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Historical Approach and Scale Reconstruction of Two Medieval Mechanisms from "The Book of Secrets"

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Abstract

"The Book of Secrets in the Results of Ideas", usually called "The Book of Secrets" is a codex containing drawings and descriptions of thirty-one artifacts attributed to the engineer Alī Ibn Khalaf al-Murādī, who lived in Andalusia in southern Spain at the beginning of the 11th century. This manuscript is one of the first written testimonies that describe medieval mechanisms with complex precision. The aim of this work is to reconstruct and study from a historical and technological point of view two of the ancient artifacts contained in the "Book of Secrets", the "Fortress Demolisher" and the "Magic Well". The "Fortress Demolisher" is a war machine designed to demolish the upper part of the walls or towers and consists of a battering ram mounted on a platform that can be raised several meters above the ground using a scissor mechanism. The "Magic Well" is a mechanism with several pulleys whose purpose is to raise water several meters from the bottom of a well by collecting a small portion of rope. To reconstruct the two artifacts, a digital model and a detailed study of the geometry and operation of the mechanisms, were first carried out. 3D printing, using the Fused Deposition Modelling technology, made the physical reproduction. The digitization and physical reproduction by 3D printing of the mechanisms represent an update of the traditional ways of transmitting knowledge. The use of these new technologies makes the knowledge more accessible, understandable and attractive.

Keywords History of machines and mechanisms · Digital modelling · 3D printing · Scale reconstruction

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1 Introduction

Since its origin, human beings have always wanted to record their passage through history and transmit to next generations how they lived. For this reason, since the invention of writing, all cultures have given great importance to the transmission of their knowledge through the written word.

The evolution of knowledge has led to the evolution of the transmission medium, evolved from oral transmission or basic writing to the variety of multimedia and digital options of today.

In this work, an emerging technology such as 3D printing will be used for the transmission of knowledge, with the aim that the real scale reproduction of ancient mechanisms helps to better understand their operation, and thus understand the most complex modern mechanisms.

This paper is a revised and expanded version of the conference paper "*Reconstruction of Two Medieval Artifacts by the Engineer Al-Murādī*" (Medina-Sánchez et al., 2022) from the 7th International Symposium on the History of Machines and Mechanisms that was held at University of Jaen and Granada University, in April 2022.

1.1 Written Transmission Of Knowledge in Ancient Times

Throughout history, the transmission of the knowledge has always been one of the priority objectives for the development of societies. This knowledge was stored since ancient times in libraries. Perhaps the earliest known library as an organized collection of documents is that of the Assyrian king Ashurbanipal, discovered during excavations in the city of Nineveh. In it, some thirty thousand fragments of clay tablets appeared buried among the remains of the Royal Palace (Fincke, 2004). Later, the libraries of Alexandria, Pergamum, and different Roman libraries were famous. From those times until the advent of the printing press (Johannes Gutenberg, 1440), the fundamental supports for this transmission were tablets, scrolls and codices (Escolar, 1990).

The tablet was an element used since ancient times in Rome, which consisted of a rectangular wooden table filled with wax. It was written on it using a wooden or metal punch, called a stylus.

The manuscript scrolls appeared in Egypt and were obtained from the Cyperus papyrus plant, very abundant in Egypt, which was cut into small strips that were later macerated and glued, overlapping the different cut layers to form the final tissue. They were stored in different temples and libraries, in clay pots, wooden boxes or leather cases (Martínez De Sousa, 2010).

The codices are one of the previous formats of the book as we know it today. They are made up of a set of folded and bound papyri or parchments (Dahl, 1998). They were the most used element for manuscript conservation and historical dissemination since the Middle Ages.

1.2 3D Printing the Ancient Knowledge

Today knowledge has found new ways for its transmission. The easy access of the population to computers, together with the development of the Internet and web applications, have allowed the appearance of a multitude of multimedia alternatives to transmit knowledge. The new generations are much more receptive to receiving information through new technologies. This fact is something that can be used to send them information about historical mechanisms and their operation in ways that are attractive to them.

There is a trend to create virtual collections of ancient objects and mechanisms modelled with CAD software. 3D models can be supplemented with additional information about their main features, their history, the materials used or their operation. In addition, they can be given movement to facilitate their understanding (Egorova & Shcherbinin, 2016). These collections allow showing old mechanisms in an accessible way via web applications. These collections are being created for educational purposes, or simply as virtual museums to complement existing information in "physical" museums or to preserve high-value pieces (Shiroshita et al., 2001; Monjas Hebrero et al., 2022).

The development of new rapid manufacturing technologies such as additive manufacturing, popularly known as 3D printing, allows us to go a step further in the recreation of old mechanisms, breaking the barrier imposed by the screen and going back to physical recreation. 3D printing allows reproducing any object from a digital model in a quick, economic and reliable way (Snyder et al., 2014; López-García et al., 2016).

3D printing of ancient mechanisms can be used for different purposes. Educational purposes, since it allows the creation of fully functional models of the mechanisms, which can be manipulated by students. For maintenance, rebuilding deteriorated mechanisms by reproducing damaged parts. To reconstruct mechanisms from ancients plans or schemes. On the other hand, to make copies of high-value mechanisms in order to preserve them, performing what is known as reverse engineering (Lipson et al., 2005; Tikhomirov et al., 2022; Short, 2015).

1.3 Science and Technology in the Medieval Arab World

The Islamic civilization of the Middle Ages encouraged and promoted the pursuit of scholarship and science. The search for knowledge about the natural world was considered the duty of every Muslim. Medieval Islamic scientific achievements covered many subject areas, such as astronomy, mathematics, physics and chemistry, medicine or engineering (Turner, 1997).

