Virtual and Augmented Reality: Applications for the Learning of Technical Historical Heritage

José Ignacio Rojas-Sola[1*], Ángel Aguilera-García[2]

[1] Department of Engineering Graphics, Design and Projects, University of Jaén, Campus de las Lagunillas s/n, Jaén 23071, Spain

[2] Department of Computer Science, University of Jaén, Campus de las Lagunillas s/n, Jaén 23071, Spain

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ABSTRACT

This manuscript presents two applications developed for learning about the details and operation of Agustín de Betancourt´s machine for cutting cane and other aquatic plants in navigable channels and rivers, drawing on virtual reality for personal computers under Windows and augmented reality for mobile devices based on Android, along with a 3D printing of the 3D model. Similarly, in the case of augmented reality an algorithm for the selection of parts or systems has been developed that shows the technical information of each piece or system of this historical invention. Finally, the evaluation of these applications has been satisfactory according to the results of an anonymous survey with 7 questions given to a group of 10 people because the values obtained from statistical variables such as the mean, median and standard deviation prove it.

Keywords: Technical Historical Heritage, Innovative Application, Engineering Learning, Virtual & Augmented Reality.

1. INTRODUCTION

The irruption of digital technologies in the educational processes has supposed a revolutionary advance since it has allowed the generation of applications which facilitate learning and improve the academic yield of engineering education. The applications of educational software, virtual and augmented reality (VR & AR) and 3D printing are all moving in this direction.

This manuscript presents an experience in which applications of virtual reality and augmented reality have been generated in order to explain an example of a historical invention developed by Agustín de Betancourt in 1795, the first machine for cutting cane and other aquatic plants in navigable waterways (Figure 1). The invention essentially consists of a horizontal drive system, another vertical one (where the double blade is located), and another of rotation of the vertical wooden frame in order to align the blades with the inclination of the slope of the channel so that the operation is carried out properly.

Figure 1. Isometric view of the 3D model.

Agustín de Betancourt was a celebrated Spanish engineer of the 18th century who was born in Puerto de la Cruz (Tenerife, Spain) in 1758 and died in Saint Petersburg (Russia) in 1824. His historical inventions had a major impact as many of his inventions contributed to the publication of his excellent work "Essay on the composition of machines" published in Paris in 1808 with his colleague José María Lanz.

There exist several publications that deal with the applications of virtual and augmented reality in the field of engineering education. For example, we can find applications of augmented reality that deal with technical drawing concepts related to the spatial conception and visualization of pieces [1]; as support for machinery operations in scholar environments [2]; AR-based value-added visualization of infographic for enhancing learning performance [3]; systems in augmented reality learning environments which give the possibility of adding 3D objects, animations of 3D objects, videos, audio files and images [4], and the assessment of augmented visualization methods in multimedia engineering education [5].

There are also publications related to virtual reality applications that deal with the creation of virtual laboratories for learning geophysics [6], with a framework for using mobile for experiential construction safety education [7], for learning systems through haptic simulators [8], VR applied to civil engineering education for construction activities supported on interactive models [9], a virtual laboratory for the study of technological process automation [10], for improving student understanding of complex spatial arrangements [11], with interactive building anatomy modeling for experiential building construction education [12], and the development of virtual equipment such as the Venturi tube experiment [13].

After this review of the publications regarding virtual and augmented reality in educational areas in engineering, it can be seen that there is no application for the learning of historical technical heritage, so this previously-unpublished and original work becomes very relevant.

1.1. Objectives

The objectives of this investigation have been to:

- Generate an application of virtual reality in order to improve the understanding of the operation of historical invention.
- Generate an application of augmented reality in order to facilitate detailed knowledge of the historical invention, identifying each of the pieces or systems with an indication of their main technical characteristics through the design of markers.
- Develop both tools in a graphic engine with wide implementation in the development of digital technologies.
- Print the 3D model with additive manufacturing techniques.

