Three-Dimensional Interpretation of Sculptural Heritage with Digital and Tangible 3D Printed Replicas

José Luis SAORIN
Universidad de la Laguna, Spain
jlsaorin@ull.edu.es

Carlos CARBONELL-CARRERA
Universidad de la Laguna, Spain
ccarbone@ull.edu.es

Jorge de la Torre CANTERO
Universidad de la Laguna, Spain
jcantero@ull.edu.es

Cecile MEIER
Universidad de la Laguna, Spain
cecile.eme@hotmail.com

Drago Diaz ALEMAN
Universidad de la Laguna, Spain
dragodiaz@gmail.com

ABSTRACT
Spatial interpretation features as a skill to acquire in the educational curricula. The visualization and interpretation of three-dimensional objects in tactile devices and the possibility of digital manufacturing with 3D printers, offers an opportunity to include replicas of sculptures in teaching and, thus, facilitate the 3D interpretation of the sculptural heritage. In this research, an open access 3D educational resource is created for teaching in the aim of Art and drawing subjects. In Santa Cruz de Tenerife, Spain, fifteen students of *High School,* worked in a traditional 2D environment and in a 3D environment with sculptural heritage replicas in digital and tangible versions. The three-dimensional interpretation of the sculptures is evaluated with a 3D viewing test created for this experiment, to verify whether the material used does indeed facilitate the 3D interpretation. The results show a greater difference using 3D representations compared with the 2D versions in the three ambits analysed. In modularity, the percentage of correct answers in the 3D viewing test are 84% with 3D technologies, versus 40% with 2D representations, in volumetry, 90,7% versus 72%, but in orthogonal views is where the biggest difference is with a 76,7% of correct answers in the 3D viewing test using 3D technologies versus 0% using 2D versions.

Keywords: sculptural heritage, replicas, digital models, 3D printing, spatial 3D interpretation

INTRODUCTION

Different international organisations emphasise the importance of including artistic heritage in teaching environments. UNESCO, at its General Conference for Education, Science and Culture, indicated the need to increase the presence of artistic heritage in education (UNESCO, 2006). In the European setting, the Educational, Audiovisual and Culture Executive Agency (Eurydice, 2009) analysed Artistic and Cultural Education and indicated the understanding of Heritage as a common objective of artistic education. The Council of Europe, in the Framework Agreement on the value of cultural heritage for society, promoted the knowledge and comprehension of common European cultural heritage and recommended including heritage at all educational levels (Council of Europe, 2005).

Cultural heritage includes architectural, artistic, archaeological works, and groupings that have a universal value from the point of view of history, art and science. Sculptural heritage is a significant part of artistic heritage. For the teaching of sculpture, artistic drawing and volume, visits to museums and the use of replicas of sculptures and architectural elements are used. This means having large classrooms with storage space for the replicas, which may present difficulties of mobility, deterioration or breakage. On the other hand, the offer of replicas or 3D objects covers only the most requested objects, with the result that it is difficult to get reproductions of local

works of art that the student can get to know in their geographical ambit. This fact means that teaching remains, in many cases, limited to the use of bi-dimensional educational resources (images, videos, plans, sketches, etc.). The limits of access to replicas are especially clear in online education.

In order to solve these problems, the reduction in the price of digital manufacturing technologies such as 3D printers makes the inclusion of tangible learning objects more and more viable in the practice of teaching. On the other hand, the use of 3D digital models constitutes an alternative to the physical models as they are easily accessible from a Smartphone, tablet or computer, and give a three-dimensional manipulation, which is similar to that of a tangible replica (Yi-Chen, C., Hung-Lin, C. & Wei-Han, H. &. S.-C. K, 2011). It is necessary, therefore, to study the potential of replicas and 3D models for the study of forms and the representation of sculptures.