In astronomy, it should be noted that observatories were built in the most important centers of the Islamic empire, highlighting those of Baghdad, Cairo, Córdoba, Toledo and Samarkand. Muslim astronomers faced this science for practical and religious reasons, astronomy helped navigation and allowed to have a precise calendar for prayer times and guide the direction of Mecca (Turner, 1997).

In mathematical sciences, many basic principles of arithmetic, geometry and algebra were discovered by Muslim scholars. In arithmetic, we still use numbers and the counting method invented by the Arabs. The invention of algebra is attributed to the Arabs. Among the most famous authors Al-Khwarizimi (ca. 780–ca. 850) stands out, one of the best scientific minds of Islam, who exerted a great influence on mathematical thought throughout the Middle Ages (Berggren, 2016).

The Arabs also made important contributions to physics and chemistry sciences. In physics science, the work carried out by Hassan-Ali-Aitan (965–1040) in the field of optics stands out. In chemistry sciences, they discovered distillation and were the first to use the methods of sublimation, crystallization, coagulation, and cupellation to extract and mix substances (Viguera & Jover, 1994).

Medicine was another key discipline for Muslims, so the number of famous doctors and medical treatises is considerable. Muslim doctors played a decisive role in Western medical science. For several centuries, the works of Al-Razi (ca. 865–ib., ca. 925), Ibn-Sina (ca. 980–ca. 1037), Abul-Cassis (ca. 936–ca. 1009) and Ibn-Zuhr (ca. 1091–1162) were the basis of medical studies in all European universities (Viguera & Jover, 1994).

In the field of engineering, it is worth highlighting the figure of Al-Murādī, on whose codex "The Book of Secrets" this work is based. This manuscript is the first example of the Western Islamic mechanical tradition, which will have continuity in North Africa and Europe, characterized by the use of crude mechanisms and powerful machines as opposed to the Eastern mechanical tradition, which stands out for its delicate mechanisms and controls.

2 The Book of Secrets

The Book of Secrets (ةجتانلا راكفألا رارسأ باتك, kitab al-asrar al'afkar alnnatija), is a codex with a collection of thirty-one artifacts attributed to the engineer Alī Ibn Khalaf al-Murādī, who lived in Andalusia, probably in Córdoba or Granada, at the beginning of the 11th century AD.

In this manuscript, the first written testimonies of medieval mechanisms with complex precision are drawn. The knowledge contained in "The Book of Secrets" was preserved thanks to a copy of it made in Toledo in 1266 by a translator at the court of Alfonso X the Wise. This copy has been preserved for centuries in the Biblioteca Medicea Laurenziana in Florence. However, his drawings were not interpreted until the 21st century.

The existence of this manuscript was brought to the fore by the engineer and historian Donald Routledge Hill around 1970 and was not given much attention until after about thirty years. It was then when, thanks to the economic collaboration of the Emir of Qatar Sheikh Hamad bin Khalifa Al Thani, who funded a research project that has led to its publication in Arabic and English. The facsimile reproduction of the manuscript was carried out (Al-Murādī, 2008), also its study both from the technological point of view and historiographic, and the reproduction of two of the inventions collected to be exhibited at the Museum of Islamic Art in Doha, in Qatar (Fig. 1).

The manuscript consists of thirty-one chapters full of secrets written in Arabic, each of which describes different mechanisms; although this manuscript is not completely preserved as many of its pages have been damaged. A description of each of the mechanisms is given in Arabic and is accompanied by sketches and drawings of the mechanisms. Among the thirty-one artifacts described in the codex, there are five automatons in the form of a "little theatre", two calendars (one zodiacal and another astronomical), four war machines, two mechanisms to draw water from a well and, above all, there are clocks. The tools most used to create the mechanisms of the artifacts are ropes, pulleys, water tanks and counterweights.

The present work has focused on recreating the 23th and 25th artifacts, a war machine called "Fortress Demolisher" and a pulley mechanism for drawing water from a well called "Magic Well".

3 Description of Mechanism 23th, "Fortress Demolisher"

The Fortress Demolisher is an assault war machine similar to the typical battering ram that was used to destroy the lower parts of the walls or the gates, and to open breaches in the defences of the enemy. The study device differs from a classic battering ram in that it is mounted on a platform that can be raised several meters high by means of a scissor

Fig. 1 Pages from the facsimile edition of the Book of Secrets (Al-Murādī, 2008)

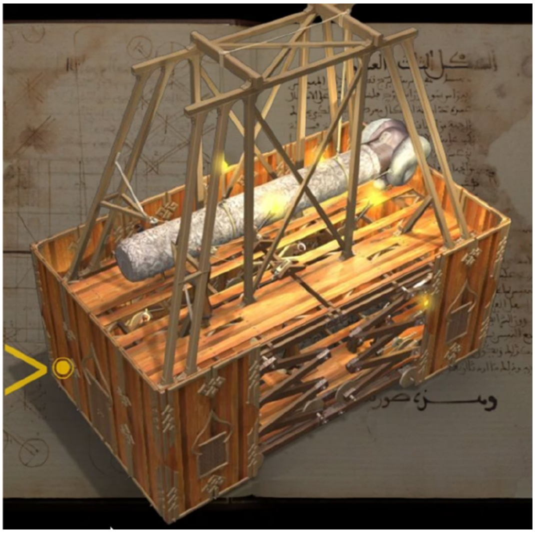
mechanism in order to be able to knock down the upper part of the enemy fortifications. The original codex defines the use of the mechanism as follows:

> We want to install on top of this tower and to its left a weapon which can demolish the top of a fortification wall or tower. We install on the figures at columns H four figures […]. The figures are installed opposite […]. We install on each two figures an axis. [Each of the figures is] twelve handbreadths [long]. The scissors should be balanced and tied strongly [so that they do not tilt] to one side or the other little or much. Then we make a solid arm [made of a column and a sphere] 30 […] in length or more according to the size of the column. It should be smooth with no irregularities. Install on the sphere […] a weight of half a central. Tie two ropes to the centre of the […] scissors. The two ropes are separated by a distance equal to that between the columns of the scissors […] Install to the sides of the sphere and on points H and H two pulleys. Attach two ropes to the sphere at point X, which is at the tip of the sphere. Extend the ropes to the pulleys. The ropes then go down to the inside of the cover and to the men inside it. When they pull the rope strongly at once and then release it, the sphere will go back in a great speed and so it will demolish whatever it meets. Then [the tower] is moved to another area and it does the same.
> The tower is manufactured in the same manner described before in the figure of the tower. And that is what we wanted to do if God desires." (Al-Murādī, 2008).

As can be seen, the description of the mechanism in the original text is not very precise. Figure 2 shows the original drawing of the codex with the elevation mechanism scheme,

Fig. 2 Image and description of the 23th figure, Fortress Demolishers (Al-Murādī, 2008)

Fig. 3 Reproduction of the Fortress Demolisher by Leonardo3 study (Al-Murādī, 2008)



and the original description. In Fig. 3 the 3D digital interpretation made by Leonardo3[1] studio is shown.

As indicated in the text, the idea is to create a mobile artifact that could be brought closer to enemy fortifications. Initially, the platform with the battering ram and the men in charge of operating it are protected by walls. The platform lifting system consists of four scissor mechanisms. The platform is raised above the walls by the movement of four

[1] Leonardo3 is a research center and a multimedia company dedicated to studying, interpreting and making known cultural heritage using cutting-edge technology. Leonardo3's main research workshops and products are focused on the work of Leonardo da Vinci, although they have also interpreted the work of the Arab engineer Al-Murādī. More information at website www.leonardo3.net.

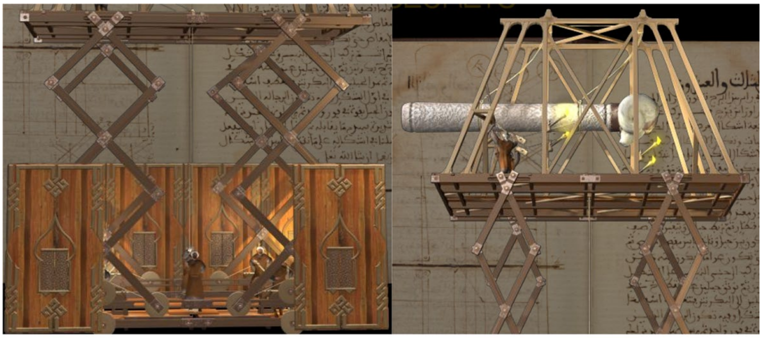


Fig. 4 Details of the reproduction of the Fortress Demolisher (Al-Murādī, 2008)

winches operated by a pair of men each. When picking up the rope with the winches, wheels on rails move and close the scissor mechanism rising the platform (Fig. 4a). Once the battering ram is positioned at the desired height, it could be moved backward with a system of ropes and pulleys, to then release it and hit the enemy wall with a strong impact (Fig. 4b.

4 Description of Mechanism 25th, "Magic Well"

This device is a simple multi-pulley mechanism whose objective is to be able to lift a load several meters collecting a small portion of rope. In this case, the load is a bucket of water into a well. The codex expressly indicates the purpose of the device:

> We want to take water from a well, whose depth is eight yards, collecting only one yard of rope. So let us make the shape of an eight-yard-deep well, ABCD. We divide the area between B and C into four parts [by making four marks on the line]. The first mark is C and the two marks after it are B. Mark D is between C and B. A nail is attached [to the well] at each mark. Nail C protrudes by three handbreadths. Nail D protrudes by two handbreadths. Nail E protrudes by three handbreadths. Take a one-yard-long or a little more rope and put one of its ends at the mouth of the well and attach a pulley to the other end. The pulley ends slightly below nail E.
> Take a second rope equal in length to the first. Attach its end to nail E. The rope then passes to the pulley, which is at the end of the first rope. Attach [another pulley to the other end of this rope]. This pulley lies slightly below nail D.
> Take [a third] rope which is [two yards] long. One end of the rope is attached to nail D and passes to the pulley [at the end of the third rope]. The other end of the rope is attached to the bucket and ends below the surface of the [water].
> To bring the bucket up, we pull the end of the rope. When one yard of rope and the pulley attached to it are pulled out, the bucket will come out if God desires. And this is its image (Al-Murādī, 2008).