2. MATERIAL AND SOFTWARE USED

2.1. Material

The starting material was the digital restitution of the 3D model of said invention carried out in a reliable way with Autodesk Inventor Professional from the information available in its file, consisting of a series of non-scale sheets and a brief description, provided by the Canary Orotava Foundation of the History of Science [14].

2.2. Software used

Different software was used to create the two applications. Although there are several graphics engines especially indicated for the creation of video games and applications of VR and AR such as Unity, Unreal Engine, CryEngine or Inscape 3D, the first of them has been chosen, as it is the most widely deployed and is considered one of the best. It is available as a development platform for Microsoft Windows, OS X and Linux. It is programmed in C, C ++ and C Sharp, and has both free and proprietary licenses.

After a brief review of the scientific publications in which this software has been used, it has been possible to find several which deal with very diverse topics, which shows the wide range of possibilities of this software. Among these can be found publications that deal with the development of a pedestrian simulator [15], the development of a virtual reality game for the improvement of the physiological functions and stability of older people through physical exercise [16], the development of a virtualized multimedia system for shoulder pain rehabilitation [17], and the development of a collaborative virtual environment for training teams in emergency situations [18]. Thus, it can be observed that there is no application developed for learning technical historical heritage, which confirms the originality, convenience and opportunity of this work.

In a similar vein, Visual Studio has also been used for programming scripts, Vuforia for augmented reality, and SDK-Android and Java JDK used for the generation of the augmented reality app.

Finally, in order to be able to make changes in the meshes or generation of animations various software applications such as Blender have been used to convert .stl files (stererolithography) into .fbx files, and CrazyBump, for the creation of textures with Bump Mapping.

Thus, from the 3D model of each piece (.ipt) that makes up the final assembly (.iam) generated with Autodesk Inventor Professional, previous operations have been followed. In the first place, said files (.ipt) were exported as .stl files, and subsequently imported to Blender in order to export them in the .fbx format.

First, the final assembly of each 3D model (.iam), could not be exported completely because it could not be animated, so we proceeded to previously identify the parts or systems (set of related parts) for which we wanted to provide animation, identifying for each of them the mesh of triangles and the limits to their movements. Thus, once these pieces were imported into the software environment they were assembled one by one, since in many cases the pieces were not in their exact position, and imaginary axes were attached to certain pieces (the blade, the crank, the worm screw, and the radius of the horizontal rotation system), in order to be able to realize the animations of their movements.

Thus two animations were designed, one with the barge moored to the jetty and another with the barge sailing. There were also three programmed animations: the swinging of the boat simulating the influence of the movement of water on it; the horizontal rotation system (crank, crank shaft, T-power and bevel gear); the vertical rotation system (vertical axis, double propeller blade); and the movement of the vertical frame in order to adapt the double blade to the slope of the channel.

On the other hand, in order to give a real appearance the textures had to be previously applied with a UV mapping with Blender in order to assign each vertex a texture coordinate since the 3D model did not allow this export either, as it did not add a position reference. Subsequently, the textures and materials were created through topological mapping techniques (Bump Mapping), using the CrazyBump software.

3. APPLICATIONS DEVELOPED

3.1. Virtual Reality (VR)

An application was developed in which a scene appears that recreates a terrain with a channel with slopes on both sides, in which there are a sky with clouds, several machines, a jetty, and aquatic plants on the bottom and sides of the channel (Figure 2). In addition, it was equipped with animation to simulate the movement of water, seeing how this affects the movement of the boats and the movement of aquatic plants.

In the same way, it incorporates a series of buttons that allow interacting on the different animations; for example, it is possible to press on a boat so that if it is in motion it then stops, and if it is stationary it begins to move.

On the other hand, in order for the user to be able to move around the scene an FPS camera controller (First Person Controller) was incorporated, and a series of buttons (keyboard and mouse) added that allow the user to move around the scene.

The virtual reality application was created as an executable with the Windows operating system (.exe) that does not need any installation.

Figure 2. Virtual reality frames.