Spatial interpretation, where students need to imagine objects from different orientations, visualise three-dimensional models and make transformations between representations in two and three dimensions is present as a competence to be acquired in the curricula of university and pre-university degrees and courses. At high school levels, there are few studies which have a bearing on the spatial reasoning of the students as well as methodologies, strategies and teaching materials for its development (Morell, R. V. G., Miranda, V. G. & Alamar, M. D. V., 2010), as occurs in fields such as Engineering and Architecture university studies (Martín-Dorta, N., Saorín, J. L. & Contero, M., 2008; Saorín-Pérez, J. L., Navarro-Trujillo, R., Martín-Dorta, N., Martín-Guiterrez, J. Contero M., 2009).

In this paper, an experiment carried out in Santa Cruz de Tenerife with 11th Grade students of Drawing and Plastic Arts is described. A three-dimensional educational resource is developed which contemplates the two 3D formats simultaneously, the digital and the tangible. The experiment aims to improve the three dimensional comprehension of the Sculptural heritage of Santa Cruz de Tenerife using new 3D low cost technological resources. The participants answered a 3D viewing test designed to analyse the impact of this technology on the student's 3D interpretation. The results are compared when using traditional 2D representations and digital and tangible 3D models.

Three-dimensional objects in drawing and plastic arts

For the study of sculpture, artistic drawing and volume it is normal to use replicas of sculptures and plaster objects. A replica is a reproduction, with the greatest possible precision, of the original of an object and it may be in a different material and be on a different scale (Almagro Gorbea, 1988). One of the reasons for which a replica is made is to replace an object of great value and prevent it undergoing deterioration. Replicas are given outstanding value because they serve to transmit art to the public in general and without them only specialists or researchers would have access to protected works of art. Replicas moreover serve to understand the three-dimensional concepts associated with the analysis of form and its representation (Rodríguez-Samaniego, 2013).

In disciplines related with drawing and plastic arts, models of 3D parts are used for learning of standardised views in the subjects of technical drawing (de la Torre Cantero, J. Martin-Dorta, N., Saorin, J.L., Carbonell-Carrera, C., 2013). These physical models are used so that the students can make sketches from different points of view and improve their comprehension of the relationship between the real world (three-dimensional environments and models) and the two-dimensional representations (drawing of standardised views). They constitute a much-used educational material in technical drawing to improve spatial skills (Ben-Chaim, D., Lappan, G. & Houang, R. T., 1988).

In other disciplines unrelated with drawing and plastic arts, the use of 3D models is also frequent such as in natural science (fossils, stuffed animals, etc.), geology (minerals and rocks), topography (digital models of terrain) and architecture (models). As an alternative to tangible objects, the appearance of 3D digital technologies makes possible the design of didactic resources allowing the user to interact with 3D contents on digital devices. Foremost among these are such multi-tactile devices as the Smartphone and tablets, whose tangible interface approximates the way of interacting with the real object (Yi-Chen, et al., 2011). High-quality, three-dimensional models make it possible to widen the knowledge of sculptural and/or architectural heritage in great detail as is the case of the heritage of Oviedo cathedral as described by Ruiz, Rovés, & Voces (2015). This is a hyper-realistic 3D model which allows the user to appreciate all the details of valuable pieces which can normally only be observed through a grille or glass and can only be seen from one side, inside urns and at a certain distance for security reasons.

The use of digital three-dimensional models can solve some of the areas where real models fall short, such as breakages or loss of objects as 3D models can not only be viewed on a range of devices both offline and online but it is also possible to download them for reproduction as often as is necessary (they are replicable). They

resolve, in turn, the problems of transport, exchange and storage as they can be filed in the cloud or virtual classrooms, thus going beyond the limits of a laboratory.

In the year 2013 a pilot study was carried out on the comparison of the use of tangible and digital models. The viability of 3D models on tablets as possible substitutes for the pieces used for learning of standardised views in subjects of technical drawing was analysed. But the results were not conclusive: the evaluation of the students was very similar in both cases as there was not a significant difference between the preferences of the students for the tangible models or for the digital models (de la Torre Cantero, et al., 2013).