Fig. 5 Magic Well mechanism scheme and description (Al-Murādī, 2008)

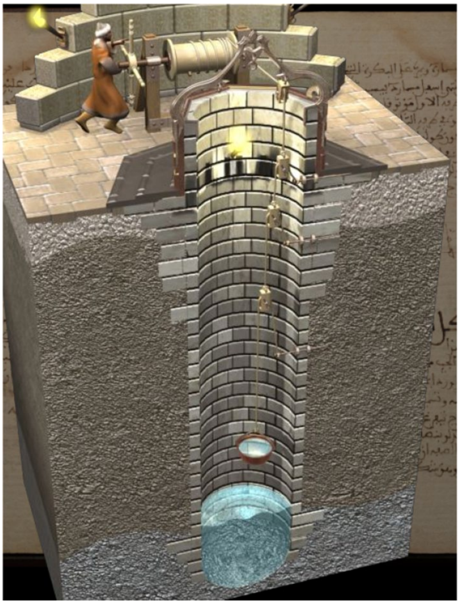


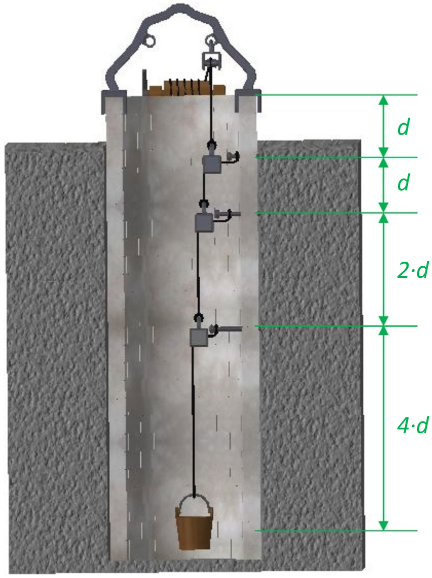
Fig. 6 Magic Well digital interpretation (Al-Murādī, 2008)

In Fig. 5 we can see the original image of the well that appears in the text with its description. The digital interpretation made by Leonardo3 studio is shown in Fig. 6.

This mechanism is based on the lock-and-board principle. A rope is passed through a pulley and tied to a fixed location. The other end of the rope is attached to the element to be lifted. The pulley is pulled up and a double-acting mechanism is obtained that makes the objects go up by picking up half the rope.

The original manuscript mentions the anchorage position of the ropes, although it does not specify exactly the anchorage distances or the length of the ropes, possibly so that the

Fig. 7 Geometric relation of the Magic Well



well would not lose its "magical" character. However, the interpretation of the drawings indicates that the length of the strings has a sequence of 1–2–4 to be able to bring the bucket from the bottom of the well to its curb. The general law that governs the operation of this mechanism is based on the distance between the supports of the pulleys and the distance to the bottom. For the device to be effective, the distances between pulleys must be in a geometric ratio of 2 (Fig. 7). With this design, the length of rope to be picked up is reduced, but the lifting force of the water is increased since the force necessary to lift each pulley is twice that of the lower pulley.

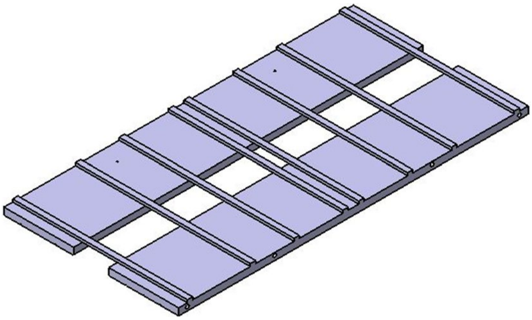
5 Digital Modelling

As a previous step to the physical reconstruction of the two aforementioned artefacts it was necessary to carry out a digital modelling of them. CAD software CATIA[2] has been used for digital modelling, which allows the design of the parts, their assembly and the conversion of each part to the STL file format needed for the 3D printing.

The original manuscript of the book of secrets contains some drawings and schematics of the artifacts, but they are deteriorated by the passage of time and present quite a few inaccuracies. For this reason, to design the geometry of the different pieces of each artifact, it has been necessary to take as reference the reproductions of the original work made by the engineers of the Leonardo3 studio (Al-Murādī, 2008). In these reproductions, an interpretation of the original schematics of the codex is made with 3D simulations (Figs. 3 and 6). The simulations show the operation of the artifacts with some clarity, but do not contain

[2] CATIA software (Computer-Aided Three dimensional Interactive Application) is a computer program developed by Dassault Systèmes for computer-aided design, manufacturing and engineering. More information at website https://www.3ds.com/products-services/catia.

Fig. 8 Floor platform design



detailed drawings or dimensions. For this reason, in order to make a digital model that could later be printed, the design had to be reinterpreted and resized based on these simulations and the little information in the original codex.

The reproduction scale has been decided based on the limitation imposed by the size of the 3D printer's printing plate, which does not allow a printed part length greater than 200 mm. Therefore, the largest piece has been designed based on this limitation, and the rest of the pieces have been scaled to maintain the geometric proportion.

5.1 Modelling Fortress Demolisher

As there is not a clear reference to the geometry or elevation height of the Fortress Demolisher scissor mechanism in the Book of Secrets, the height has been deduced from the information in another mechanism in the book with a similar lifting system, the 22th mechanism called Mechanical Tower. After interpreting the data from this mechanism, it was deduced that the platform rise from a height of three meters to a height of eleven meters. A design of the scissor mechanism has been made based on these measurements, adapted to the reproduction scale. The rest of the elements have been designed with dimensions proportional to the scissor mechanism.

The first pieces designed were the floor and the lifting platform (Fig. 8). These are the largest pieces and are the ones that will condition the final size of the reproduction. The rest of the pieces were designed to the same scale.

Then the scissor mechanism, the winch, and the wheels and rails for its movement were designed (Fig. 9). Four units were assembled to form the four columns of the elevation system (Fig. 10).

Subsequently, the ram and the upper structure that supports it were designed. All these pieces were assembled on the elevation system (Fig. 11).