3.2. Augmented Reality (AR)

Augmented reality combines the real world with the virtual one, enriching the user experience. The main difference with virtual reality is that it superimposes the virtual data on the real model, and does not replace it. It presents different levels according to Vate-U-Lan [19]: Level 0 hyperlinks to the physical world through the use of barcodes and 2D (QR codes); Level 1, augmented reality based on markers; Level 2, augmented reality without markers, replacing these with GPS and the compass to show points of interest on real-world images; and Level 3, or augmented vision, with devices such as Google Glass or high-tech contact lenses. Also, according to Rice [20] a Level 4 could be added where contact lens displays and/or direct interfaces to the optic nerve and brain would be used.

The application developed corresponds to Level 1, that is to say to augmented reality based on the use of markers, and visualizes the animated 3D model of the machine for cutting cane and other aquatic plants associated with the corresponding marker when the camera of the mobile device recognizes the marker.

For the realization of the application of augmented reality Vuforia software was used, since with this software it is possible to add the marker, the 3D models and the associations where to each marker is indicated the 3D model that should be visualized when it is recognized by the camera. Previously one must register on the Vuforia website, create a developer account, and associate a database that contains the images of the markers. Finally, two elements must be configured: the ARCamera, the camera that is responsible for recognizing the patterns of the markers and for viewing the 3D models, and the ImageTarget, which includes the image of the marker and the 3D model associated with that marker. Finally, it only remains to generate the executable of the application in one of the previously-mentioned formats.

Thus, an application for a mobile device with the Android operating system (.apk) has been generated using the SDK software. Also, as a requirement for running the application on Android devices they must have installed version 5.0 (Lollipop) or later, and enough space to store the .apk file and the application once installed.

3.2.1. Marker design

For the design of the marker, a composition of two images and a table was generated (an image of the ensemble of the machine with the marks of all the pieces that form it, an image of the shield of the University of Jaén, and the table of all the pieces that compose it), so that later the user could identify them in the model (Figure 3).

18	1	Vertical-axle tapered gear	Wrought iron
17	1	Horizontal mobile frame	Wood
16	1	Horizontal axle	Wrought iron
15	1	Vertical mobile frame	Wood
14	1	Blade wheel	Wrought iron
13	2	Blade	Wrought iron
12	1	Fixed L-shaped frame	Wood
11	1	Worm screw	Wrought iron
10	1	Quarter gear	Wrought iron
9	1	Arched strip	Wood
8	2	Knee bracket	Wrought iron
7	2	Straight strip	Wood
6	1	T-shaped structure	Wrought iron
5	1	Crank axle	Wood
4	1	Boat	Wood
3	1	Crank handle	Wrought iron
2	1	Horizontal-axle tapered gear	Wrought iron
1	1	Vertical axle	Wrought iron
Reference	**Quantity**	**Term**	**Material**

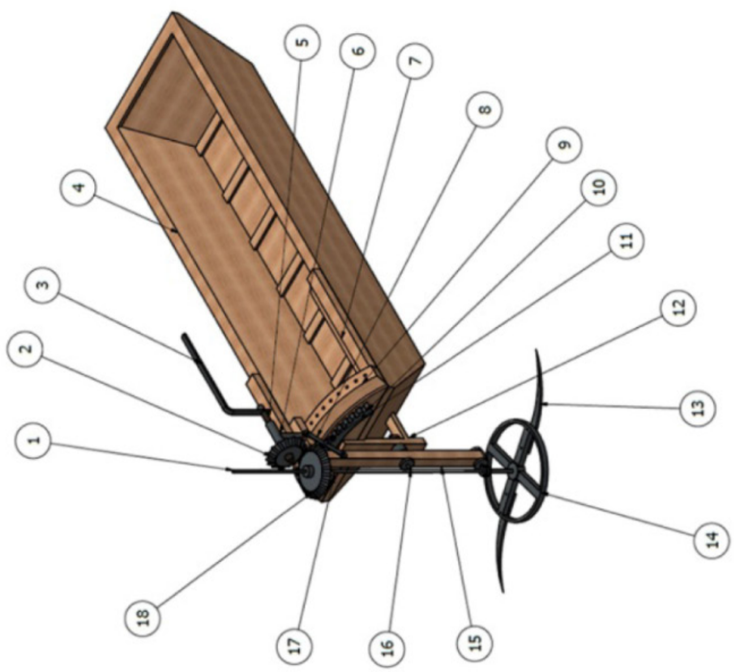

Figure 3. Marker designed for recognition of the historical invention.