Legal aspects related with replicas

The intellectual ownership of a literary, artistic or scientific work belongs to the author due to the simple fact of its creation. With regard to the materials accessible through the network, they can be read, watched or heard for free if the author so decides, however, making a copy or redistributing it without authorisation is not allowed. When scanning a sculpture using any technique, whether laser or photography, you are making a copy of an object protected by Copyright. Copying and distributing a sculpture requires the permission of the person who has the rights of reproduction (Weinberg, 2013).

It is important to indicate that the laws of intellectual property vary according to the country. This research has been carried out in Spain, where, in the teaching sphere, the law of intellectual property (section 2, article 32 of the Boletín Oficial del Estado, 2006) sets down that "teachers in formal education will not require the authorisation of the author to carry out acts of reproduction, distribution and public communication of small fragments of works or of isolated works of a plastic or figurative photographic nature, excluding text books and university manuals, when such acts are carried out solely for the illustration of their educational activities in the classrooms, to the extent that they are justified by the non-commercial purpose, provided that it is a matter of works that are already in the public domain and, except in the cases in which this is impossible, the name of the author and the source is included.

NEW TRENDS FOR TEACHING 3D CONTENTS

Among the international reports on technology in education (OCDE, 2014; Instituto de Educación Internacional, 2014) there is one, which has become a point of reference: the Horizon Report (Johnson, Levine, Smith, & Smythe, 2011-2016). This report, prepared by the New Media Consortium, identifies new types of technology, which can be used in teaching, and analyses their impact on education, learning and research. Among these technologies, the applications for 3D digital modelling stand out, together with digital tablets and/or Smartphones as well as 3D printers. The report also looks at a new trend: BYOD (Bring Your Own Device), which promotes the use by students of their own devices to access innovative resources as a complement to traditional teaching in the classroom.

In the experiment carried out in this research, for the creation of the 3D material used, use is made of digital 3D modelling, tablets and/or Smartphone (the students gain access to the information using their own devices: BYOD) and 3D printers, all of which trends were highlighted in the Horizon reports. Digital tablets and Smartphones constitute a technology with great potential in the classroom: 30% of Spanish children of ten years of age have a Tablet or a Smartphone, 70% at the age of 12 and 83% at 14 (Cánovas, García-De-Pablo, Oliaga-San-Atilano, & Aboy-Ferrer, 2014). Modelling, scanning and 3D printing until about eight years ago were technologies reserved for experts in the subject and required a long and costly learning process, and an advanced technical team was also required and the price of the programmes was very high and only accessible for large centres, companies or universities (Caño, de la Cruz, & Solano, 2007). This panorama changed in 2006 with the distribution free of charge of the SketchUp programme by Google. SketchUp is a multi-platform programme (PC and Mac) with a free version, which offers the possibility of introducing the user to 3D modelling with very little background knowledge and in only a short time. This program has been used already in the teaching of subjects with 3D content offering excellent results (de la Torre Cantero, Saorín, Carbonell, de Castillo Cossío, & Contero, 2012). Blokify, Pottery and the Autodesk 123D Suite are other applications of 3D modelling with a free version which are simple to use, with which, at low cost, digital replicas of sculptures have been obtained (de la Torre-Cantero, Saorín, Meier, Melián Díaz, & Alemán, 2015).

In relation with the scanning of objects, there are peripherals of video games, which have the possibility of detecting 3D space, which has given rise to the appearance of highly accessible three-dimensional scanners although with resolutions that are not so good as professional ones. One example is the use of Microsoft's Kinect with the Skanet programme, which makes it possible to have a 3D scanner for less than 500 Euros. On the other hand, apart from the possibility that the students or teachers might create their own 3D models, there are web pages specialising in the free dissemination of three-dimensional models such as Thingiverse, 3D Warehouse or

SketchFab. These repositories have special resources with 3D models aimed at education. In order to view a 3D model it is necessary to have an application installed in the device (Smartphone or Tablet). However, in the repositories specialising in 3D objects, the viewing and direct interaction in the online environment via one's own browser, without the need to have installed any 3D viewing application is possible. The online environments specialising in 3D models for education also offer the possibility of downloading and printing the models with a 3D printer. In the ambit of Art, there are museums and institutions, which make their works available to the user via the internet for on-line 3D viewing, such as for example the Smithsonian Museum (Smithsonian, 2015) or the project for the spreading of heritage in 3D of the Virtual World Heritage Laboratory (Frischer, 2016).

