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Sección de artículos / Papers section

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Información general / General information		
TÍTULO:	Study, revalorization and virtual musealization of a ceramic kiln based on information gathered from old excavations	:TITLE
AUTORES:	Álvaro RODRÍGUEZ MIRANDA José Manuel VALLE MELÓN Estefania CALPARSORO Javier G. IÑAÑEZ	:AUTORS
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Resumen	
TÍTULO:	Estudio, puesta en valor y musealización virtual de un horno de cerámicas basados en la información procedente de antiguas excavaciones
RESUMEN:	Las posibilidades actuales de visualización y difusión a través de las tecnologías digitales tienen un efecto favorable en la conservación y la puesta en valor de los restos arqueológicos depositados en los museos. Por lo tanto, deben ser consideradas como herramientas esenciales en la gestión de las colecciones y una manera de comunicarse con todo tipo de usuarios, desde los que cuentan con un elevado perfil tecnológico hasta los visitantes ocasionales. El artículo presenta un caso de estudio en el cual se ha revisado la información recogida durante una serie de excavaciones arqueológicas relativas a los restos de un horno, las cuales se realizaron en la localidad de Orduña (España) en los años 2000 y 2001. Esta información, conjuntamente con una nueva inspección de las piezas almacenadas en el Museo Arqueológico de Bizkaia, ha permitido la generación de nuevos productos -como el modelo virtual tridimensional- que ofrecen posibilidades mejoradas de estudio, comprensión y difusión de las piezas, su origen y la importancia que el oficio de la cerámica y su comercio tuvieron en el pasado.
DESCRIPTORES NATURALES:	documentación arquitectónica, modelo 3D, modelo virtual, realidad aumentada
DESCRIPTORES CONTROLADOS:	(Procedentes del Tesauro UNESCO [http://databases.unesco.org/thessp/]) Arqueología, Etnología, Cerámica, Fotogrametría, Reconocimiento topográfico, Infografía

Abstract	
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NATURAL KEYWORDS:	archaeology, 3D virtual model, pottery, kiln, information retrieval, virtual museum
CONTROLLED KEYWORDS:	(From the UNESCO's thesaurus [http://databases.unesco.org/thesaurus/]) Archaeology, Ethnology, Ceramic art, Photogrammetry, Surveying, Computer graphics

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Study, revalorization and virtual musealization of a ceramic kiln based on information gathered from old excavations

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ABSTRACT

The current possibilities of virtualization and dissemination by means of digital technologies have a favourable effect on the conservation and valorization of archaeological findings held in museums. Therefore, they should be considered as essential tools in the management of the collections and a way to communicate with all kind of users, from the ones with an highly technical profile to the occasional visitors.

This article presents a case in point, in which the reviewing of the information generated during a series of archaeological excavations into the remains of a kiln, conducted in the town of Orduña (Spain) in 2000 and 2001, together with a new inspection of the pieces stored in the Bizkaia Museum of Archaeology, allowed for the generation of new products such as three-dimensional virtual models that improve the possibilities of studying, understanding and disseminating the pieces, their provenance and the importance that the craft and the trade of the pottery had in the past.

1. Introduction

Although sometimes seen as simply melancholic reflects on the past, archaeological artifacts hold a huge potential for continuous re-interpretation, thus paving the way for a better understanding of the past. This is especially the case when two factors combine: on the one hand, the existence of several implementation constrains (budget, time, human resources, etc.) that often make studies fall short of in depth explanations; on the other hand, the continuous development of new paradigms that obliges to re-contextualize the findings once and again. Consequently, information reviewing is an essential part of the scientific methodology applied to the archaeological science and, hence, the preservation and the access to the objects curated in museums, on-site remains as well as the associated information (such as original reports, plans or photographs taken during the excavations) have become indispensable parts of research in the field.

Moreover, new technologies allow for innovative ways of exploring, linking, representing and sharing information. For example, the techniques for geometric description and virtual modelling of objects, combined with the management possibilities provided by modern databases and the remote query via Internet let us to disseminate, both locally and worldwide, the collections of museum items and the knowledge about them. Unquestionably, this scenario provides promising tools that guarantee innovative approaches to support the archaeological interpretation process. Many encouraging examples of this can be tracked in the ongoing H2020 projects: “ArchAIDE” for the automatic interpretation and documentation of ceramics, “GRAVITATE”, “Scan4Reco” and “DigiArt”, which seek to develop cost-effective solutions for 3D recording, linking and sharing cultural heritage objects; and “iMARECULTURE”, “ARCHES” and “Terpsichore”, which are aimed at the development of virtual museums and e-archives, just to mention a few.