Figure 4 shows the result of the application developed after recognizing the marker.

Figure 4. Superimposed 3D model of the invention after recognition by the marker.

Similarly, a new functionality has been added to the application so that by clicking on the Information button in the upper right corner the information of the invention is accessed with indication of the name of the same, of the materials from which it was made and a brief description of its operation (Figure 5).

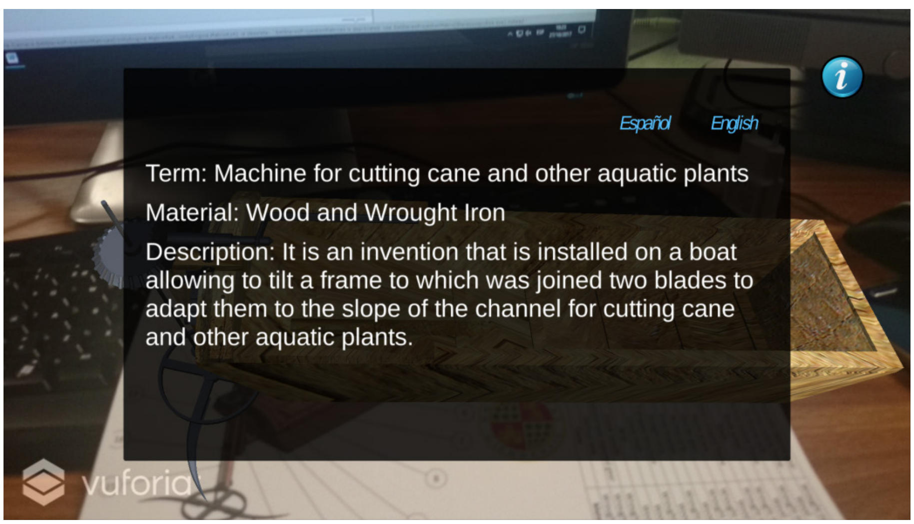

Figure 5. Technical information of the historical invention.

3.2.2. Selection algorithm of parts or systems

For the selection of parts or systems in the superimposed 3D model, an algorithm was developed using the raytracing technique. But previously, two operations must be performed: Each of the parts or systems are labelled as possible selections, assigning them an identifier, and then wrapped in enveloping or parallelepiped boxes in order to be able to subsequently apply the raytracing technique. Figure 6 shows an image of the machine for cutting cane and other aquatic plants where the surrounding boxes can be seen for the selection of the different parts or systems.

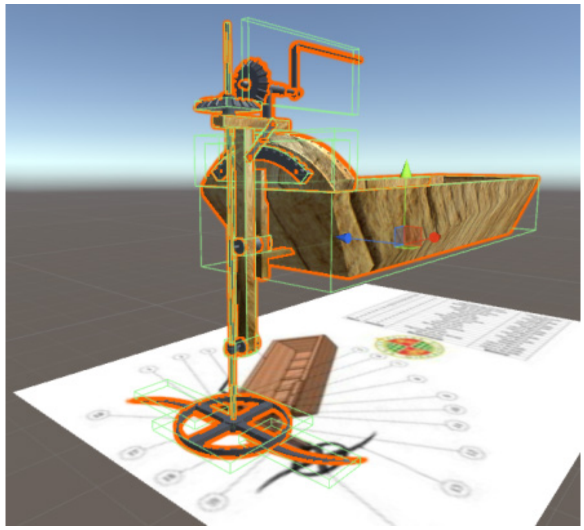

Figure 6. Historical invention with wraparound boxes for the selection of different parts or systems.