Finally, the protective side walls were designed, on which some aesthetic details were made (Fig. 12).

An attempt has been made to make the reproduction as faithful as possible to the original model. However, because the design is oriented towards its subsequent 3D printing and manual operating, small modifications have had to be made in order to print and later assemble the parts. For example, to reproduce the movement of the scissor mechanism and that it could be carried out with only two hands, the shafts

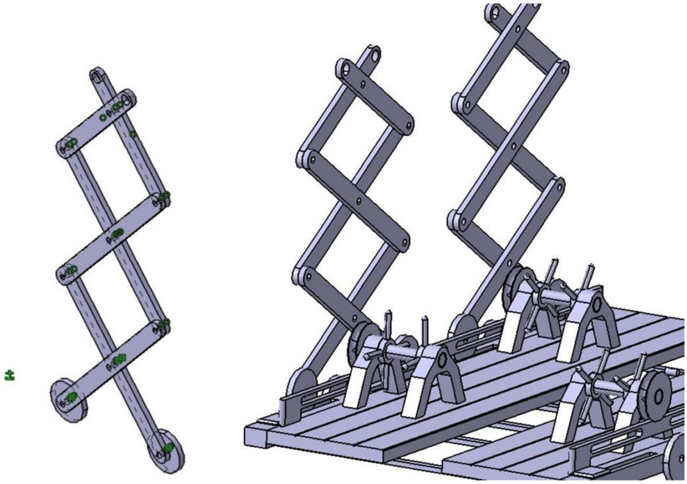
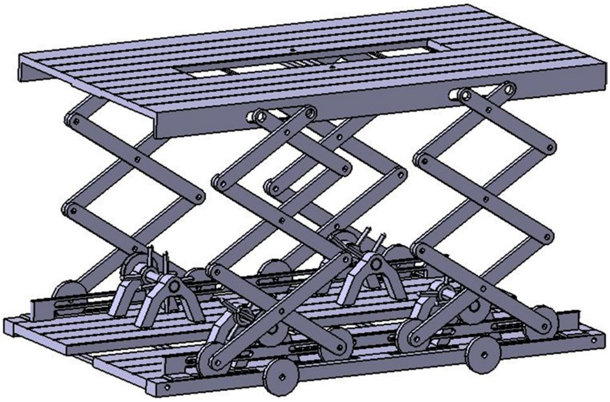


Fig. 9 Details of scissor mechanism

Fig. 10 Assembly of the elevation mechanism



that move the pulleys have been lengthened to be able to be driven from the outside (Fig. 13).

To give greater realism to the designed Fortress Demolisher, its design has been rendered resulting in the image shown in Fig. 14.

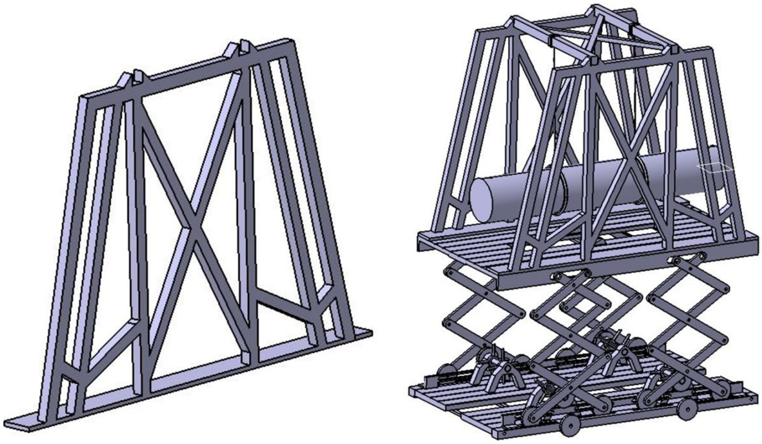


Fig. 11 Details of the upper structure and the ram

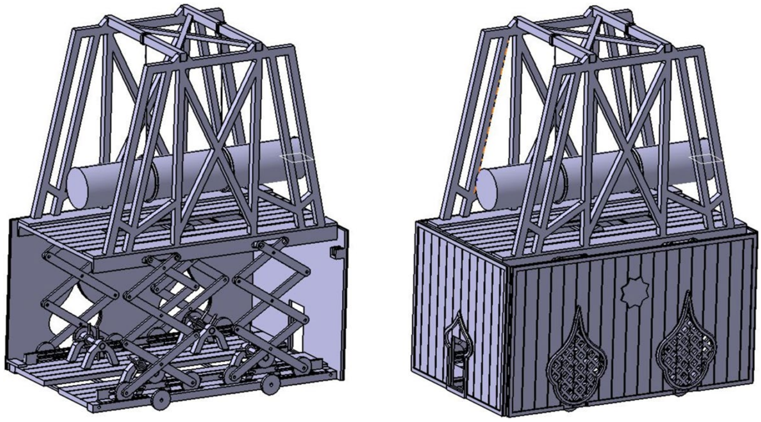


Fig. 12 Fortress demolisher complete assembly

5.2 Modelling Magic Well

The dimensions of the pieces of the digital model have been designed by scaling the depth of the well with the maximum dimension available in the printer. All pieces have been scaled according to this ratio.

In Figs. 15 and 16 we can see some of the parts designed, and the complete assembly of the elevation system. The pulley, being the smallest element, was designed on a larger scale to be able to be printed and assembled without problems.

Magic Well has also been rendered and textured to give it more realism. The result is shown in the Fig. 17.

