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Computer-aided Design in the Recovery and Analysis of Industrial Heritage: Application to a Watermill*

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Applications of computer-aided design (CAD) techniques in the creation of teaching tools used in applied history of technology and mechanical engineering are described. We present the recovery and analysis of an old wheat mill, which used water as its energy source. The mill has been completely modelled using SolidWorks™ software, and a computer animation of the production process has been generated using 3DStudio Max™ software. The generation of CAD models and learning from simulations is the subject of the course in technology history.

Keywords: Computer-aided design, watermill, industrial heritage, computer animation, industrial archaeology, engineering education.

PROUD HERITAGE

THE IMPORTANCE of recovering the industrial heritage left by our ancestors is unquestionable. Equipment which is no longer functioning, often incorporating mechanisms which were revolutionary in their time, still gives us the opportunity, once graphic and technological restoration has taken place, to see it at work in all the pride of a previous industrial age.

Computer-aided design techniques are playing an important and varied part in restoration projects. Their possibilities are numerous, if only because they allow us to construct three-dimensional models of mechanisms in which we can identify and analyse technological characteristics [1], [2]. They have been applied and are reported here as part of a doctoral thesis.

The engineering artefact concerned is a watermill in the south of Spain. It has features in common with all Spanish watermills, as it is situated on a river with a small and irregular flow. A diagram which shows how it would have worked can be found at www.waterhistory.org/histories/waterwheels. Its type was widely used in the past and is still used today in some corners of Spain to process wheat and produce flour.

First, we had to carry out rigorous fieldwork. The mill is derelict and many of its distinctive features had to be reconstructed hypothetically from oral testimonies [3]. Assisted by these 'memories' and the results of more substantial investigations we were able to move towards the construction of a three-dimensional model of the mill, including all the machinery and its connections, in order to generate high quality computer animations. These animations could then be used in engineering courses, both to show old production processes, and also to illustrate the different stages in the construction of CAD models.

THE WATERMILL

The watermill which is the object of this study is situated in Alcalá La Real (Jaén, Spain). Between 1750 and 2000, up to 290 watermills were functioning in the Province of Jaén, among a total of 21,792 in the whole of Spain [4].

The first known data are from the 17th century. At the beginning of the 20th century, a mill for oil production was built alongside the existing flour mill, using the same source of energy, water.

In 1949 a diesel engine was added to power the oil mill, as the force of the water was insufficient to power both mills at the same time.

In 1979, after several reforms, the flour mill ceased operation. This was due to the scarcity of Valencian 'local' wheat, and the growing practice of buying bread with money which was replacing the traditional barter system of exchanging bread for wheat. Moreover, the work involved in milling flour with a primitive water mill was proving unacceptably laborious in the opinion of millworkers, and it was more convenient to buy flour from large flour factories.

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There were technological reasons also for the loss of popularity. The force of the water moved only an old milling stone, and the waterwheel was replaced by a centripetal turbine in order to obtain more power. The mill ceased functioning at the end of the 1980s.

COMPUTER-AIDED DESIGN

Before beginning the modelling process, fieldwork was carried out for about a year, consisting of sketches and determining dimensions of the mill and its machinery, based on what we were told and, more precisely, what we were able to glean from records and the literature; how realistic the final CAD model would be depended on the accuracy and precision of this information. Therefore, it was important to ensure that the subsequent mechanical calculations made with the help of computer-aided engineering would be as reliable as possible.

The software used was SolidWorks^{TM} [5]. This package was chosen because of its outstanding performance in comparison with other more educational software. The modelling of different machinery is generally carried out from simple elements, which, with extrusion, revolution or cutting tools, among others, are converted into solid models. These simple elements were obtained from the sketches made and photographs taken during fieldwork.

The final model of the mill is shown in Figures 1 and 2.