Figure 7 shows the result obtained after using the selection algorithm on the 3D model, in which the horizontal drive system composed of 4 parts was selected, these being the crank, the crank axis, the T-power and the bevel gear.

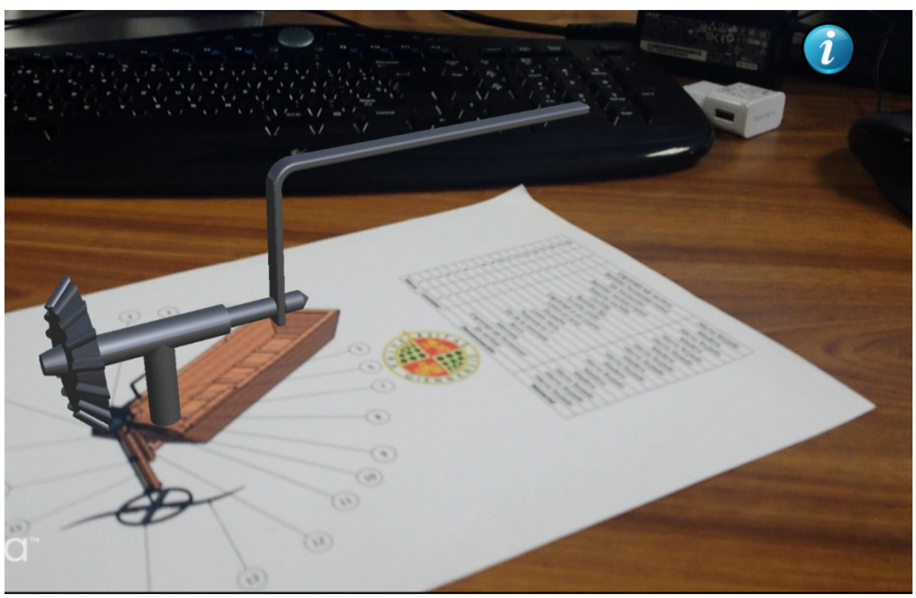

Figure 7. Selection of the horizontal drive system of the historical invention.

It should be noted that, as indicated previously, a new functionality has been incorporated into the application, taking advantage of the fact that the different parts or systems that formed the 3D model could be selected. This is an information button which when clicked will show technical information regarding a selected part or system.

In order to achieve this, a dictionary has been stored in the marker to display the information of each part or system through the identifier, loading the information of each field (Term, Material, and Description) for each part or system. Figure 8 shows the information that will appear on the screen after clicking on the information button when the horizontal drive system is selected.

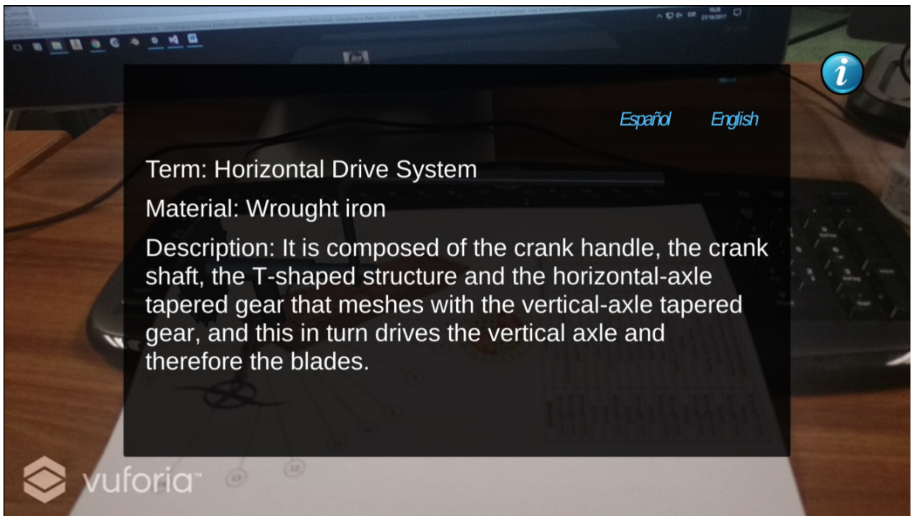

Figure 8. Information shown on the horizontal drive system.