Fig. 13 Detail of modified shaft to facilitate manual operation

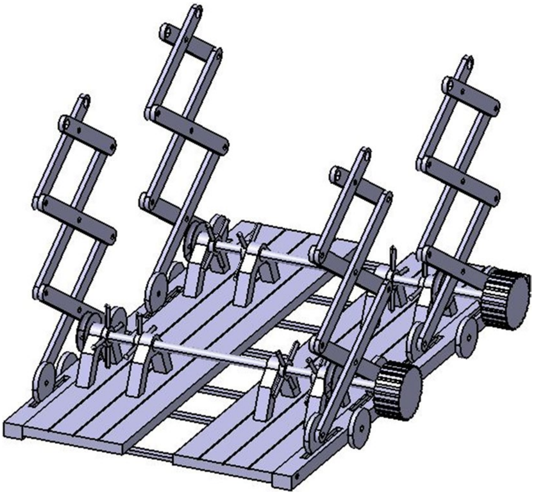
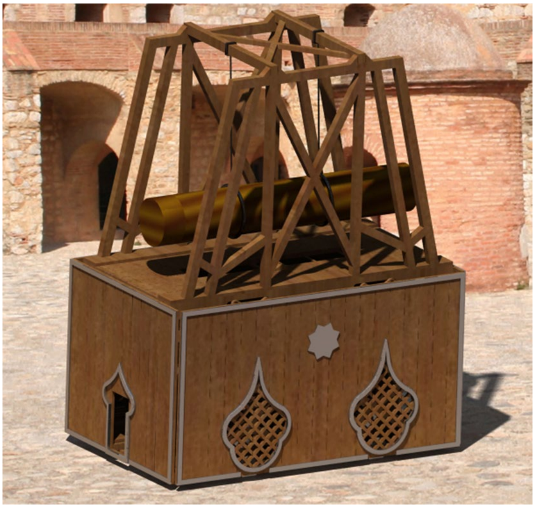


Fig. 14 Fortress Demolisher digital reproduction



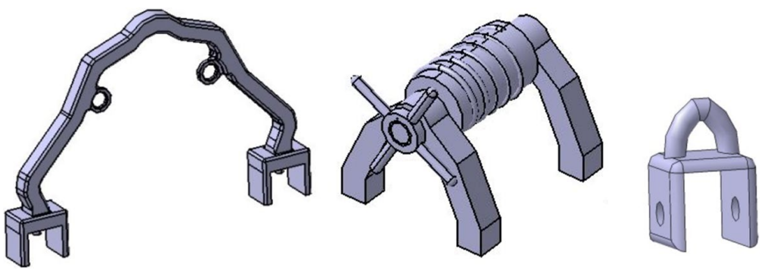


Fig. 15 Design of arc, winch and pulley

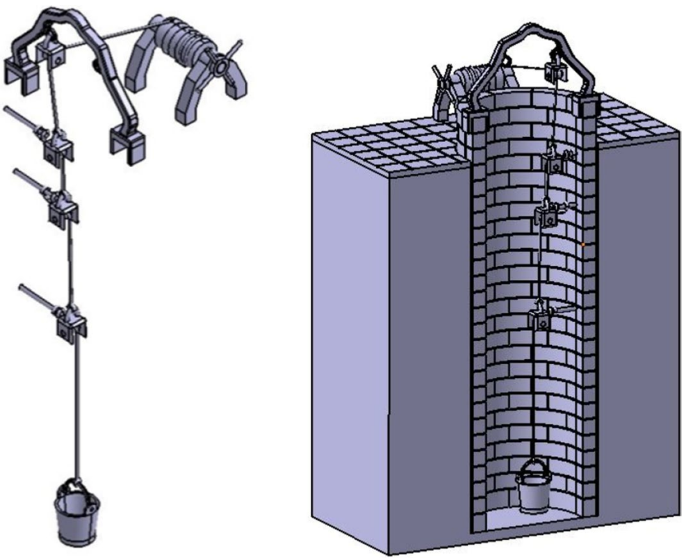
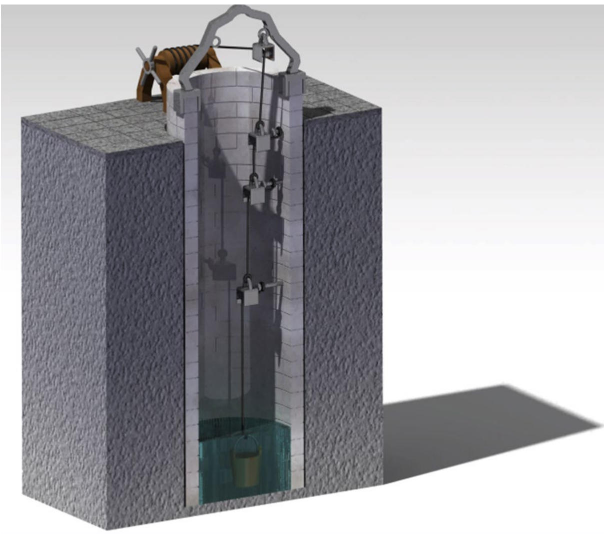


Fig. 16 Complete elevation system assembly

Fig. 17 Magic Well digital reproduction



6 Physical Reconstruction

6.1 3D Printing

Once the digital modelling was done, the two artifacts have been physically reproduced. All the parts of the mechanisms were manufactured with a 3D printer using Fused Deposition Modeling (FDM) technology. FDM technology is based on depositing layers