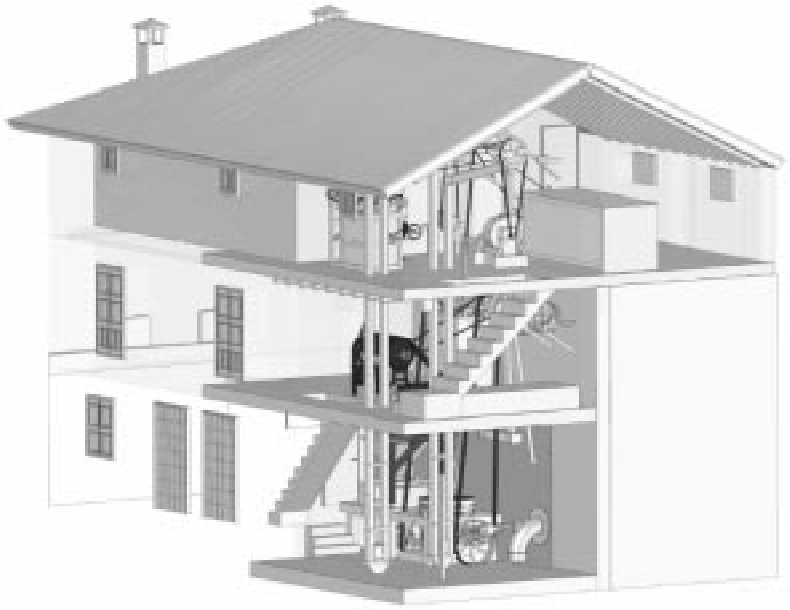

Fig. 1. Axonometric view of watermill.

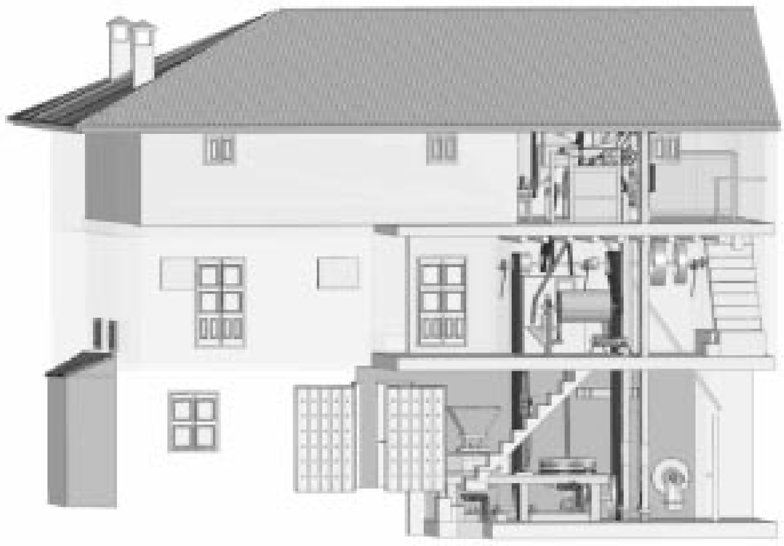

Fig. 2. Front view of watermill.

As can be seen in Figures 1. and 2., this type of mill had three floors. The ground floor housed the milling stones and the turbine; the first floor the machinery for washing and dampening the wheat; and on the top floor all the machinery for cleaning the wheat and the flour, as well as the transmission shafts and the pulleys which moved the machinery. The miller's house also formed part of the structure of the mill.

COMPUTER ANIMATION

The machinery and equipment which formed the mill had to be realistic, not only in their geometric forms, but also in terms of appearance and colours, as light and texture had to be applied to them. A specific program called *3DStudio Max* was used [6], because of its ability to generate high-quality photo-realistic images, using image and texture maps.

The format of files generated with SolidWorks is **.sldprt* and that of the assemblies is **.sldasm*. In order to import files from 3DStudio Max, the mill machinery, made up as an assembly of parts modelled in SolidWorks was saved in **.stl* format (stereolithograph), a generic format for the majority of CAD programs.

All the parts of each piece of machinery were imported from 3DStudio Max in **.stl* format until the assembly of the machinery was complete, and this was then saved in **.max* format. It is important to note that each part in the final assembly maintained all the characteristics that it had in the SolidWorks assembly, including its position. Once the machinery had been imported, solid and wire models could be generated, and the suitability of the mechanism checked (Figures 3 and 4.).

Once the complete assembly of all the parts of the machinery had been imported and checked, the appropriate materials were assigned to each part. For the model to appear as real as possible, its texture had to be right, so this was taken directly from the photographs.

All textures were created with the application software which adapts optical characteristics to the needs of the model. In this way, the opacity, reflection, refraction and relief, among others, play an important role in the quality of the texture applied.

Given the complexity of what had to be modelled, non-animated machinery and scenes in the mill (which only need texture and lighting) were created separately from machinery involving movement (to which texture, lighting and movement were applied).

We applied the colours of each material to each mode (ambiental, diffused and specular) and adjusted other parameters such as brightness, intensity, lighting and the opacity of the material, which allowed us to create materials with different degrees of transparency, such as glass or water. The creation of materials is a complex process and if it not done correctly, the part will lack realism.

