of fulfillment of the key points

Evaluation	
A	High fulfillment
M	Medium fulfillment
B	Low fulfillment

Table 5 Evaluation of the 10 key points that a machine model should fulfill

Key points		Oscillating spoons	Valturio stairs
1	Valturio stairs	M	A
2	Complex conception	M	A
3	Numerous calculations	B	A
4	Pause of elements during the water transfer	B	A
5	Numerous parts and interrelated movements	M	A
6	Balanced, symmetric group	M	A
7	Continuous unit	B	A
8	2 spoons and pipe, strange stem, 1,500 spoons per machine	M	A
9	Machine should adapt to the slopes of the land	A	A
10	Water transfer according to cadence defined by A. Morales	A	A

Summary of the comparative study

Model		A	M	B
1	Tower with oscillating spoons	2	5	3
2	Valturio stairs	10	0	0

8 Conclusion

With the new model of Valturio stairs presented, a comparison is made with the model of the tower with oscillating spoons, evaluating the correct fulfillment of the 10 key points, with the goal of estimating which of them offers a better approximation (Tables 4 and 5).

The conclusion is that the new model with Valturio stairs comes closer to the historical texts, and especially to the description of Ambrosio de Morales.

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A Mystery of One Havana Portrait: The First Steam Machine in Cuba

Olga V. Egorova

Abstract An iconographic detail as well as some archive documents help us to prove that the first steam machine, or the "bomb of fire" as it was called in the eighteenth century, introduced in Cuba in 1797, was constructed according to the project and under the direction of the father of modern engineering in Spain and Russia, Agustin de Betancourt y Molina who was not only a great inventor and engineer, architect and city constructor, but also one of the founders of science "Theory of Machines and Mechanisms" (TMM). He was born on February 1, 1758, on the island of Tenerife and during his life managed to visit many countries – France, England, Germany, Russia, but he never came to Cuba. However he figured prominently in the development of innovative technical ideas of the Island.

1 An Iconographic Detail

In a corner of the "Plaza de Armas" (Weapons Square) (Fig. 1), the most ancient part of Havana, there stands the Palace of Captains-Generals (Fig. 2), an important example of civil architecture of the eighteenth century. It was designed by the famous Cuban engineer and architect Antonio Fernandez de Trebejos, and was constructed under the guidance of the Captain-General Felipe de Fonsdeviela, Marquis de la Torre, a notable Governor and urbanist .

Many years passed before the Palace was opened in 1791 by the Marquis de la Torre's successor, illustrious Spanish, Don Luis de las Casas-and- Aragorri (1745–1800), the best Governor that Cuba ever had and the one who contributed much to the prosperity of the country (Fig. 3).

Among the most interesting collections in one of the second floor rooms of the Palace of Captains-Generals – today the Museum of the City of Havana – we can

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Fig. 1 Plaza de Armas

find a portrait of Ignacio Pedro Montalvo y Ambulodi (1748–1795), the first Count de Casa Montalvo. The potrait (Fig. 4) was painted by Creole Juan del Río, probably about 1794 or 1795, shortly before the Count's death. This important and noble figure was born in Havana and later became one of the founders of the Royal Economic Society of Friends of the Country (Real Sociedad Económica de Amigos del País – SEAP).

The Count de Casa Montalvo was considered to be one of the most powerful and influential landowners of his epoch, possessing not less than 9 sugar-mills (ingenios), 500 slaves, 5,500 knighthood of ground (73,700 ha) and 14,000 head of cattle. Seibabo and Montalvo villages, placed to the southeast of the capital in the most fertile plains, between San Antonio-de-las-Vegas and San Jose-de-las-Lajas towns, was part of his property (Cornide 2003).

In the legend placed in the lower part of the portrait and briefly defining the subject we read:

> Mister Don Ignacio Montalvo de Ambulodi Count de Casa Montalvo, Honorable Gentleman of Chamber of His Majesty and Brigadier of the Royal Armies. Colonel of Regiment of Dragons of Matanzas Village, Caballero of the Order of the Saint Jacob and the first named by the King prior of the Royal Consulate of this Island. Fellow (Full member), Royal Economic Society.

Fig. 2 Palace of Captains-Generals

While viewing the portrait we should notice one attractive detail – an incomprehensible drawing that the figure of the Count indicates with his right hand. What mystery does it keep? More attentive investigation helped us to prove that it is a drawing of the first steam machine, or the “bomb of fire” as it was called in the eighteenth century, introduced in Cuba in 1797, and the one that was constructed according to the design and under the direction of the father of modern engineering in Spain and Russia, Agustin de Betancourt y Molina.

We could easily compare the machine made by Betancourt by his own hand (Fig. 5) and presented to the Academy of Science in Paris, with the drawing on the portrait of Count de Casa Montalvo and determine that they are almost of the same shape (Fig. 6) (Egorova 2010).

It was not insignificant that the drawing of the steam machine was put in the corner of the portrait; it represented the lineaments of the painter and his epoch. Among the most famous colonial plastic artists of the time, the Creole Juan del Río (1748–18.?) was known as a painter of religious matters and a good portraitist. He was believed to be a student of Vicente Escobar, but it is also true that in his pictures