4. 3D PRINTING: ADDITIVE MANUFACTURING

As a tangible additional learning resource to better understand the operation of the machine for cutting cane and other aquatic plants in navigable waterways, each of the pieces that make up the historical invention was printed on a scale of 2:5.

For the additive manufacturing of the prototype (Figure 9), two 3D printers located in the Manufacturing Laboratory (FAB LAB) of the University of Jaén were used. On the one hand, the AirWolf 3D HD printer of lesser precision, which was used to print the support structure of the mechanism (boat and its parts, in white), and on the other hand the Stratasys Objet 30 printer with better precision in printing, for all the elements that make up the mechanism (in black). Thus, for the 3D printing of the model all the pieces were exported from the Autodesk Inventor Professional software itself as .stl files, a format used by both 3D printers.

Finally, once all the pieces had been printed individually they were assembled, conserving the movements of each one and checking their operation and mobility.

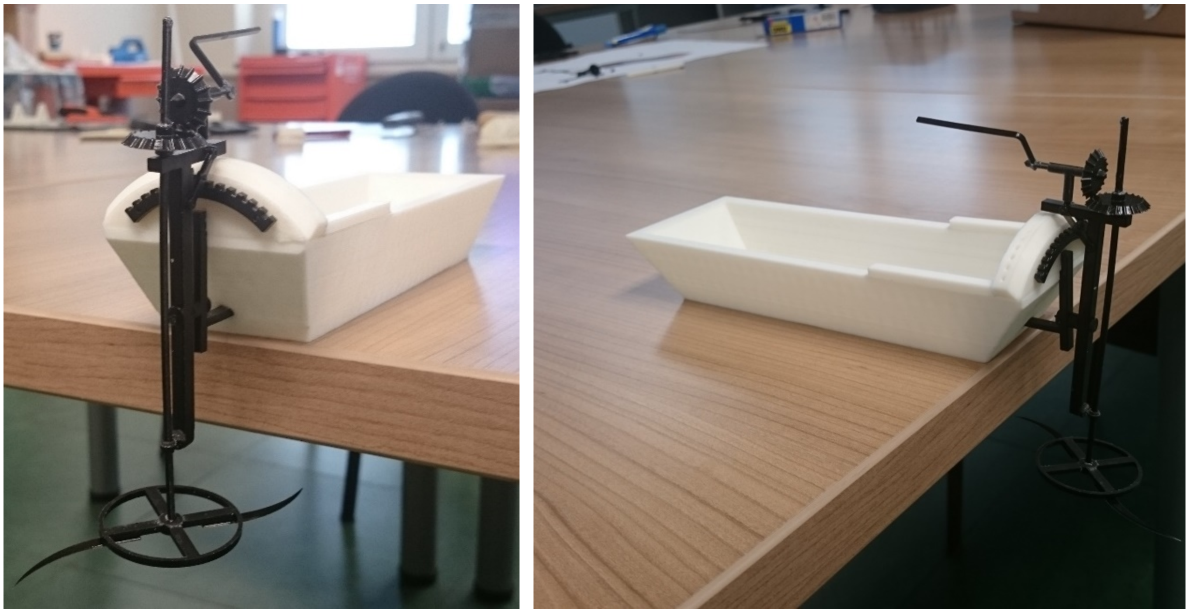

Figure 9. 3D model of the historical invention obtained with additive manufacturing techniques.

5. ASSESSMENT OF THE APPLICATIONS

5.1. Material and methods

In order to assess the user's experience with respect to the applications developed, an anonymous survey was carried out on a group of 10 people through a self-administered structured questionnaire, having previously carried out a self-assessment which proved very satisfactory. Thus, 7 questions were asked with two specific objectives in mind: On the one hand to analyze the usability and management of the applications and on the other hand to analyze whether they constitute an aid for understanding the operation of historical invention and the systems that make it up from the engineering point of view.