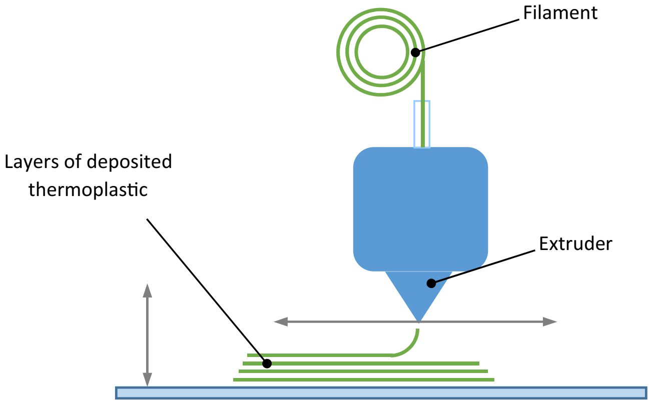


Fig. 18 Scheme of movement of a FDM printer

Table 1 Characteristics of PLA filament

Recommended printing temperature	200/220 °C
Melting temperature	145/160 °C
Glass transition temperature	56/64 °C
Density	1.24 g/cm^3
Filament diameter	1.75 mm

of a molten polymer filament according to a horizontal path followed by an extruder (Fig. 18). The polymer is extruded at a temperature close to melting temperature, so it quickly solidifies after being deposited. The overlapping of solid polymer layers allows the generation of three-dimensional structures. The movement of the extruder is what defines the geometry of the printed part. This movement is governed by an alphanumeric code similar to the ISO code used by Computer Numerical Control (CNC) machines (Gibson et al., 2010).

Starting from the digital model made with CATIA software, a discretized STL model can be obtained. This model approximates the surface of the three-dimensional object with a closed triangle mesh. The discretized file is processed with a slicer software that performs horizontal slices of the discretized model. The intersections of the triangular planes with the horizontal planes generate joined straight lines that mark the contour of the part in each plane. The coordinates of these lines are those that the extruder will follow to deposit the molten polymer.

The Ultimaker CURA 3.6[3] (Ultimaker, 2022) slicer software was used to generate the GCODE text file with the code of the paths and the conditions of the movements. This file is reproducible by the 3D printer to generate the part. This software not only allows the processing of the digital model but also manages its printing by choosing the critical printing parameters such as temperature, printing speed, layer height, wall thickness, filling type and density, etc.

[3] Ultimaker Cura is an open-source 3D printing management and slicer software developed by Ultimaker. More information at website https://ultimaker.com/software/ultimaker-cura.

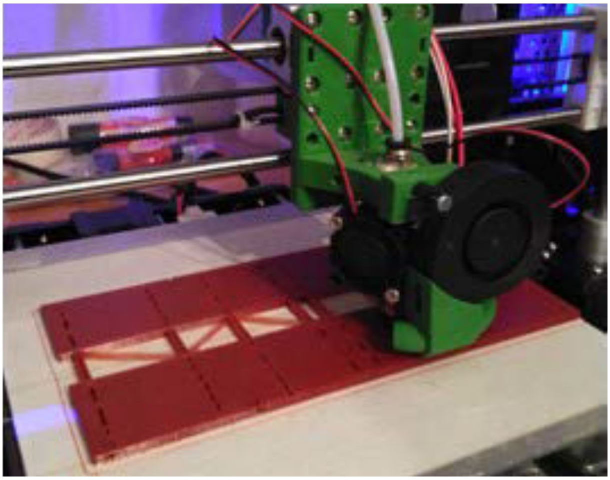


Fig. 19 3D printing process

Table 2 Main printing parameters

Layer height	0.1 mm
Wall thickness	1 mm
Top/bottom layer thickness	1 mm
Infill density	20%
Infill pattern	Triangular mesh
Printing temperature	210 °C
Print speed	60 mm/s
Infill speed	80 mm/s

6.2 Materials and Printing Set Up

The material used for the printing of the mechanisms parts has been PLA (polylactic acid). The PLA is a biodegradable thermoplastic polymer obtained from cornstarch, and is widely used in molten deposition printing. PLA does not have great mechanical resistance but is widely used for prototype reproduction due to its ease of printing and low cost. To give the reproduction more realism, gray and brown filament spools have been used, which simulate the stone and wood that would be the originally used materials. Table 1 shows the characteristics of the PLA used.

An ANET A8[4] printer has been used for printing, which is a low cost printer with quite good print quality for its price. The printer has a square print surface of 200 mm per side, and a maximum print height of 215 mm. These printing dimensions conditioned the scaling of the printed parts. To reduce vibrations and improve the quality of the finished parts, the original design of the printer has been modified, lightening the weight of the extruder by changing the position of the extrusion motor (Fig. 19).

Table 2 shows the value of the main printing parameters.

[4] ANET A8 is a low cost FDM technology 3D printer developed by Anet Technology Company. More information at website https://anet3d.com/pages/a8.