Fig. 3 Luis de las Casas y Aragorri

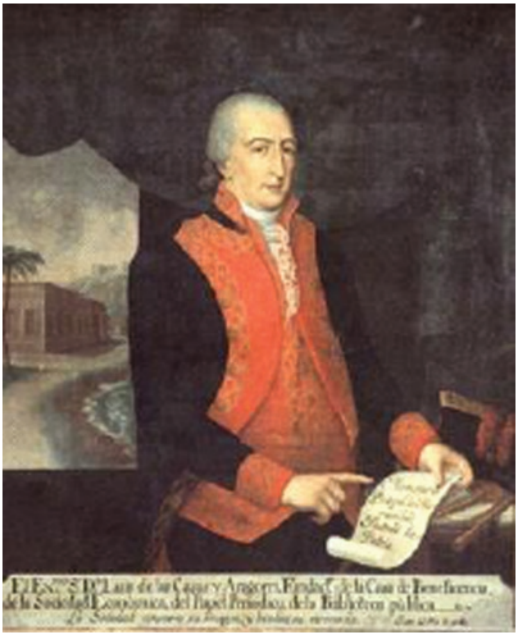

Fig. 4 Count de Casa Montalvo

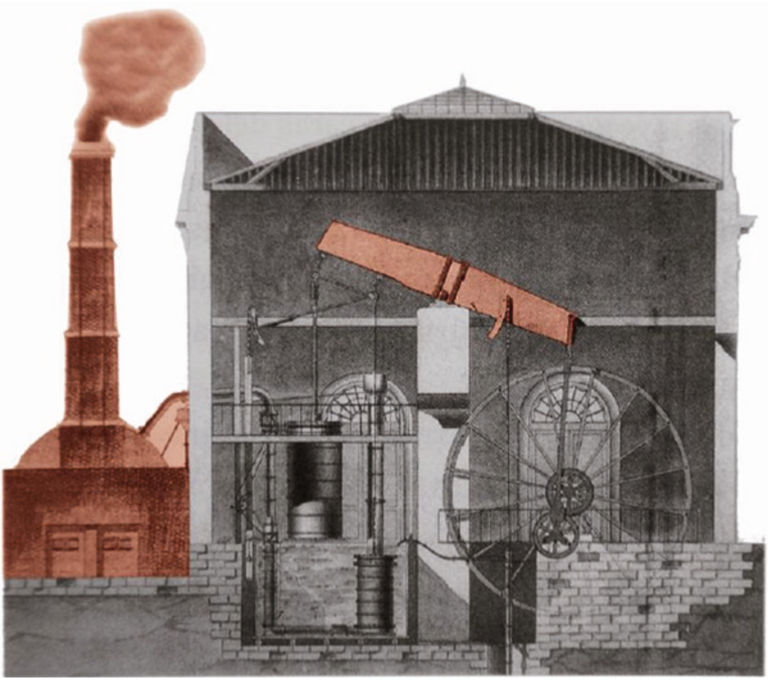

Fig. 5 Vapor machine made by Betancourt

Fig. 6 Drawing on the portrait of Count de Casa Montalvo

he shows a style quite different from his supposed teacher. The first del Rio works we know of are dated in the last decade of the eighteenth century. Unquestionably, his primary masterpiece is the wonderful and eloquent portrait of Luis Ignacio Caballero. Not coincidentally the Royal Society (SEAP) considered Juan del Río to be their chief portraitist and ordered him to paint the portraits of the most powerful Havana personalities: Governor, Bishop and noble members of the aristocracy.

It is known also that the lineaments of the Creole painter who signed the foot of his works: "Juan del Río painted it", were reproductions of some very important subject, or object, or symbol of the person he portrayed. For example, on the portrait of Don Luis de las Casas, who had ruled since 1790 up to 1796 on the Island, there appeared a rendering of the Royal Welfare Home, later known as the Royal Consulate of Agriculture, Industry and Commerce, which Don Luis founded. Another del Rio painting, also kept in the Museum of the City, is the portrait of Salvador del Muro y Salazar, Marquis de Someruelos (1754–1813), Captain-General from 1799 up to 1812, who is represented along with shelves of books. It is legendary to us that this Marquis was the founder of the Public Library and headed it for 12 years and 11 months.

So we can say that the above mentioned iconographic details, very typical of the Enlightenment epoch and of Juan del Rio in particular, help us to clarify not only some biographical and genealogical information, but also some historical facts, as it is the case of the first steam machine introduced in Cuba.

2 Brief Biography: Agustin De Betancourt in Spain and France

Agustin José Pedro del Carmen Domingo Candelaria de Betancourt y Molina (that is his full name) (Figs. 7 and 8) was born on February 1, 1758 in Puerto de la Cruz (Tenerife, Canary Islands, Spain) in a noble and aristocratic family. From 1778 to 1784 he studied in Madrid at the school named "Reales Estudios de San Isidro" and currently at the Royal Academy of San Fernando, where the world famous romantic painter Francisco José de Goya y Lucientes (1746–1828) studied at the same time (García-Diego 1985).

In March 1784, as a capable student, Betancourt was sent to Paris where he participated in the activity of the School of Bridges and Channels (École des Ponts et Chaussées). But very soon he went back to Madrid and, after an interview with the Secretary of State Don Jose Monino, the Count de Floridablanca, he was asked to establish in Spain a new school, namely, the School of Roads and Channels (Escuela de Caminos y Canales).

The agreement with Floridablanca included also the following tasks (AHN 4088):

– select students for the "École des Ponts et Chaussées" in Paris, where they could in future obtain the degree of Hydraulic Engineers;
– educate and train experts in mechanical engineering;
– collect models and drawings of machines that were known at that time and used in industry, agriculture, transport and other fields.

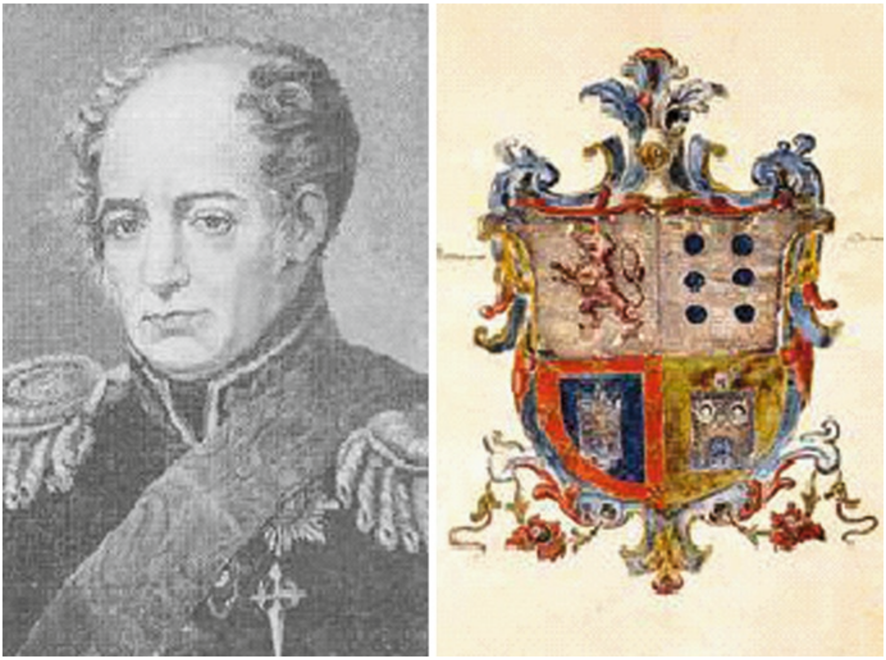

Fig. 7 Agustin de Betancourt and his family coat of arms

Fig. 8 Alexander I, Emperor of Russia

To fulfill the agreement, on September 10, 1785, Betancourt went again to Paris, where he was warmly welcomed by the Director of the above mentioned School – Jean Rudolf Perrone (1708–1794) and Professor of the School – Gaspar François de Prony (1755–1839).