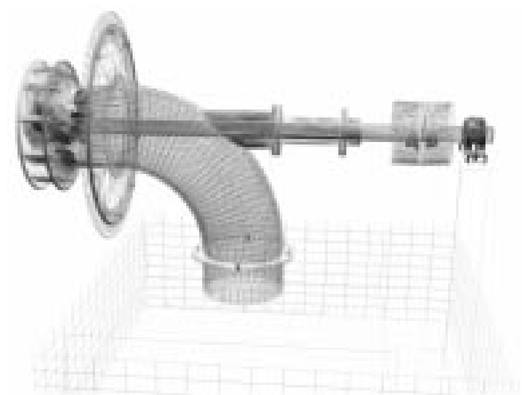

Fig. 3. Wire model of centripetal turbine.

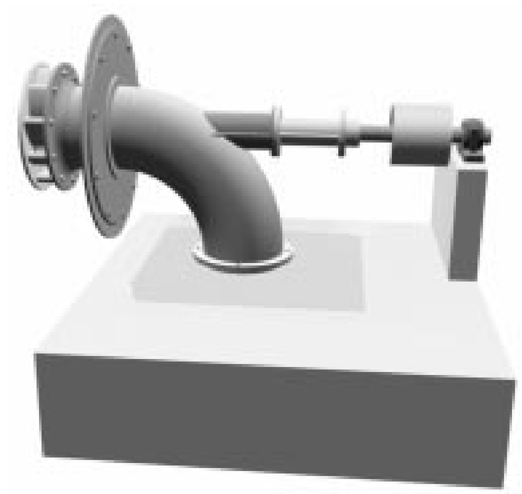

Fig. 4. Solid model of centripetal turbine.

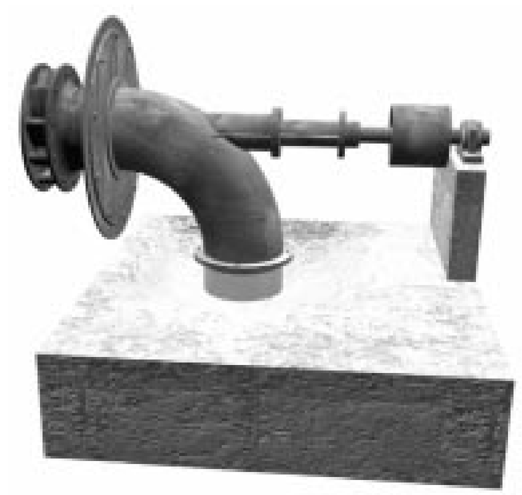

Fig. 5. Texturized model of centripetal turbine.

All the photographic compositions of textures were subsequently improved, modified, cut and corrected with Adobe Photoshop [7]. Figure 5. shows the model with textures of the centripetal turbine.

Once the textures had been applied, the machinery and transmission elements were geometrically

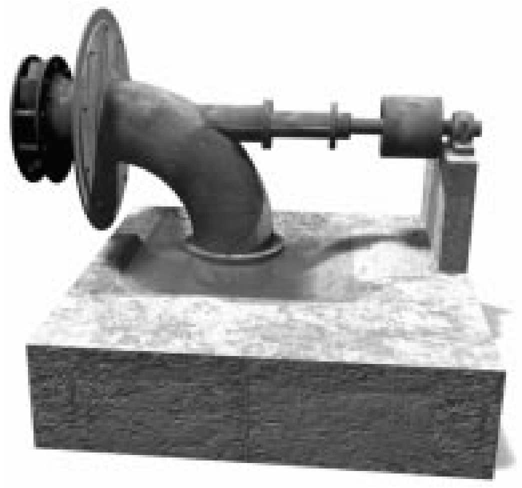

Fig. 6. Final model of centripetal turbine.

Fig. 7. Real state of centripetal turbine.

related, and in turn properly positioned in the building. In order to introduce and assemble the pieces of machinery correctly in the building, measurements of their positions were taken in relation to walls, ceilings, corners, using any reference that allowed the precise determination of their location in the construction.

Lighting and shading were selected so that machinery inside the mill could be seen in the most realistic conditions possible. Natural light was 'engineered' by placing a source of sunlight outside the mill. This had to have an appropriate elevation and inclination, similar to that of a spring morning entering the mill through windows and doors.

For artificial interior light, light sources were incorporated to imitate lamps hung from the ceiling and filler lighting. All these light sources generate shadows to determine the degree of realism, which can be compared with the photographic report. Figure 6 shows the result of the final model with textures, light and shade of the turbine.

Figure 7 shows the turbine in its final state, and confirms the high degree of realism which has been obtained with the CAD model.

These programs also generate exploded views, which allow us to understand how the machinery was assembled. Figure 8 shows the assembly of the mill's centripetal turbine.

Finally, Figure 9 shows a general view of the complete assembly, with working connections between the mechanisms, including the transmission shafts, pulleys, and everything else involved in the process and transmission of movement.