Against this background, the case study presented in this article focuses on the pottery production of the town of Orduña (Biscay, Spain). Due to its location and topography, this village served through centuries as an important connection point from the Spanish plateau to the Basque coastline villages. Furthermore, several trade agreements made the village an important exchange point of goods. In this context, the potter activity flourished from the 13th century onwards. Nevertheless, the study of the pottery activity at Orduña has received meagre attention so far, in spite of the significant role played by this village as trading center.

More specifically, this article deals with data from a series of archaeological fieldworks conducted between 2000 and 2001 at the

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village, where an important collection of ceramic fragments and the remains of a kiln from the late seventeenth or early eighteenth century were discovered. The research strategies that were established encompassed not only the generation of new datasets from accessible pottery shards (including a large range of chemical and mineralogical analyses, information about the manufacturing processes and their detailed geometric description according to the possibilities of the current equipment) but also the retrieval and inclusion of old information available from grey literature (e.g. research reports, archaeological field notebooks, local publications, etc.).

2. Research aims

The aim of this work is to assess the capacity of generating new knowledge and to allow its dissemination and re-use through virtualization. Presently, the fragments of pottery under study in this project are curated by the Bizkaia Museum of Archaeology because the site does not exist anymore after the urbanization of the area. Therefore, hardly any access to this information was possible to both archaeologists and local inhabitants. In order to solve this situation and make the information widely available, we generated virtual models of some of the most representative pieces of pottery and a recreation of the appearance of the kiln as it should have been when was in use. The adopted solutions are presented here in the context of the current state-of-the-art of the techniques for three-dimensional modelling of archaeological pottery items and the ones for the virtual reconstruction of no longer existent buildings.

3. Materials and methods

3.1. Study material

The archaeometrical study was performed over a hundred pieces corresponding to different typologies (plates, bowls, jars, pots, kiln utensils, refuses of the firing, etc). First of all, a database incorporating all the details provided by the museum was created and then descriptions were further enriched in terms of physical features (decoration, coatings, chronology, location, etc.). Besides, the geometric characterization of each fragment was obtained by means of traditional archaeological drawing with a vernier caliper, a profile gauge, rulers, compasses and radius charts.

A new photographic recording of the pieces was obtained, both for the right and the reverse sides (Fig. 1). Apart from the improved image resolution, careful attention was paid to the reliable registration of the colours. To that end, the pieces were placed inside a light box so as to shoot the photographs in diffuse and stable lighting conditions; moreover, a colour checker card (X-rite) was used for the spectral calibration of the pictures.

From this set, a small selection of the most representative pieces ($n = 8$) was considered for three-dimensional modelling. When it comes to tackling the geometric documentation of pottery items, we can register either the real three-dimensional complexity of the object or, alternatively, the piece can be modelled in a simpler way by taking into account different kinds of symmetries, such as the revolution geometry. Actually, both strategies are complementary, the choice or the combination depending on the use we foresee for the virtual model. In the case of fragments, the less representative the available shards are, the more important the hypotheses and the suppositions of symmetries become if a complete view of the original appearance of the piece is to be shown.

3.2. State-of-the-art and main goals

The two mains methods for recording the real geometry in 3D that have been used for modelling pottery are three-dimensional scanning and photogrammetry. Regarding the former, different types of scanners, such as triangulation, time-of-flight (ToF) or structured light scanners, can reproduce the geometry of the objects with levels of accuracy and resolution from a few micrometers to millimeters (Mara, 2009; Bruno et al., 2010; Serrano et al., 2013; Balleri et al., 2014…). Regarding the photogrammetry, it is based on the processing of groups of images in order to recover both geometry and texture (Fellner et al., 2011; Barreau et al., 2014; Gianolio et al., 2014; Avella et al., 2015). Image-based methods have experienced noteworthy improvements in recent years. Their advantages include, to begin with, that they require less investment than scanners in terms of equipment; secondly, that the software for processing the images is highly automated and, thirdly, that the quality of the outcomes is suitable for most downstream applications.