One day in April, 1788, the Spanish ambassador, the Count Fernan-Nunez, who on occasion visited Betancourt's home-workshop in Paris, was so impressed with the great number of scale models of machines and engines, collected and built by Agustin, that later in his letter to the Secretary of State, dated 23 April, Fernan-Nunez proposed the creation of a Royal Cabinet of Machines in Madrid on the base of this collection (AHN 5910–5990).

In 1791, in view of the unstable situation in France, the king of Spain Carlos IV decided that Betancourt should return home, to Madrid, and that he should bring with him all he had as an assemblage. The whole collection was received in Spain between July and September and in April 1792 the Cabinet, located in the king's house "Palacio del Buen Retiro", was opened to the public. On the 14th of October Betancourt was officially appointed as the Director of the Royal Cabinet of Machines. The whole collection was composed of 271 models, 359 drawings and 99 memoirs, and a vast library of rare books and manuscripts. Thus, the first-ever world museum on Science and Techniques History was established.

By the end of the eighteenth century Betancourt was already considered to be one of the greatest and best-known engineers of Spain. In 1802 he was appointed to the position of Chief Inspector, and also established the School of Roads and Channels, which was located at the Royal Cabinet of Machines. From 1802 to 1807, he worked at the School of Roads and Channels, the Royal Cabinet of Machines and the General Inspectorate of Engineers of Roads corps.

3 Activity in Russia

In October 1808 because of the unstable political situation in Spain, complicated family reasons or other causes, Agustin de Betancourt moved to Russia to work under the auspices of Emperor Alexander the First (Fig. 8) by the Czar's private invitation. After his arrival he was accepted in November 1808 into the Russian military service and was appointed to the rank of General-Major. In Russia, Betancourt exerted great efforts to develop, successfully, an engineering framework through a number of activities in designing, teaching, and organizing in many fields of engineering until his death in 1824 in Saint Petersburg. Betancourt's activities were fully appreciated and still today there is a great admiration for him in Russia (Egorova and Ceccarelli 2006).

The beginning of Betancourt's activity in Russia coincided with his 50th anniversary. He came to a new country with all his family: wife Anna, three daughters and son – Carolina, Adeline, Matilda, and Alfonso.

It is known also, that a year before, in November 1807 under the recommendation of the well-known Russian diplomat Ivan Mouraviev-Apostle who was the Secret Adviser of Foreign Affairs Colleague and the Envoy of Russia in Madrid from 1802 to 1805, Betancourt visited Russia for the first time in order to get acquainted with a new (to him) country and to discuss an opportunity to join the Russian Military service. He was received by Count Nikolav Rumyntcev (Minister of Commerce from 1802 to 1811 and Minister for Foreign Affairs from 1808 to 1812) with great courtesy and a little later presented to the Emperor for a private audience (Russia and Spain 1997). It is obvious that for Betancourt, a nobleman, the attitude toward him on the part of high-ranking officials and the Russian Czar in particular played an important role and was quite possibly the determining factor in his choice to move to Russia.

It is difficult in a short article to estimate the heritage that was left by Betancourt to his new motherland – Russia. Even an enumeration of the towns (Tsars Selo, St-Petersburg, Tula, Kazan, Warsaw, Tver, Moscow, Nizhniy Novgorod) where Betancourt's projects have been built can give us only a limited image of it. For 16 years he preside over a staggering number of engineering projects; he invented a mechanical dredge with a steam engine for clearing Kronshtad port water area, improved the army industry, designed and built bridges using a new system of arches, etc. Being a talented engineer and a great organizer he tried in his own words, to turn Russia into one of the most advanced countries of that time.

In 1817, according to his design, the Riding-School of Parades (Manege) was built in Moscow (Fig. 9) with the sizes inside the walls 166.1 by 44.7 m (Betancourt 1819).

He offered an original design of an overlapping construction made from wooden rafters. The arena had no inner support, and the rafters in lengths of 44.86 m supported the entire space. Such an engineering design was unique at the time. On the 30th of November, the same year, the Manege was opened for public and social celebrations. Its area consisted of about 7,500 m^2 and could hold more than 2,000 people. Betancourt's contemporaries wrote that "in formidability, in architecture and designs of a roof precisely are not present in Europe similar" referring to the unusual combination of wood and metal that gave to the design durability and simplicity (Egorova 2006).

Betancourt-engineer developed special fixing elements due to which two details from a wood did not adjoin among themselves. The innovation consists that on the end of every rafter had been used a tip from the bleached iron that interfered direct

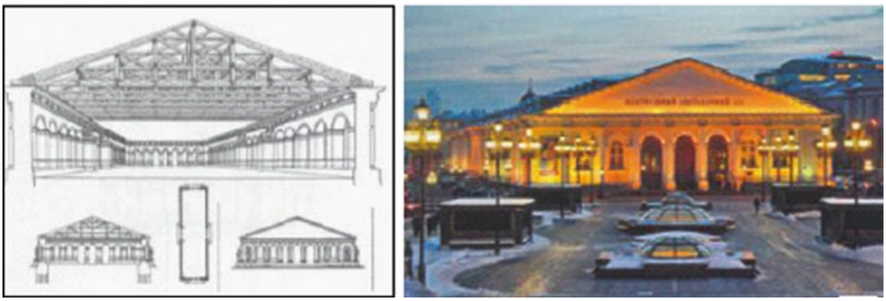

Fig. 9 Moscow Riding-School (Manege)

Fig. 10 Moscow Manege today

friction of wood in other parts of a sup-porting arch. Betancourt had taken advantage of his own experience of building the Kamenoostrovsky Bridge over the Malaya Nevka River in Saint Petersburg where he had connected seven large wooden arches with similar elements.

In his Manege design Betancourt tried to exclude all possible risks which could arise in the future, for example the likelihood of flooding because of a very close Moscow-River location. So, he ordered the base to be deepened by 4 m and the walls to be made thicker at the bottom. The roof of a particular building had been specially designed under asymmetric loading, because a layer of a snow could be unequal on the shadow and solar sides (Fig. 10).