In order to video the procedures, it was necessary to carry out a cinematic study and calculate the rotation speed of each of the shafts, which, with the diameters of the different pulleys, assisted the re-creation of uniform relative movement. In this way, one of the objectives of this study was achieved, namely, to reconstruct the mill virtually and to simulate its functions.

Two videos have been produced, one of which shows an approach to the mill and a virtual tour of its surroundings and the characteristics of the building, and another which tours the different areas inside the mill and shows it in full working order. Each floor comprises views of the machines, transmissions, conduits for wheat or flour and the workings of the mill. The program Adobe Première was used [8] to edit the sequences of the video.

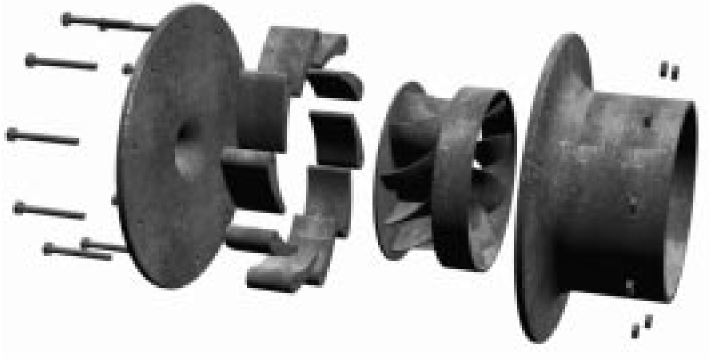

Fig. 8. Exploded view of centripetal turbine.