In general, image-based virtual reconstruction is the approach selected by projects, such as 3D-ICONS, that seek to create 3D contents of museums pieces which can be disseminated through the Europeana portal (Guidi et al., 2015). Nevertheless, the adaptation of these techniques to pottery is not without problems, among which we can remark the difficulties of focusing in close range with the necessary depth of field, the existence of hidden areas, the need to merge several partial models and the behaviour of the surfaces under changing lighting conditions (Chow and Chan, 2009; Nicolae et al., 2014).

Alternatively, the characterization through profiles is a traditional method for both representation and classification of pieces of pottery, especially when it comes to revolution geometries. The development of digital techniques, far from having cast aside this approach, has streamlined the drawing process (Kampel and Sablatnig, 2003; Karasik and Smilansky, 2008), provided advanced calculation tools and eased the three-dimensional representation. Thus, for example, profiles have been in use for multiple purposes, from the straightforward computation of the volume of the vessel (Zapassky et al., 2006; Sánchez and Cerdeño, 2014) to more complex applications including the classification of pottery items and their description by means of a series of mathematical parameters. Afterwards, such parameters can be used for establishing similarities between pieces, clustering and searching (Sablatnig and Menard, 1997; Liu and Razdan, 2004; Koutsoudis et al., 2010; Martínez-Carrillo et al., 2010a; Karasik and Smilansky, 2011; Wilczek et al., 2014; Lucena et al., 2016). Actually, the resort to geometric parameters has even been suggested as a way to overcome the interoperability issues that arise when trying to compare studies based on different typological classifications (Smith et al., 2014).

Depending on the aim of the 3D model, it might be necessary to provide a realistic representation and, therefore, to cover the model with a texture. Sometimes the real texture can be obtained from the available remains but, in other cases -especially if a virtual representation of the whole piece is created from small fragments-, texture recreation becomes indispensable (Irujo and Prieto, 2005; Briand et al., 2008; Martínez-Carrillo et al., 2010b). In any case, good practice recommends to create models in which users can distinguish between existent and reconstructed parts (Kotoula, 2016), as well as the level of likelihood of the reconstruction.

Regardless of the method used for the geometric characterization, three-dimensional modelling does bring many benefits (Santos et al., 2014), including: (i) arbitrary availability and parallel access to digital replicas of cultural heritage artifacts; (ii) use of realistic 3D models for documentation, exhibition and acquisition planning; (iii) virtual presentation of hybrid collections made of originals and virtual replicas that boost attractiveness of an exhibition; (iv) physical replicas based on the 3D model of a cultural heritage artifact; (v) borrowing a high quality 3D virtual or physical replica as an alternative to borrowing the original artifact (damage prevention, less or no insurance costs); (vi) reusability of historically correct 3D models in documentaries, serious games or gaming and film industry; and (vii) digital archive (digital preservation to prevent physical loss due to natural disasters).

As has been said above, our goal is to generate three-dimensional models of a selection of representative pieces. This selection would be