Among Betancourt's main achievements was establishment of the first-ever in Russia Higher Engineering School that was named the Institute of Corps of Engineers of Routes of Communication – ICERC (nowadays Petersburg State University of Means of Communication).

The Institute was established according to a document signed by Alexander I, Emperor of Russia, 20, November, 1809, where there is a paragraph about the organization of the Corps and the Institute of Corps of Engineers of Routes of Communication. It is important to point out that, from the very beginning, Betancourt participated in the activity of the commission for developing the project called by for this document. For his excellent work in this commission he was promoted to the rank of General-Lieutenant and on August, 30, 1809 was appointed as the Institute Inspector. Later in 1816 he was appointed to the post of President of the Committee for Constructions and Hydraulic Works and in the same year he organized an important fair in Nizhniy Nóvgorod. In 1818 he was nominated as Chief of Department of Routes of Communication.

Fig. 11 First building of the Institute

Betancourt chose the Manor of the noble Yusupov family as the first building for the Institute because it was surrounded by a wonderful park with a lake where all students could gather during breaks, and it had also a lot of large and light rooms for lessons (Fig. 11).

To develop a new educational system Betancourt made use of his own experience of the establishment of the above mentioned School of Roads and Channels in Madrid. Based also on achievements of his French teachers: Gaspar Monge (1746–1818), the founder of the Polytechnic School, and Jean Rudolf Perrone (1708–1794), the founder of the School of Bridges and Roads, he did not simply repeat the western style of teaching in Russia, but he made a significant improvement as specifically adapted to Russia's environment in such a way that it was a new type of higher technical education which still, two centuries later, maintains significant value.

By the beginning of the nineteenth century in France there was already a numerous staff of engineers, and therefore Betancourt could invite qualified experts for teaching special disciplines in the Institute of Engineers of Routs of Communication in Russia. The first 20 years of teaching at the Institute was carried out in French and this permitted students to study the latest proceedings on engineering inventions from original documents and early publications. The program and curricula were defined by Betancourt while providing simultaneously scientific, engineering and practical training that was an innovation for Russia and, as a whole, advanced at that time. Theoretical teaching of students was combined with their practices in laboratories and workshops, even outside the Institute, by including intensive work on design and drawing. All that gave a profound basis for good professional young specialists.

The approach of the new program was verified by time, and became an example for other higher technical schools through the nineteenth century. Russia at that time was in great demand of the new generation of professionals capable of designing a wide spectrum of engineering projects. Major principles of the new educational system were:

1. Serious general-theoretical education of students with a strong basis in mathematical disciplines;
2. Universal approach to engineering activity on the basis of a wide culture, providing a creative orientation of graduates;
3. Development of practical skills of students for working with mechanisms and machines;
4. Practical training under real conditions.

The main aim of an education program as Betancourt liked to repeat was "to supply Russia with engineers who after graduation from the Institute could immediately be effective in industry". He wished all students of the Institute "should be familiar with the basis of science and its practical application to engineering". The Institute of Corps of Engineers of Routs of Communication really became "that trunk" of Russian higher technical school from which all the numerous branches were formed later.

From the very beginning, parallel with the Institute, Betancourt started to organize a library and a room for practical studies. For that purpose the first books, various tools and scale models under his order had been purchased in Paris and in 1810 delivered to Saint Petersburg.

With a view to continuity, the best graduates stayed in the Institute and later became well-known professors and scientists. One of the most talented graduates of 1813 was A. D. Gotman (1790–1865) who later became the Rector of the Institute from 1836 to 1843.

Betancourt paid very special attention to manuals. From 1816 the Institute began to lithograph and to issue professor training courses and lectures. In "Voenii journal" (Military magazine) from 1811 it was remarked, that "higher mathematics and mechanics in Russia are taught in the only one Higher School – the Institute of Corps of Engineers of Routs of Communication where the well-known General Betancourt introduced it recently".

Among special disciplines for the high level of engineering teaching, the "Course of construction", was developed by M. S. Volkov. The new course included methods of designing and construction of all transport overland and hydraulic engineering systems and it included as important sections: building materials, building mechanisms, manufacture of civil construction, highways, bridges, hydraulic engineering.

The second significant course was Applied Mechanics. In 1821 it was allocated as an independent subject from "Theoretical mechanics". This course provided knowledge in steam machines, building and road mechanisms and all other mechanical devices and machines that are connected to construction and operation of transport constructions and water supply.

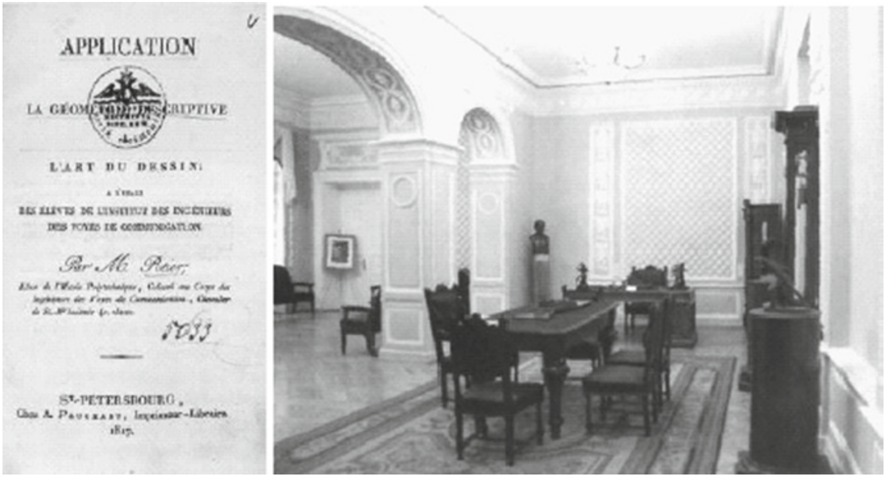

Fig. 12 “Basis of descriptive geometry” by Charles Potier and Betancourt’s Cabinet in the Institute

In 1823 “Note about appendix of the beginnings of mechanics to calculation of action of some of machines, the most common” by professor D. S. Chizhov was published as the first textbook on Applied Mechanics in Russia.