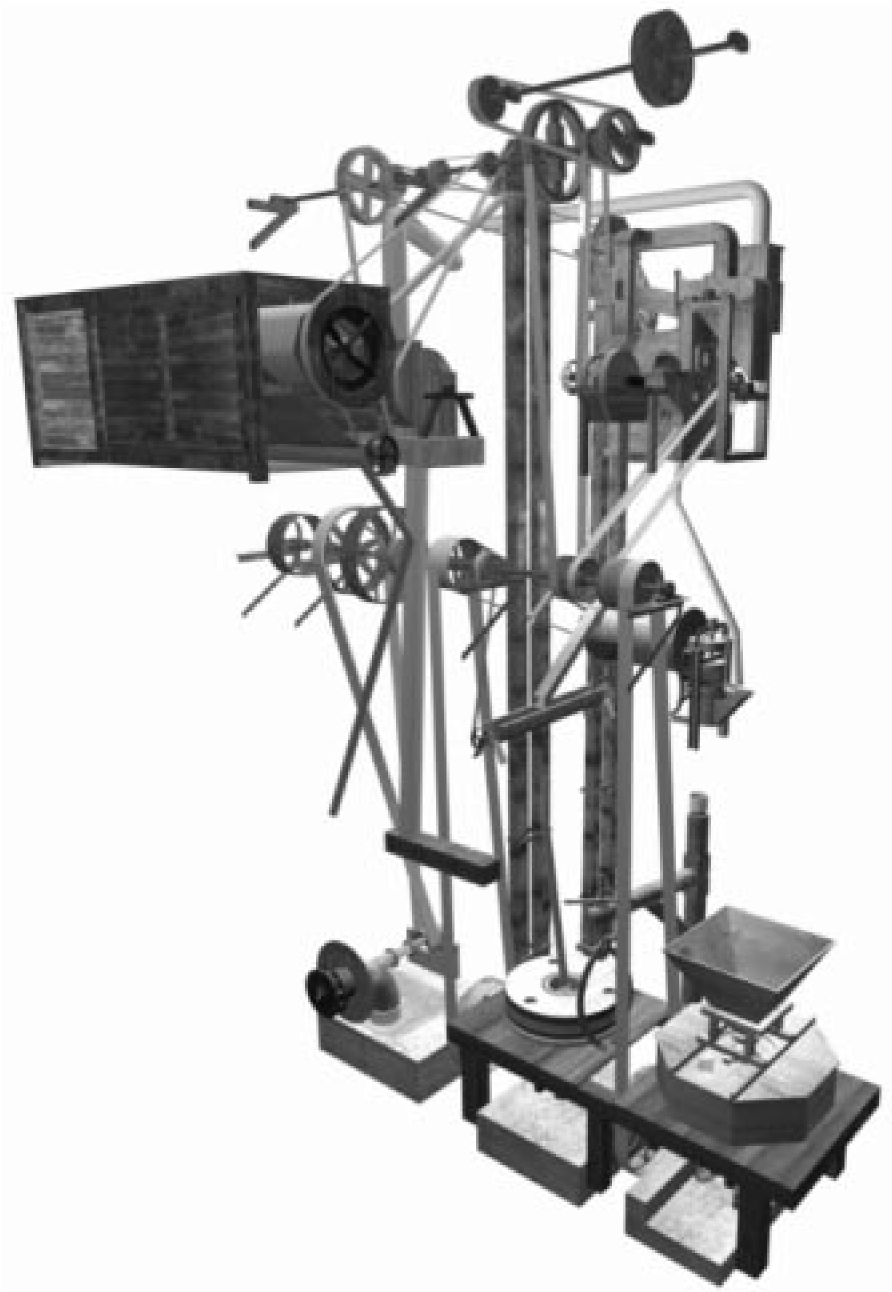

Fig. 9. Axonometric view of mechanical connections of the installation.

TEACHING CONSIDERATIONS

The objective of the computer animation was to recreate virtually the whole mill, in order to observe how it worked; given the current state of the mill it could never work again. It was necessary, therefore, to apply textures taken from the photographs of the mill to the CAD models generated, so that they are as faithful a representation as possible of the real mill. The objective was, therefore, not to show the texture of the technology, but rather to show step by step how CAD models are generated from a wire model, through a solid model, a model with texture and finally a model with illumination and shading.

Another objective was to show that with CAD models it is possible to obtain exploded views, so revealing the elements of a machine, which can be moved or modified.

About the CAD models

The CAD models were given to the students in class so that they could observe how the workings of the mill were implemented, that is, which operations were used (extrusion, revolution, etc.) in the construction both of the machinery and the building, and make exploded views of some of the machines.

A few days later, after the CAD models had been studied, but without them being present, the students were asked in class to explain how the models were generated and what problems arose when working with them.

Lessons learned from student involvement

It is well known that graphic language is a universal language, and that visual representation helps learning. With a CAD program, it is common to encounter resistance to change when a new version is used instead of a known version, which leads to a lack of motivation. However, with computer animation the students' motivation is very high when the degree of realism in the simulation is good, irrespective of the version of the program with which the simulation has been made. That is, any simulation should have a high degree of realism in order to attract the attention of students and improve their motivation.

Also incorporated in the simulation was a cinematic perspective used to study the true speeds (rpm) of the pulleys and milling stones. Without this, it would not have been possible to relate an animation of 25 frames per second to the true speed of the pulleys. A basic engineering study was crucial if we were to achieve a simulation which faithfully reflected the speed relationships between the pulleys and therefore showed the true speeds of the machinery. Without this, the simulation would not have appeared real.

It was important to create more than one simulation of the mill and the machinery, one to show the mill and the location of the machinery, and another which only showed the working machinery, principally so as not to distract the students with the productive environment of the mill.

EXAMINATION QUESTIONS

The questions related to the simulations were posed at the end of each demonstration. The questions relating to the first simulation were concerned with the spatial geometry aspects of the mill. The questions relating to the second, i.e. the technical simulation, were:

1. What was the energy use based on?
2. Did the turbine shaft transmit power directly to the shafts of the milling stones?
3. If not, to which shaft was the power transmitted?
4. Which element moved and turned the milling stones?
6. What type of gearing was there?
7. What was the gear ratio?
8. Were the milling stones joined by the same axle?
9. Which transmission shaft operated at the higher speed?
10. Which machines were operated by each of the transmission shafts?
11. What types of transmissions were used?

The results were very good; almost 85% of the students answered all the questions correctly for each of the animations.

CONCLUSIONS

The teaching methods used in the application are based on the two different simulations.

The first simulation showed the architectural structure and the layout of the mill, with the disposition of the machines, the spaces between them and their characteristics. Thus, it shows the different floors in the building and which machines were on each floor, encompassing details of the architecture and the construction.

The second animation showed the turning speed of the stones and of the machines powered by the belts of the pulleys linked to the transmission shafts, the diameters of the pulleys, the ratio of the conical gears and the working of the conduits (pipes and bucket lifts) which transported the wheat, other subproducts and the final product (flour). The machines are outside their architectural setting, following a helicoidal trajectory.

The importance of computer simulation in engineering studies is clear. History of engineering is explained by the technological evolution which has taken place in the field under study. The transformation which machines undergo requires a vision of their physical presence and their setting.

However, given the abandoned state of the old production processes and of the machinery, the simulation becomes a powerful tool which allows us to understand a process and to compare it with current technology.

In some cases, some machines and production processes are renovated by science and technology museums, but there are without any doubt many process that have been forgotten, and which without the use of simulations would never be recovered.

Simulation is an effective teaching tool for history of technology studies.

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