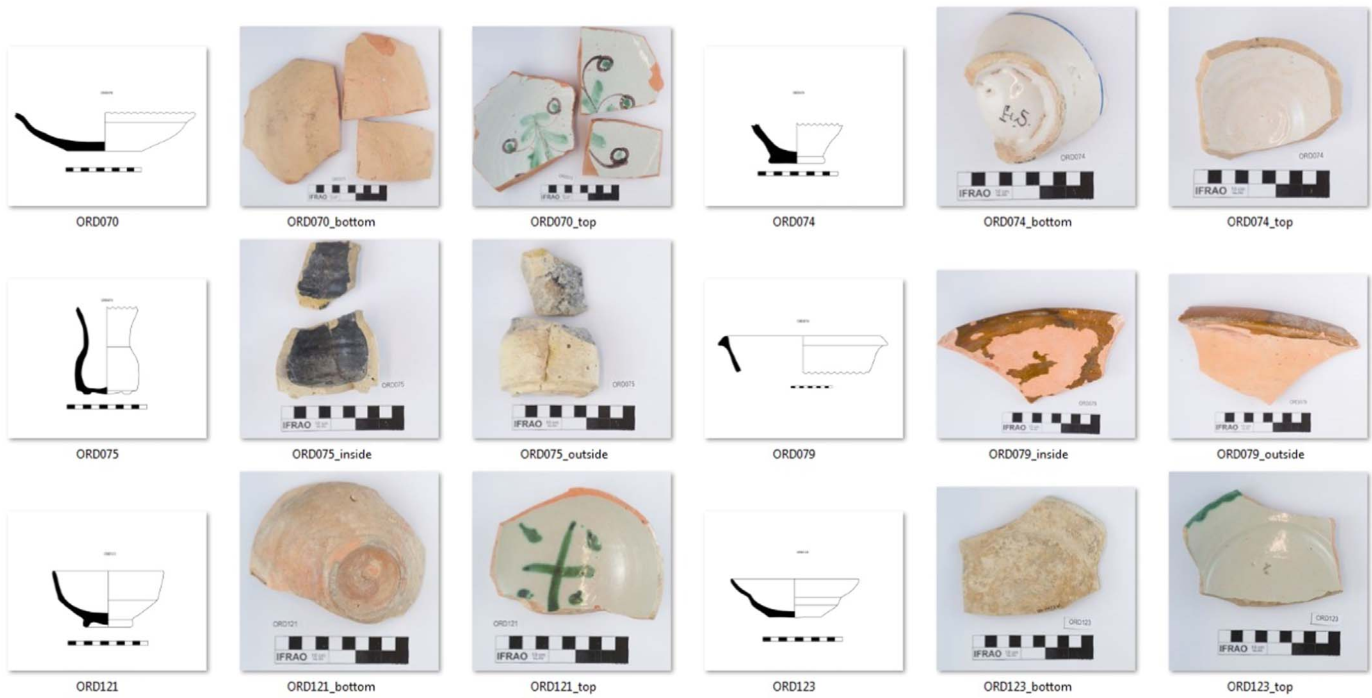

Fig. 1. Sketches with the geometric characterization of six pieces and a pair of descriptive photographs of each one.

useful for the study, dissemination and the articulation of exhibition discourses. The methodology used should also be applicable to more pottery elements in a simple and inexpensive way, even to pieces which are not accessible at present and from which no more than indirect information is available (for instance, pieces that are only reported in file cards, papers, drawings, etc.) (Langley and Rua, 2009). This methodology is expected to enable us to compare elements from many excavations conducted over decades by different researchers, with manifold protocols and various results.

4. Results and discussion

Given that the information about pottery items of old excavations frequently include drawings of profiles, that will be the point of departure of the proposed procedure. For this purpose, many CAD (*Computer-Aided Design*) programs can generate the three-dimensional volume through the revolution of the profile (Fig. 2).

When there are photographs from which the texture of the pieces can be obtained, one way of establishing the relationship between the 3D geometry and the pictures is to resort to modelling software based on the perspective geometry of the image. There are several computer programs that provide this functionality, including some popular ones – both commercial and *GNU General Public License*- offer free versions, such as *SketchUp* or *Meshlab*. The image is usually shown at the background with the mobile 3D model on top, in such a way that the model can be freely moved, rotated and scaled over the image. At the same time, the intensity of the perspective (that is to say, the focal length of the picture) can be also adjusted. All these operations are done by modifying the location of the vanishing points until the 3D model overlaps exactly with the image. The main difficulty is that this procedure is specially designed for 3D models with straight lines (as is usually the case with architecture). Thus, the user defines the vanishing points by drawing on the image representation a set of four lines – two pairs of parallel lines in the 3D space that are perpendicular to each other. In the case of pottery shards, straight lines are infrequent, particularly if we are considering a piece with revolution geometry. Therefore, the match image/3D model has to be done visually by using another type of references, such as the rim or the location of the revolution axis (Fig. 3).

Once the 3D model is well placed in relation to the image, the texture can be projected. This procedure is repeated with the photograph of the other side of the fragment and as many times as required if more photographs and/or fragments exist for the same 3D model.

The next step is to trim off all the projected textures according to the real boundaries of the fragments. Areas without texture are the equivalent to the physical reconstruction of the pieces that are to be exhibited in a display cabinet. In accordance with the usual restoration standards, reconstructed areas should be clearly identified, for instance, by means of a neutral colour (Fig. 4). Then, the edges of the meshes can be hidden in order to obtain a realistic view of the piece.