As a whole from 1816 to 1828 several courses were published or litho-graphed: “Lecons de mecanique applique” by B. Clapeyron, “Traite des proprietes projectives des figures” by J. V. Poncelet, “Traite elementaire de calcul integral” by Pierre Bazaine avec Gabrial Lame, “Basis of De-scriptive Geometry” by Charles Potier (Fig. 12), translated into Russian by J. A. Sevastjanov, “Spatial Geometry” by A. I. Majorov, “Initial bases of analytical geometry” by J. A. Sevastjanov, “Differential calculus Initial base” and “Integral calculus Initial base” by P. Bazaine (in French), “Base of Mechanics” by Morice Destreme, etc.

Betancourt managed to organize a Museum of Models in the Institute by using his own previous experience of the Royal Cabinet of Machines in Madrid. It was opened in the “Special hall” only in 1813 after the first exhibits arrived. The Museum consisted of six cabinets: modeling and mechanical, building – working tools, samples of building materials, physical, geodetic, mineralogical. In those cabinets practical lessons were given. The collection of the Museum was continuously enriched with scale models, drawings concerning construction of bridges, channels and buildings. The collection helped to study disciplines more deeply using all the knowledge in practice. Students were used to make scale models and mechanisms in workshops of the Institute (thus, in the Museum there are 14 models of Descriptive Geometry, some models and mechanisms made by Betancourt himself or under his supervision, Fig. 13).

Betancourt’s basic efforts were directed toward education of qualified Russian engineers on a European level. He became the founder of professional traditions

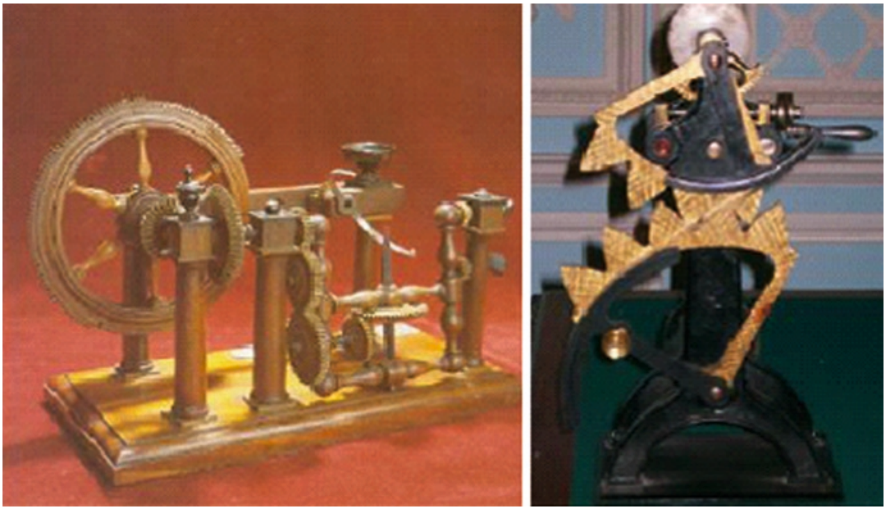

Fig. 13 Mechanisms fabricated by A. Betancourt

which even nowadays provide the country with qualitative experts in mechanical engineering, construction of bridges, roads, and buildings.

Betancourt's contribution to establishment of Russian higher engineering education was truly significant. The young scientists who graduated from the Institute established a Russian scientific language by translating textbooks into Russian terminology and adapting the Institute's system of engineering training to Russian culture.

The Institute of Engineers of Routs of Communication became a cradle of Descriptive Geometry in Russia, because the theory of this branch of mathematics was well developed and many new applied disciplines appeared on its basis. Monge's dream: "young experts will apply Descriptive Geometry in many areas and use it for machine construction and then a human being using the power of nature will need only add the power of his brain" came true.

With the advent of railways Russia immediately has joined the European community of railway construction because it had produced super professional engineers and they all were Betancourt's students – graduates from the Institute. They were able to solve any kind of problem: technical, cultural national. And, certainly, they had always Betancourt's example to follow.

Students of the Institute received the highest technical and engineering education ever known in Russia. The intellectual scope of the theory, experience and talent in Engineering and Pedagogics helped Betancourt to establish a new educational system with huge potential opportunities. It is remarkable, but Russian engineers of the nineteenth to twenty-first centuries cannot be reproached for lack of competence or scarcity of imagination.

In his activity Betancourt followed principles of the well-known Roman architect and engineer Vitruvius: durability, common weal, beauty. Thus those few guidelines assured that Betancourt's designs were not only engineering constructions, but also masterpieces of art. Primitive service for momentary benefit was alien to him. He used to say: "In technical equipment it is not enough to get the desirable result, it is necessary to use the most simple, easiest, strongest designs and most suitable to the workers skills".

Petersburg University of Routs of Communication, founded by Betancourt, became one of the leading Russian scientific educational centers, the foremost higher engineering institute in the country.

Still it is interesting that before his coming to Russia, Agustin de Betancourt had a real plan for working in Cuba, but the wars and hidden intrigues prevented him from following Columbus' steps and he never went to Cuba. Nevertheless, the Spanish engineer played an important role in the development of innovative technical ideas in Cuba.

4 Cuba as a Part of Spain's Empire

For a long time Cuba held an important place in the imperial economy of Spain. Without gold and silver deposits and with an insufficient working population, economic activity in the Island was concentrated in the port of Havana (Fig. 14) because of its excellent position on the Gulf of Mexico for ships to dock and trade.

Spanish King Charles III died in 1788 and the throne was occupied by Charles IV, a king who was weak and without real power. Spain was governed by Maria Luisa and her favorites; her main support was Manuel Godoy (Fig. 15), officer of

Fig. 14 Havana port

Fig. 15 Manuel Godoy, fragment (By Goya)

Fig. 16 Francisco Arango y Parreno

the guard. At the age of 25, he was named Prime Minister. Under his tutelage, political power in Cuba passed into the hands of the Cuban bourgeoisie, more known as “saccharocracia”, which means related to the sugar production. One of its most prominent representatives was Francisco de Arango y Parreno (1765–1837) (Fig. 16) owner of vast lands and an intellectual. He was born in Havana on May 22, 1765 in a family of elite ancestry and with large economical resources. Francisco de Arango headed Havana’s saccharocracia and became one of the most devoted fighters for reforms in Cuba.

At the end of the eighteenth century, the “Century of Light”, under the direction of the Governor Luis de las Casas there appeared in Cuba some institutions, that made important contributions to the development of the country. The above mentioned Economic Society (SEAP) and the Royal Consulate of Agriculture, Industry and Commerce were founded, and the first daily newspaper “El Papel Periodico-de-La-Habana” was established.