Another example is the Art Project, in which Google has collaborated with seventeen museums around the world for the diffusion of a virtual version of their collections. Apart from permitting a virtual visit to the interior of a number of chosen galleries, it is possible to admire works of the most renowned artists in history. These virtual visits are made up of 360º photos of the halls in a similar format to the Google application, Street view.

In the sphere of teaching, accessibility and dissemination of digital 3D models is the same as any other digital file and can be included in specialised 3D repositories free of charge (e.g. Sketchfab or Thingiverse), in virtual classrooms, or online repositories such as Dropbox, Drive, etc. Thus, three-dimensional objects can be included easily in multi-media presentations or even in paper books by means of a link. The books, despite the multiple formats of communication that there are, continue to be a widely-used format of diffusion of knowledge in educational settings. There are at least nine different technologies, which make it possible to include three-dimensional objects in digital or paper books (Carbonell Carrera, Vlad Avarvarei, Chelariu, Draghia, & Catrinel Avarvarei, 2017)). In order to include 3D information in a book, it is possible to indicate a reference to a web page, which obliges the reader to key in the URL. Although there is the possibility of using short URLs, there are applications, which make it possible, by means of a code, to gain access to the indicated address such as for example a QR code. There are generators of QR codes that are free on the Internet, such as for example QR Creator.

3D interpretation

Given the three-dimensional nature of sculptures, their dissemination via a flat resource (2D) such as the images in a traditional catalogue means that information is lost and the comprehension of the works is limited (Chamizo, 2010; Rea-Ramirez, Clement, & Núñez-Oviedo, 2008). In the learning of materials related with concepts of a three-dimensional nature, the use of traditional teaching resources in 2D such as books, photos, plans or drawings may be complex and sometimes insufficient for spatial reasoning on the part of the student.

Three dimensional interpretation features among the skills to be acquired in the subject of Drawing and Plastic Arts and it make reference to the use of technologies for visual interpretation, such as for example the acquisition of graphic skills, the capacity to use techniques of 3D representation, the capacity to work with 2D and 3D interfaces as well as the perceptive visual capacity (Aneca, 2004). Stavridou and Kakana (2005) suggest that the more extended use of 3D models, either physical or digital, could help to a better understanding of spatial relationships and evoke the use of more advanced drawing techniques for the depiction of 3D layouts.
Numerous studies show that three dimensional interpretation can be developed using training if the appropriate materials are provided (Cohen, Hegarty, Keehner, & Montello, 2003; Potter & Van der Merwe, 2003), (Kinsey, 2003), and there is unanimity about the fact that spatial thinking can be improved by means of training (Sorby, Wysocki, & Baartmans, 20013). The use of 3D models is a proven strategy to increase the improvement of spatial reasoning (Ben-Chaim, et al., 1988). For example, in secondary education, metallic models of 3D pieces are successfully used for learning of standardised views in the subjects of Technical Drawing and Analysis of Forms and Their Representation (de la Torre Cantero et al., 2013). With these models, the students develop their sketches from different points of view and improve their understanding of the relationship between the real world (settings and three-dimensional models) and two-dimensional representations (drawing of standardised views).

In university education, an improvement in the spatial interpretation of students of Engineering has been obtained using three-dimensional models of land printed in 3D (Carbonell & Bermejo, 2016), as well as three-dimensional representations of industrial parts in digital format such as augmented reality (Saorín, de la Torre-Cantero, & Martín-Dorta, 2014). It is necessary, therefore, to study whether there is an improvement in spatial comprehension in pre-university levels, where the use of 3D replicas of sculptural works in subjects related with drawing and plastic arts is usual so as to facilitate the comprehension of 3D concepts associated with the analysis of forms and their representation (Rodríguez-Samaniego, 2013).