One interesting feature of this procedure is that real photographs are not even necessary since textures can also be obtained from drawings (Valle and Rodríguez, 2011; Tsai and Chang, 2014). Let us see this in the following example (Fig. 5). At the top, texture is projected from a handmade drawing of a decorated dish to the 3D model, for which the drawing was taken from a paper reporting the findings of an archaeological site near our area of study (Cajigas et al., 2007). At the bottom, two 3D models of the same piece are presented. The geometry is the same in both cases since it was created from the same profile published in the mentioned paper from which the image used for the texture –on the left- was also taken. On the other hand, the model on the right gets the texture from a photograph published in the catalog of an exhibition after its restoration.

As important as the generation of the virtual models of the pottery pieces is to ensure that they will be useful for their established purposes, for which the models will have to be bound together with all the background information necessary for their correct interpretation. In our particular case, our main interest lies in the production process. Therefore, the information we are interested in linking to the 3D models of the pottery items is the one related to the places, moments and ways in which the pieces were produced.

The bibliography presents many examples of virtual reconstruction of industrial buildings, such as watermills (Morandi et al., 2017), sawmills (Morin and Seigne, 2007), furnaces (Benoit et al., 2010), foundries (Adamski et al., 2010) and, of course, ceramic workshops and facilities (Papadopoulos and Sakellarakis, 2013). By taking these