Luis de las Casas also, with good will, received refugees from Haiti after the rebellion of slaves, which took place there in 1791 and gave them credits and lands in the eastern part of the Island. The new colonists had great experience in the production of coffee and sugar. In this way, more and more plantations and sugar-mills appeared in Cuba. At the end of the Eighteenth century in a very brief time, Cuba surpassed Haiti as the most important sugar producer and exporter of the epoch.

5 Sugar-Cane Production in Cuba

Sugar cane started to be cultivated in Cuba at the end of the sixteenth century. The sanction that had been given first to Santo-Domingo was accepted in the Island in 1595. Still, only in the middle of the eighteenth century was the real cultivation and sugar manufacture started, which immediately took one of the most important places in the Cuban economy.

Sugar production was based on the juice of sugar-cane called "*guarapa*", which was produced by means of wooden tools which were called "*trapiche*" or "*cunyaya*". According to Fernando Ortiz, a famous Cuban historian, a "cunyaya" (Fig. 17) was a rudimentary device similar to a press used by Greeks and Romans in antiquity to press olives to produce oil.

The Cuban historiography uses words "sugar-mill", "trapiche" or "ingenio" to identify the unique existing mechanical engineering in sugar production of the

Fig. 17 Primitive cunyaya (Trapiche)

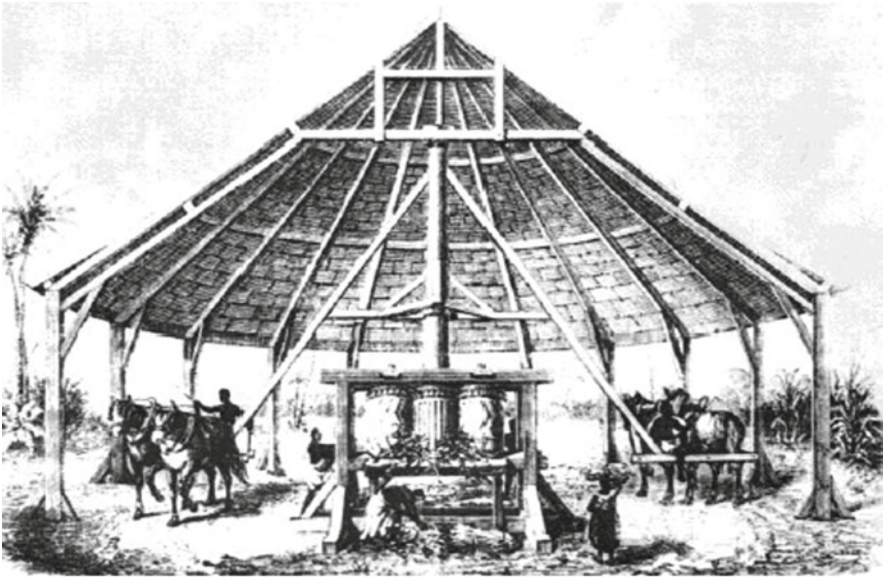

Fig. 18 Sugar-mill (Trapiche) using power of animals

seventeenth to eighteenth centuries. Trapiches as inventions used a similar mechanism, made in the beginning, of two placed cylinders made from firm wood in a horizontal form.

Later, this technology with application of a system of three vertical cylinders, wood or iron which rotated in a form contra each other was improved, wiping and squeezing out sugar-cane with greater intensity. However, it was actually differentiated by its driving force. First, trapiches were drived by mules, donkeys or horses, according to what was available to a landowner (Fig. 18). Animals, with covered eyes, moved in a circle, turn after turn, attached to levers of a mill which actuated the central wheel, and then moved the system of cylinders.

Trapiches could be also moved by hydraulic force (water mills) (Fig. 19) or wind force (wind mills), but in reality, its procedures were very similar to the trapiches with animals (Egorova 2010).

If we analyze in detail cunningly most revolutionary applied innovation violently driving, that have presented mills within the first colonial centuries, can assert, that was the replacement of two horizontal cudgels because of use of three vertical cudgels started in process contra each other, that made the greater extraction the juice having moved sugar-cane because of process double or threefold grinding and squeezing.

Sugar production demanded a plentiful supply of labour to execute all the work required. Therefore, the progress depended completely on Negro-slaves and their productivity.

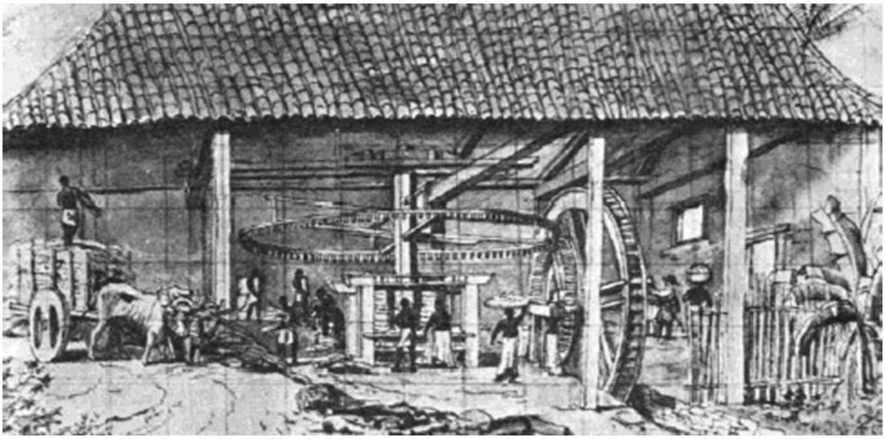

Fig. 19 Sugar-mill (Trapiche) using power of water

It is clear that the Cuban landowners had a talent for sugar production and appreciated the potential benefits of a robust sugar industry, but did not fail to notice the dangers that loomed on the horizon. As evidence of their vigilance, they paid close attention to a new technical development that had been introduced in the world. The first steam machine as a universal engine was constructed in England between 1774 and 1784; as nearly as 1794, Don Francisco de Arango y Parreno and the Count de Casa Montalvo were already in England, looking for an opportunity to make a vapor machine adapted to the necessities of sugar manufacture. They were ready and eager to take advantage of modern technology.