EDUCATIONAL 3D RESOURCE REPLICABLE FOR THE TEACHING OF THE SCULPTURAL HERITAGE

In the present research, an educational resource is rated for content related with the sculptural heritage: a catalogue of sculptures, which includes replicable three-dimensional models. The catalogue contains twenty-seven public sculptures from Santa Cruz de Tenerife from the First International Exhibition of Sculpture in the Street available at: http://goo.gl/wD3EwS. It is presented in the traditional format of a book where the sculptures are described with a specifications card (name, description, author, year, materials, dimensions and a link with additional information), one or several images of each sculpture and a schematic map of the city with its location.

The difference with regard to a conventional catalogue lies in the incorporation of two links: one to gain access to the online view of the 3D model and the other to download and print the sculpture on a 3D printer (Fig. 1). In this way, if the electronic version of the book is available, it is possible to gain access to and view the three-dimensional model with just a click. If only the paper version is available, it is possible to gain access and handle the digital model of the sculpture by means of a Smartphone or tablet using the QR code.

Figure 1: Catalogue with links and QR codes for viewing and downloading the models

In order to organise all the works printed in 3D, a packaging has in turn been created (Fig. 2). The design and the templates to make this packaging, made up of two boxes, are included in the catalogue so that any user can make his/her own box for packaging with cardboard for which he/she will only need a large sheet of cardboard (approximately 130 x 130 cm) and a normal paper printer. The design of the boxes includes identifying cards of each work with a link, which makes it possible to download and print the work again in case of loss or breakage. Replicas have been printed of all the works on a 3D printer, Makerbot Replicator 2, in white PLA filament.

Figure 2: Catalogue of sculptures and the set of 27 sculptures printed with their packaging

This educational resource, therefore, gives access to 3D files, which allow the creation of tangible replicas by means of a 3D printer of the sculptures it, contains. The teacher thus has a catalogue of sculptures in two different formats: the book format with access to digital models and the box format with the tangible models.

The steps for the creation of these replicas are described in the work of de la Torre, et al. (2015), where the entire process is detailed for generating 3D objects as well as the costs deriving from creating a replica using a 3D printer or buying in an outside printing service.

METHODOLOGY

In order to check this new 3D resource as a method to improve the 3D comprehension of sculpture heritage an experiment was design. A school that studied the sculptural heritage of Santa Cruz as part of the drawing subject was selected. This was important because we wanted to compare the traditional 2D resources with the new 3D materials described in this paper.

Participants

The experiment was carried out with fifteen volunteer (eight male and seven female) 11th grade students from the Dominicas Vistabella School in Santa Cruz de Tenerife, who were studying the subject of Drawing, and Plastic Arts. Before the experiment was carried out, the participants responded to a survey with eight questions on viewing technologies and 3D printing.

Measuring instrument

A 3D test of viewing sculptures was carried out by DEHAES, the research group into spatial abilities at the University of La Laguna. It consists of ten questions aimed at the 3D analysis of the sculptures, separated into two blocks: volumetry and modularity, as well as two exercises on standardised views (Table 1).

Phases

The experiment took place in an hour-long session in the drawing, and plastic arts classroom. It was divided into two phases:

Phase I. 2D. (25 minutes): the students were given a 3D visualisation test, in which they were asked a number of questions about the 27 publicly-displayed sculptures in Santa Cruz de Tenerife from the First International Exhibition of Sculptures in the Street. For finding the information, they had computers with an Internet connection, apart from their own Smartphones and computers, from which they could gain access to the information in text and images (photos) of the sculptures on the Internet. It was verified that the graphic information on Internet about the sculptures was only in 2D format.

Phase II. 3D. (25 minutes): the participants responded to the same 3D visualization test again but on this occasion they had the catalogue of sculptures in two formats: the book format with access to digital models and the box format with the tangible models. They made use of their Smartphones to view the sculptures from the catalogue in 3D as well as directly handling the replicas made on the 3D printer.