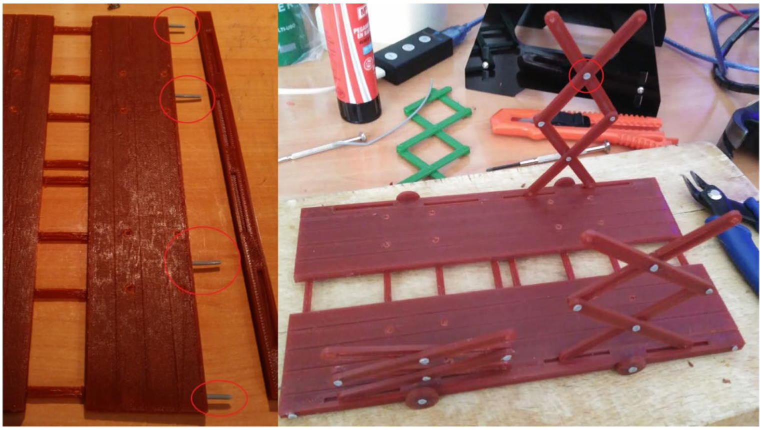


Fig. 20 Detail of the assembly of the joints

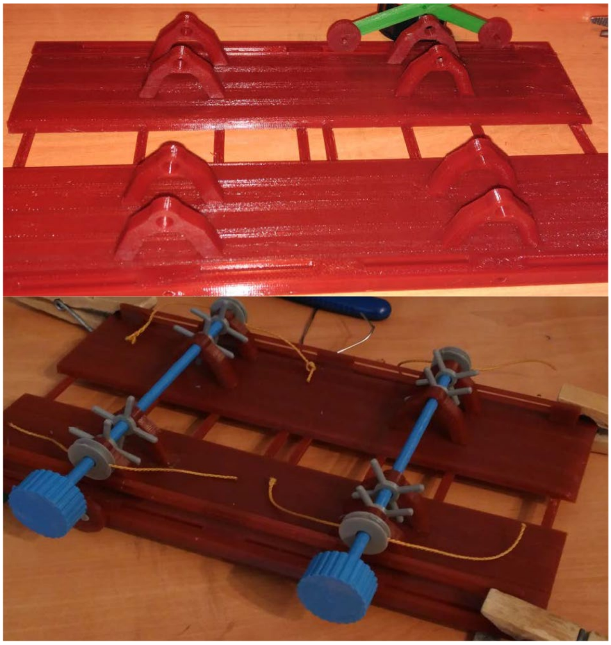


Fig. 21 Lifting mechanism shaft alignment

6.3 Assembly and Real Scale Reproduction

After printing all the parts, they were assembled to obtain a real scale reproduction of each artifacts. The union between parts were made using a cyanoacrylate adhesive, since its result in the gluing of PLA is very satisfactory. To join the larger fixed parts, a joint system with holes and shafts has been designed, which facilitates assembly and gives greater

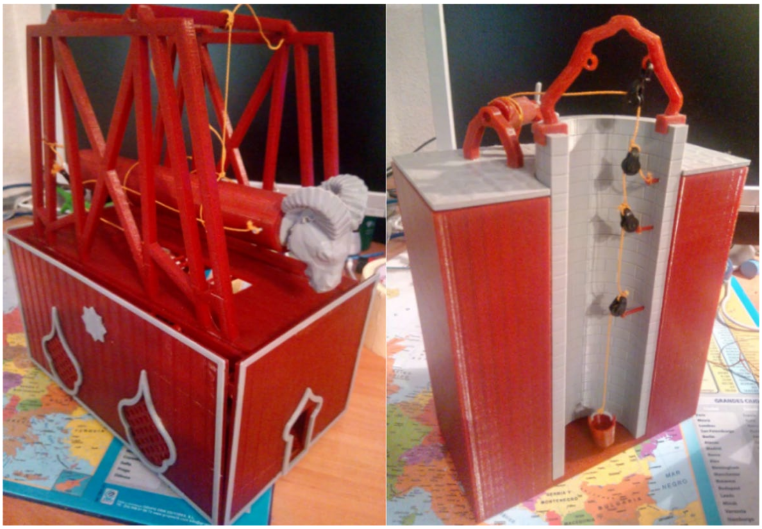


Fig. 22 Fortress demolisher and magic well real scale reproduction

stability to the reproduction. For the union of the mobile elements, such as those of the scissor mechanism, small shafts were manufactured and inserted between the moving parts. The end of the shafts was flattened by applying heat, acting as a rivet (Fig. 20).

To ensure the correct operation of the fortress demolition lifting mechanism, the eight trestles that house the shafts for manual lifting had to be aligned and adjusted (Fig. 21).

Figure 22 show the results of the two reproductions.

The only difficulty in assembling the Magic Well is determining the length of the strings. Before the printing of his pieces, a physical simulation was made with a wooden slat and four eyebolts to which the rope was attached. The length of the rope was varied until reaching the solution that was closest to reality. Due to their small size, the pulleys could not be printed to the same scale as the well. Pulleys with a larger scale have been used to be able to give it a real movement.

7 Conclusion

As a result of this work, the digital modelling and physical reconstruction of two medieval artifacts, the "Fortress Demolisher" and the "Magic Well" have been obtained. Digital modelling allows to study in detail the geometry of artifacts and to subject them to mechanical analysis using engineering software. The physical reconstruction allows to study its movement and operation in a more visual and didactic way. The study of historical machines allows us to deepen our knowledge of the most elementary mechanisms and better understand the evolution that has been followed up to the most complex actual mechanism designs.

The use of new technologies allows us to take another step in the transmission of knowledge. Nowadays knowledge is not only transmitted through printed writing, but it is mostly done digitally in written, graphic or audiovisual form.

The use of 3D printing in the reproduction of machinery or mechanisms, manages to go from digital information to a real three-dimensional scale model, quickly and economically.

This physical reproduction allows a more direct interaction with the reproduced artifact. This can help to understand the functioning of the mechanisms that compose it, which is a great help for students, especially in the field of mechanical engineering.

The reproductions presented in this work are the results of some of the final degree projects of students of the degree in mechanical engineering at the University of Jaén. The aim of these projects is that the students complete their training in the areas of manufacturing and mechanical design. It also provides the university with a collection of physical mechanisms to be used as learning elements in initial courses.

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