6 A Secret Meeting

We may suppose that Francisco de Arango y Parreno met Agustin de Betancourt in 1794. This conclusion is based on existing data and documents with regard to his long trip with the Count de Casa Montalvo to Portugal, England and its colonies, Barbados and Jamaica, to become familiar with the new technical inventions. Their visit to England coincides with Betancourt's staying in London (Francisco Arango y Parreno 2005).

On October 14, 1795, after having finished his trip, Francisco de Arango spoke to a session of Royal Society about the steam machine ordered in England by the Count de Casa Montalvo; he also made available to the public a small pattern and some drawings of mechanisms of the machine. We have to point out that one of Betancourt's passions was construction of machine patterns, practically exact copies but on a much reduced scale. The existence of this particular pattern points

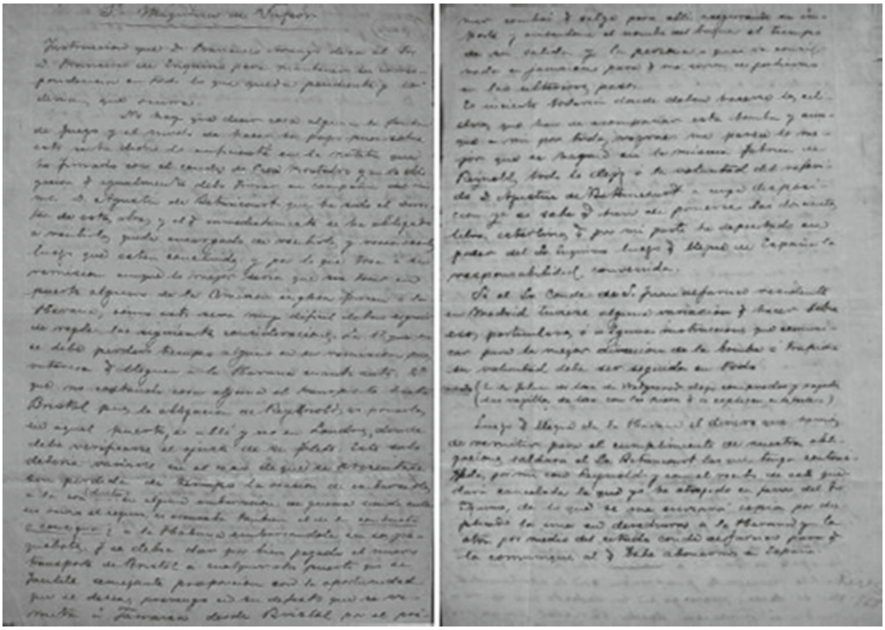

Fig. 20 Original letter written by Francisco de Arango y Parreno

indirectly to authorship of Betancourt in the creation of the mentioned vapor machine because of his great experience in this occupation. In the files of Don Perez Beato of the National Library of Cuba in Havana (BNC), there is preserved, under the number 968, the original letter (Fig. 20) written by Francisco de Arango y Parreno with instructions on reconfiguration and transportation of the steam machine to Cuba (BNC et al. 968). The name of this file is "*The instruction which was left by D. Francisco Arango to Sr. D. Francisco de Enquino to keep his correspondence about everything pendent and the rest that happens*". Here are some fragments of it:

> It's not necessary to say anything about the fire bomb (the steam machine) and the way to make its payment because it has been said enough in the document which I've signed with Count de Casa Montalvo and I also signed an agreement with Don Agustin de Betancourt who has been the supervisor of these works….
>
> …I left everything to Don Agustin de Betancourt's discretion who will receive 200 pounds…
>
> …If Count de San Juan de Jaruco, with residence in Madrid, had to make some variation on these topics or to communicate some instructions for a better transportation of the fire bomb (the steam machine) or trapiche, his will should be followed in everything.
>
> …After having received the money from Havana for fulfilling our obligation, Don Betancourt will pay my bills with Reynolds. It will be also paid Don Equino's debt and the receipts will be sent in two copies. One of them will be sent to Havana and the other to Count de Jaruco for making the payment in Spain.

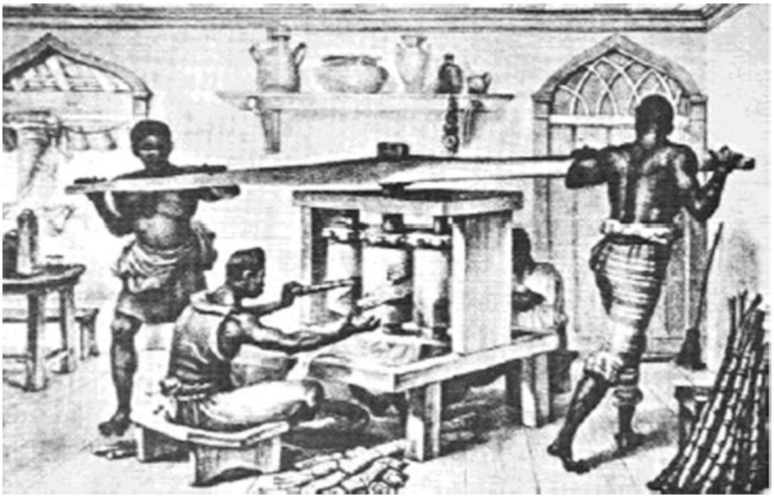

Fig. 21 Sugar-mill (trapiche) using power of Negro-slaves

This letter is the unique document where we can see that Francisco de Arango and Agustin de Betancourt subscribed to an agreement for the production of a new steam machine for grinding of sugar cane. This contract also responded to Betancourt's plans to design steam machines for different technological purposes. In those times, Watt steam machines were unknown in Cuba and the above mentioned machines which used the power of animals and Negro-slaves (Fig. 21) were not so profitable because of their low productivity.

There is also a letter which Betancourt wrote in French on December 10, 1794, to his friend Breguet (Fig. 22) mentioning the received order (García-Diego 1985). This letter, preserved in Breguet's archives, serves as a proof. Among other observations, it says:

> This summer two friends from the Spanish America have been here and I proposed them the project of installing the steam machines in their possessions to avoid the use of oxen and negroes for expelling juice from the sugar cane; I did some calculations and they asked me to produce two of these machines designed by me and they are being done now… Two of these machines will be finished soon and I hope their effectiveness could be seen on the islands and the owners would leave the ones they have now.