Specifically, the following statement was made: Indicate your degree of satisfaction in relation to the following items on a scale of 1 to 5, the scale being:1: very unsatisfactory; 2: unsatisfactory; 3: indifferent; 4: satisfactory; 5: very satisfactory. Thus, the survey questions were:

1. User friendliness
2. Easy browse
3. Interaction clear and understandable
4. Speed of response
5. Overall assessment

6. Have the VR & AR applications helped you to better understand the operation of the invention?

7. Have the applications of VR & AR helped you identify the three mechanical subsystems of historical invention: horizontal, vertical and rotational transmission, as well as their elements?

On the other hand, the devices used have been a personal computer for the executable application of VR on the Windows 10 operating system, and a mobile phone to test the AR application with a version equal to or higher than the 5.0 (Lollipop) of the Android operating system, the minimum requirement.

The methodology used in the analysis and treatment of the data obtained was the use of descriptive and inferential statistics techniques, more specifically univariate analysis techniques that study the measurement and behavior of a single variable. The software chosen for the processing and analysis of data has been Microsoft Excel 2016.

These techniques can be divided into two types, depending on whether we work with qualitative or quantitative variables. In the study of qualitative variables the distribution of frequencies has been used as the most relevant information, and for the study of quantitative variables we have used the mean and median (as measures of central tendency), the standard deviation (as a measure of dispersion), and Asymmetry and Kurtosis (as measures of the shape of the distribution).

5.2. Results

Figure 10 shows the frequency distribution of the answers for each of the 7 questions posed. It can be seen that for each of the questions the minimum value was 3 (indifferent) and the maximum 5 (very satisfactory), and therefore they do not present negative values (1 and 2), which indicates a high degree of satisfaction.

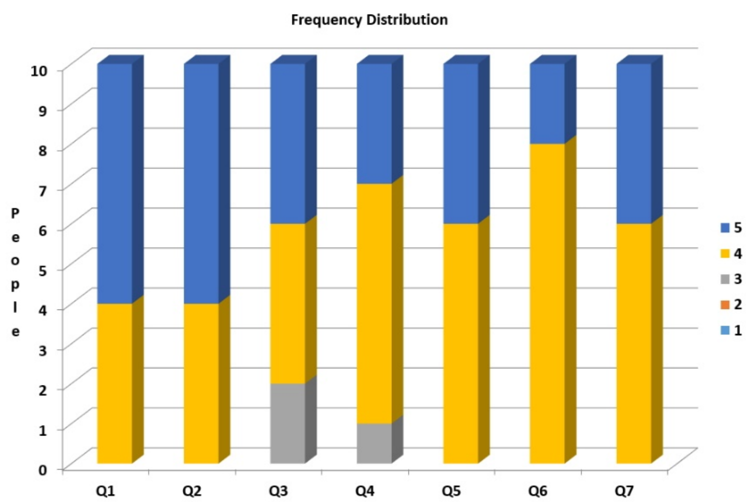

Figura 10. Frequency distribution of the answers.

Figure 11 shows the evolution of the value of the 5 quantitative variables analyzed for each of the 7 questions posed.