RESULTS

The experiment aimed to improve the three dimensional comprehension of the Sculptural heritage of Santa Cruz de Tenerife using new 3D technological resources. In the survey of viewing and 3D printing technologies, 93 % of the participants declared that they had a Smartphone and a computer for their private use and 60% already had a QR code reader installed on their Smartphone. All of the students said they would like to have educational material printed in 3D and 86 % believed that a 3D object helped them to study better. 86 % knew 3D printers but only 26 % had seen them working in person. 93 % of the participants stated that they were interested in art but only 53 % showed interest in sculptures or had noticed the urban sculptures in Santa Cruz de Tenerife. To check the reliability or the internal consistency of the questionnaire the Cronbach's alpha coefficient is calculated. The value obtained, 0,71 is acceptable according to Pallant (2007).

In table 1, it is possible to observe the number of correct responses obtained for each question in the test of 3D visualisation of the sculptures. It can be seen that in the second phase, the students were able to answer many more items by means of the observation of the 3D printed sculptures.

Table 1: Responses obtained in the 3D viewing test

3D Viewing Test

Type	Question	% Correct answers Phase I 2D	Phase II 3D
Modular questions	Of how many modules is the Labyrinth sculpture made up?	53	100
	Does the large module of the Solidarity sculpture have a hole inside? Is it rectangular or round?	40	80
	Are all the modules of the Lorea sculpture the same?	53	80

	In the Tribute to Pascal sculpture are there two modules, which are exactly the same?	0	67
	Which sculptures are made up of identical modules?	53	93
	Average results modular questions	40	84
Volumetric questions	Is the shield of the Goslar Warrior flat on its rear side?	100	100
	Is the hand in the Introversion sculpture a bas-relief?	33	100
	Is the thickness of the sculpture Hombre by María Simón the same all over the sculpture?	93	100
	In the sculpture called "Dado para 13", can you enter and leave on different sides?	87	93
	Can the sculpture Tribute to Millares be moved?	47	60
	Average results volumetric questions	72	90,7
Exercises for standardised views	Draw the top view of the sculpture "Dado para 13".	0	80
	Draw the Top view of Labyrinth sculpture.	0	73
	Average results standardised views	0	76,7

DISCUSSION

Nowadays, digital replicas of sculptures can be obtained and manipulated with free software (de la Torre, et al., 2015). The editing and digital printing technologies allow teachers to have local replicas in three dimensions for the teaching. These innovative technologies are accessible and easy to use for teachers and students and allow new teaching resources to be introduced into the teaching and learning processes in accordance with the BYOD trend emphasised by the Horizon report.

The digital versions in 3D offer the possibility of having a large number of models to which the students have access from settings of virtual teaching such as virtual classrooms, or in free repositories such as Dropbox or Google Drive, which facilitates their implementation in formal teaching. The tangible versions, printed in 3D, are an alternative to the digital ones and a single replica can be presented to the student in the two versions. For our experiment, we create, using only low cost 3D technologies, a box that includes twenty-seven replicas of public sculptures from Santa Cruz de Tenerife from the First International Exhibition of Sculpture in the Street. This resource is available, in catalogue format at: http://goo.gl/wD3EwS.

The results of the survey show a high degree of interest among the students in 3D educational materials, which they consider would help them to study better. The 3D replicas can increase the interest among students in sculptural heritage.

In relation with spatial 3D interpretation, the analysis of forms and the representation of the sculptural heritage, the student understands spatial relationships of the sculptures better with the 3D representations than with the 2D versions. The percentage of correct answers in questions related with the modularity and volumetry of the sculptures is higher using 3D (84% modularity and 90,7% volumetry) than 2D (40% modularity and 72% volumetry). The participants also obtain better results in the exercises with systems of representation (standardised views) of the sculptures with the three-dimensional versions (76,7%) than with the 2D viewings (0 %), in agreement with Stavridou & Kakana (2005), who found serious difficulties in depicting the third dimension in the absence of a model, either physical or digital

CONCLUSIONS

Using only the access to the Internet as a source of information, the students were not capable of answering two of the ten questions asked, nor could they create a bird's eye view of one of the sculptures despite the fact that they had 25 minutes to draw it. However, using 3D models, they were able to answer all the questions and activities and to do so with a higher percentage of success.