It is seen from the text that the order was made by two travelers from "Spanish America" who could well be Cubans. It is obvious that new machines were designed for grinding the sugar cane and were planned to be located in sugar-mills. Francisco de Arango y Parreno and the Count de Casa Montalvo were the owners of vast lands and without any doubt were interested in the use of modern technology and new machines in their sugar-mills. Betancourt's plans for using his machine in future show us that it could be Cuba where the production of sugar was the principal line of economy and all the country was turned into a "world wide sugar-bowl". Cuban saccharocracia kept the power in their hands and for sure were thinking about increasing of the productivity of this industry.

Fig. 22 Abraham-Luis Breguet, fragment (By Goya)

7 The First Steam Machine in Cuba

In a monumental and comprehensive work "The Sugar-mill" ("*El Ingenio*") written by Manuel (Moreno Fraginals 1986), an outstanding investigator of the history of the sugar industry, we can read the following:

> Finally, in 1796, the motive power of the large industry, the steam, arrived in Cuba. It was a machine bought in London with the Count Jaruco`s money. Its installation became a unique event surrounded by an atmosphere of tense expectation. It has been seen to function for the first time on January 11, 1797 at Seybabo sugar-mill and it had been working for several weeks. The experiment wasn't a success but the saccharo-crates didn't lose heart. They understood that the main problem wasn't in the "bomb of fire" (steam machine) itself but in the type of the grinding machine (trapiche) that was moved and in the absurdity of the system of the installed transmission.

Unfortunately, Fraginals and others do not appear to have uncovered a name for the inventor of the above mentioned machine, neither any detail of its construction, nor the data on its moving to Cuba. But a significant fact is that the first steam machine was installed at Seybabo Sugar-mill, which belonged to the Count de Mopox y Jaruco, who led the scientific expedition in which Betancourt and his Spanish colleagues would have participated. The Count de Mopox y Jaruco was also the son-in-law of the Count de Casa Montalvo who accompanied Francisco de Arango y Parreno in his trip to England. These coincidences make us think that Betancourt was the designer of the first steam machine used for grinding cane in Cuba.

Unfortunately, this machine was broken very soon because there were neither qualified operators nor competent engineers on the Island. In 1796 the Count de Mopox y Jaruco left for his expedition to Cuba, which lasted 6 years, and he could hardly attend to the problems related to the new equipment. In those years, Agustin de Betancourt dedicated himself to the construction of an optic telegraph and to organization of the School of Roads and Canals in Madrid. However he was never able to come to the Island.

8 Agustin De Betancourt as a Pioneer of the Sugar Industry of Cuba

In the book "*Francisco de Arango y Parreno* (2005). *Obras*." we can read the words of Don Diego M. Gardoqui:

> machine was broken… and this unfortunate circumstance has deprived us with a plenty of years of the profit of the most amazing invention of our epoch.

It is true that this first steam machine to be used in Cuba was broken very soon after its installation, within several weeks; but it is important to recognize that the reason was the inability of sugar-mills of that epoch to assimilate this new technology and not because of mistakes in the machine design. Saccharocrates understood also that they needed to change and transform the complete circuit of the technological process. As a result, large-scale use of steam machines in sugar production in Cuba began much later, after 1827. According to Fraginals, more than 20 types of various steam machines were used in different Cuban regions until eventually, a successful one was established in a sugar-mill of Juan de Madraco, in Matanzas. The new steam machine was produced in London by the firm Fawcett, Preston and Co., in 1816, and transported to Cuba through the USA. The time interruption between 1797 and 1816 was due to a lack of international trade, which was related to the ongoing European conflicts, in particular, with Napoleon's wars and consecutive continental blockades. It is necessary also to take into account the peculiar restrictions that occurred in a factory system that functioned on the basis of slavery. And, eventually, we must not forget that England did not want to lose the advantage it had received from the Industrial Revolution and, consequently, the English government made various arrangement to interfere with the distribution of secrets of new machines. Watt steam machines in particular, which could be of the most interest. Because of this policy and its resulting laws, between 1765 and 1789, and even in 1794, no textile machines or related projects were exported, and the emigration of workers specializing in the textile industry or mechanical engineering, in general, was forbidden.

Undoubtedly, the meeting of Agustin de Betancourt with Francisco de Arango y Parreno and the Count de Casa Montalvo influenced greatly on the use of steam machines in Cuban sugar-mills, which is proved by the words of Don Gardoqui:

> we shall be also the first who have forced to carry out through the Atlantic Ocean the most powerful agent that has learned the industry. When it is not possible to use water in nature (water-mill), we could use bombs of fire (steam machines) to move our trapiches and have left for ever expensive, uncertain and weak means of mules and donkeys.

Comparison of archive documents, the "mystery drawing" on the portrait of the Count de Casa Montalvo and some other facts prove convincingly that Agustin de Betancourt was unquestionably the designer of the first steam machine to be installed at Seybabo Sugar-mill and used for the first time in sugar production of Cuba in January, 11, 1797 (Egorova 2010).

Later, steam machines became popular and in 1837 Cuba became the first country in Latin America to have a railway from Havana to one of its Municipios, Guines (Fig. 23), even before the Metropolis had, but in the same year that Russia put one into operation.

In 2003, according to the initiative of Saint Petersburg professors and scientists and with the aim of glorifying the name of the Spanish-Russian engineer , there appeared in the register of small planets of the solar system, the planet "Betancourt" with the number 11446.

Fig. 23 First railway in Cuba (A stamp of Cuba)

9 Conclusion

Our investigation proves convincingly that the designer of the first steam machine used in the sugar industry in Cuba in 1797 was the Spanish-Russian engineer Agustin de Betancourt. This work also stands as a case history in science, emphasizing the role of one dedicated scientist in the person of Betancourt. He epitomizes the role of an individual who stood out in the history of and dialectic interrelation between public consciousness and economic relations, a story that resulted from the one individual leading in pursuit of a process of manufacture on which his own very existence depended.

Agustin de Betancourt was a foremost pioneer in the long history of industrialization in Cuba, and in sugar production in particular. He has cleared a number of scientific roads, exploited a passionate desire for technical progress and has contributed considerably to the establishment of higher technical and engineering education in Russia. His ideas have exerted great influence on the development of modern engineering techniques all over the world. He has earned his place in history.

Acknowledgements I would like to thank all my Cuban, Russian and Spanish friends who helped me to finish my investigation on the first steam machine introduced in the sugar industry of Cuba.

I also hope that the young generation will study much more the History of Machine and Mechanism Science as well as biographies of famous scientists and philosophers.

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