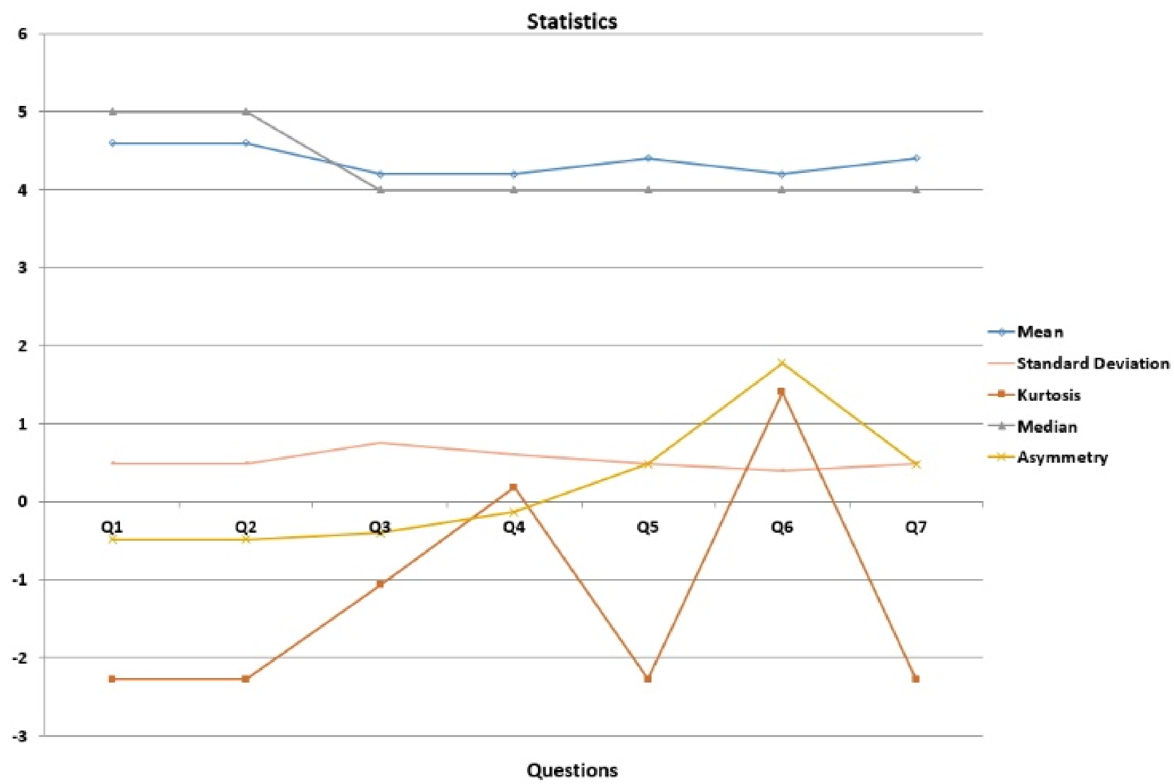

Figura 11. Cuantative variables of the survey.

Thus, from the study of the mean it can be seen that the lowest value is 4.2, so the general assessment is higher than satisfactory. The same applies to the median that has obtained a value of 4 in 5 questions, and a value of 5 in 2 questions. For all these reasons, it can be said that, in general, the respondents are satisfied with the applications developed.

On the other hand, from the analysis of the standard deviation it can be seen that for all questions the values are between 0.4 and 0.7, presenting a horizontal trend line of equation $y = -0.0157x + 0.5923$ with a value of $R^2 = 0.0904$, which shows little dispersion among the answers obtained and confirms the validity of the survey and the applications developed.

Also, with respect to the Asymmetry it is observed that most of the questions, 4 of the 7, present a negative asymmetric distribution, that is to say that there is a higher concentration of values to the left of the mean than to its right, and only three questions present a positive asymmetric distribution. On the other hand, the Kurtosis obtained in 5 of the 7 questions has been negative, which shows a platicuric distribution, that is to say, with reduced concentration around the central values of the distribution.

6. CONCLUSIONS

This manuscript presents two applications developed for learning about the details and operation of an example of historical technical heritage: Agustín de Betancourt´s machine for cutting cane and other aquatic plants in navigable channels and rivers. The importance of this study has been based on the development of applications of VR & AR applied to the learning of historical technical heritage and thus improving the user experience. In this way it is possible to explore the characteristics of each part or system separately.

The advantages of the applications developed are several: Firstly, they do not suppose an expensive investment; Secondly, they are easily installable in any device with Windows or the Android operating system, which allows users to configure the application in a fast and intuitive way; and thirdly, they present a friendly environment, easy to use, with a clear and understandable interaction and quick response.

The applications have been subjected to an evaluation, obtaining a satisfactory user experience in light of the results, since the values of the mean and median demonstrate it (values higher than 4), and with a low dispersion as indicated by the standard deviation (with a value of R^2 of 0.0904), which gives validity to the survey and therefore, to the applications developed.

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