The versatility that the innovative editing and digital printing technologies offer for teaching and diffusion of the sculptural heritage make the teaching resource described in this research just one example that can be extended to other subjects which require, in the teaching and learning process, representation and interpretation in three dimensions.

The present research is focused specifically on the 3D interpretation using 3D replicas, but in disciplines related with the Art and Design, in addition to the spatial interpretation, the creative thinking process of generating new ideas and forms is also important. Therefore, as a future work, we propose a research about how the 3D technology could help to the student of Art disciplines to work more accurately and efficiently, generating solutions in a 3D environment in a creative way.

ACKNOWLEDGMENT / STATEMENT

We thank the participation of the teacher and the students from the 2nd year of the subject of drawing, design and plastic arts of the MM. Las Dominicas school for their participation in the experiment. The institution signed a document called "informed consent" on the experiment to be performed, according to the 95/46/CE European Directive and Organic Law 15/1999 of the Spanish Cabinet Office number 298.

The complete data obtained in the 3D Viewing Test are available (creative commons) in the institutional repository of the University of La Laguna, at the following link: http://riull.ull.es/xmlui/handle/915/4754. The educational resource used for the experiment, a catalogue of sculptures, which includes replicable three-dimensional models is available at: http://goo.gl/wD3EwS.

This paper has been funded by the Spanish Ministry of Education, Culture and Sport, within the framework of the State Program for the Promotion of Talent and its Employability in I+D+i, State Mobility Subprogram of the State Plan for Scientific and Technical Research and Innovation 2013-2016.
There is no conflict of interest in the present work.

REFERENCES

Almagro Gorbea, M. J., (1988). La utilidad de sustitutos y repreduciones en los Museos. *Boletín de la Anabad, 38*(3), 177-186.

Aneca. (2004). *Libro Blanco para el diseño de la titulación de Grado: Bellas Artes*. Barcelona: Agencia Nacional de Evaluación de la Calidad y Acreditación.

Ben-Chaim, D., Lappan, G., & Houang, R. T., (1988). The effect of instruction on spatial visualization skills of middle school boys and girls. *American Educational Research Journal, 25*(1), 51-7.

Carbonell Carrera, C., Vlad Avarvarei, B., Chelariu, E.L., Draghia, L. & Catrinel Avarvarei, S., (2017). Map-Reading Skill Development with 3D Technologies, *Journal of Geography*, *116*(5),197-205. DOI: 10.1080/00221341.2016.1248857.

Carbonell-Carrera, C., Saorin, J.L., Meier, C., Melian-Diaz, D., & de la Torre, J. (2016). Tecnologías para la incorporación de objetos 3D en libros de papel y libros digitales. *El profesional de la información, 25* (3), 661-670.

Chamizo, J. A., (2010). Una tipología de los modelos para la enseñanza de las ciencias. *Revista Eureka sobre enseñanza y divulgación de las ciencias,7*(1).

Cohen, C., Hegarty, M., Keehner, M., & Montello, D., (2003). *Spatial ability in the representation of cross sections.* s.l., 25th annual conference on the cognitive science Society, 31-2.

Council of Europe. (2005). *Value of Cultural Heritage for Society,* Faro: Council of Europe Treaty Series - No. 199.

de la Torre Cantero, J. Martin-Dorta, N., Saorin, J.L., & Carbonell-Carrera, C. (2013). Entorno de aprendizaje ubicuo con realidad aumentada y tabletas para estimular la comprensión del espacio tridimensional. *RED. Revista de Educación a Distancia,* Issue 37.

de la Torre-Cantero, J., Saorin, J.L., Melian-Diaz, D., & Diaz-Aleman, M.D., (2015). Creación de réplicas de patrimonio escultórico mediante reconstrucción 3D e impresoras 3D de bajo coste para uso en entornos educativos. *Arte, Individuo y Sociedad, 27*(3), 427-444.

Eurydice, E., (2009). *Educación artística y cultural en el contexto escolar europeo.*Bruselas: Secretaría General Técnica.

Frischer, B., (2016). *Virtual World Heritage Laboratory.* [Online]
Available at: http://www.digitalsculpture.org/laocoon/index.html

Instituto de Educación Internacional. (2014). *Annual Report,* USA: Instituto de Educación Internacional.

Johnson, L., Levine, A., Smith, R., & Smythe, T., (2011-2016). *Horizon report,* Austin, Texas: The New Media Consortium.

Kinsey, B. (2003). *Design of a CAD Integrated Physical Model Rotator*. Proceedings of the Annual Conference & Exposition Engineering Education, Tennesse, USA.

Martín-Dorta, N., Saorín, J. L., & Contero, M. (2008). Development of a fast remedial course to improve the spatial abilities of engineering students. *Journal of Engineering Education, 97*(4), 505-513.

Morell, R. V. G., Miranda, V. G., & Alamar, M. D. V. (2010). Consideraciones sobre las imágenes mentales en el sistema diédrico español. *Arte, individuo y sociedad, 22*(1), 111-120.

OCDE. (2014). *Panorama de la educación,* Madrid: Ministerio de educación, cultura y deportes.
Pallant, J. (2007). *SPSS Survival Manual A Step by Step Guide to Data Analysis Using SPSS for Windows*. Third Edition. Open University Press. England.
Potter, C., & Van der Merwe, E. (2003). Perception, imagery, visualization and engineering graphics. *European journal of engineering education, 28*(1), 117-133.
Rea-Ramirez, M. A., Clement, J., & Núñez-Oviedo, M., (2008). An instructional model derived from model construction and criticism theory. In: *Model based learning and instruction in science.* Netherlands: Springer, 23-43.
Rodríguez-Samaniego, C., (2013). La educación artística en la Escuela de Bellas Artes de Barcelona durante el siglo XIX. El caso de la escultura. *Arte, Individuo y Sociedad, 25*(3), 495-508.
Ruiz, J., Rovés, L. & Voces, Á. G., 2015. Visualización tridimensional hiperrealista e interactiva: Cámara Santa y Joyas de la Catedral de Oviedo. *Virtual Archaeology Review, 6*(12), 69-76.
Saorín, J. L., de la Torre-Cantero, J., & Martín-Dorta, N.(2014). Anfore 3D: objetos de aprendizaje tridimensionales con información ampliada a través de Realidad Aumentada. *Comunicación y pedagogía: Nuevas tecnologías y recursos didácticos, 277*, 22-25.
Saorín-Pérez, J. L., Navarro-Trujillo, R., Martín-Dorta, N., Martín-Guiterrez, J., & Contero M., (2009). La capacidad espacial y su relación con la ingeniería. DYNA-Ingeniería e Industria. *DYNA-Ingeniería e Industria,* 84(9).
Smithsonian, I., (2015). *Smithsonian x3D.* [Online]
Available at: http://3d.si.edu/browser
Sorby, S., Wysocki, A., & Baartmans, B. (2013). *Introduction to 3D Spatial Visualisation: an active approach.* Clifton Park, NY: Thomson Delmar Learning.
Stavridou, F., & Kakana, D. (2005). When adolescents represent the third dimension: three case studies. *Journal of Art & Design Education*, *24*(1), 53-70.
UNESCO. (2006). *Textos Básicos de la Convención del Patrimonio Mundial 1972.* Francia, UNESCO, p. 245.
Weinberg, M. (2013). *What's the deal with copyright and 3D printing?*s.l.: Institute for Emerging Innovation (IEI).
Yi-Chen, C., Hung-Lin, C., Wei-Han, H., &. S.-C. K. (2011). Use of Tangible and Augmented Reality Models in Engineering Graphics Courses. *Journal of Professional Issues in Engineering Education & Practice, 137*(4), 267-276.