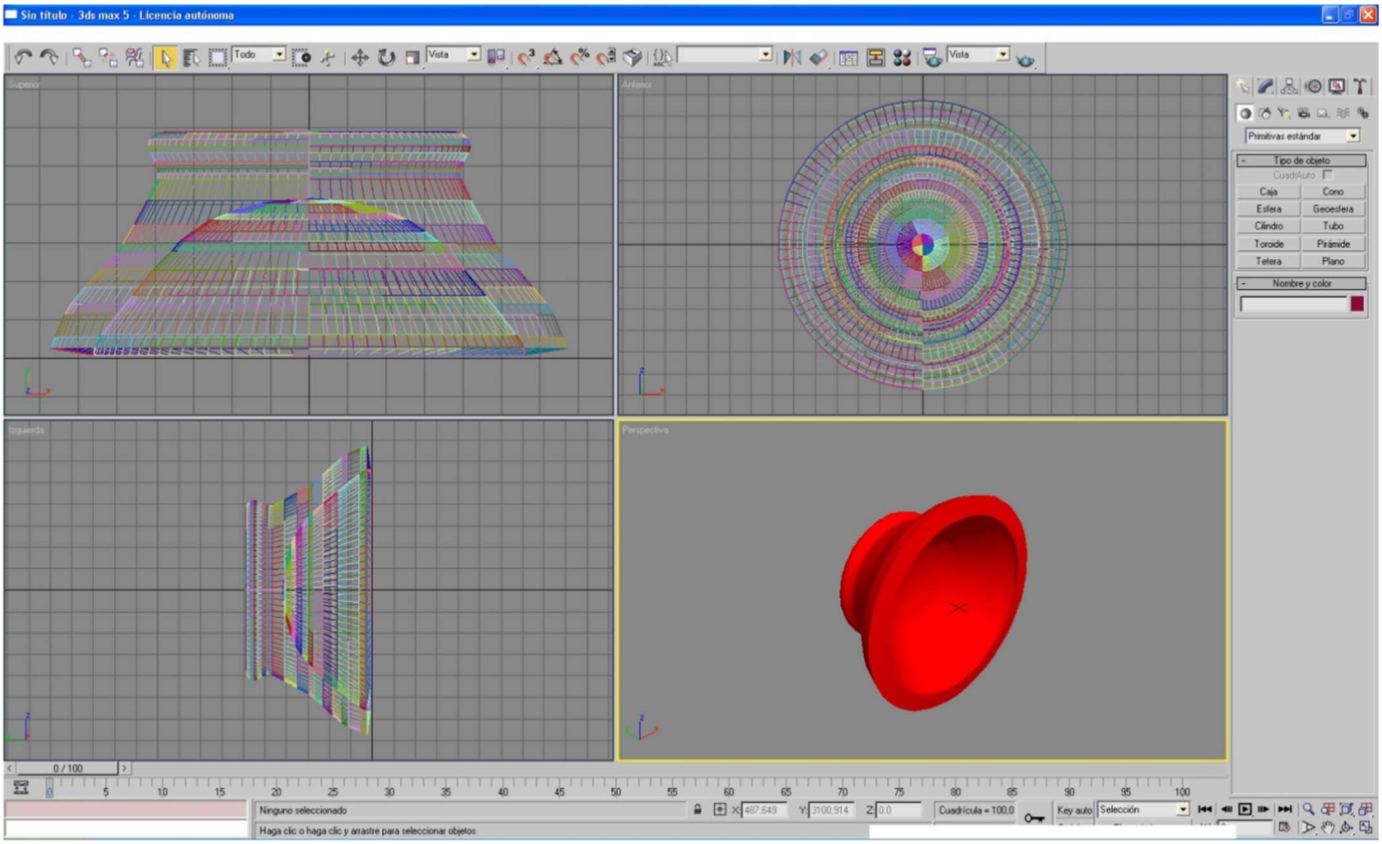

Fig. 2. Different views in a CAD environment of a three-dimensional model of a pottery piece obtained after the revolution of a profile (software: *Autodesk 3DS Max®*).

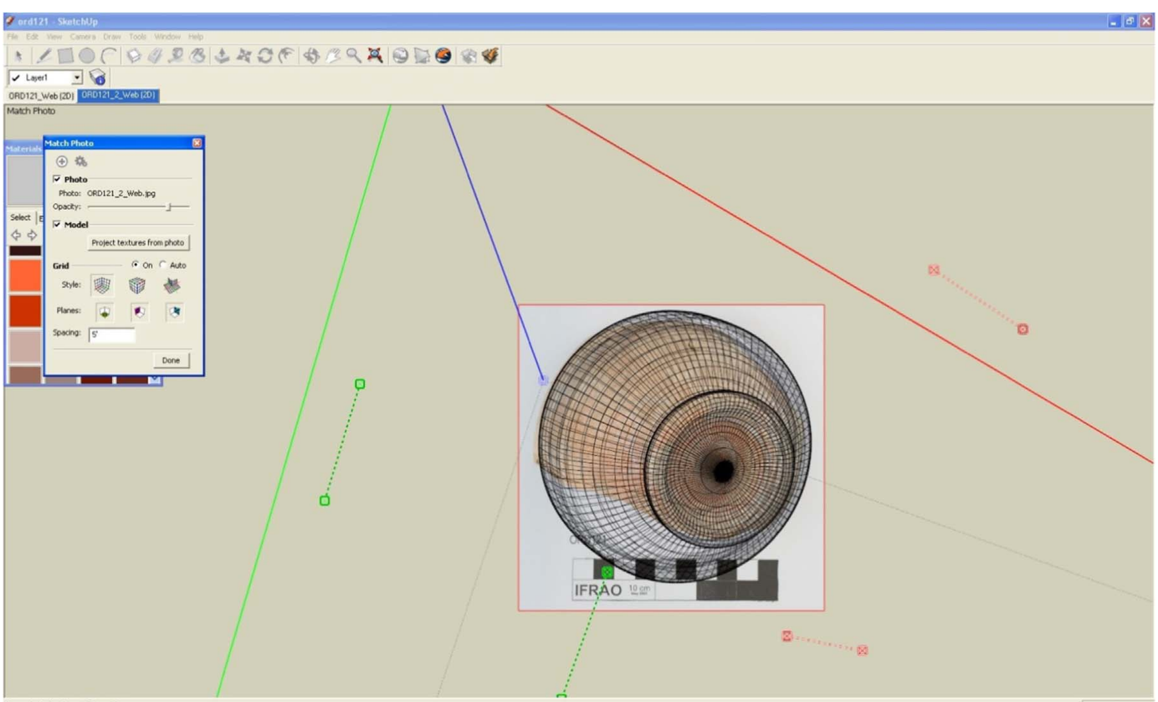

Fig. 3. Green and red lines show the direction of two perpendicular vanishing points. The 3D model is presented as a wireframe view so it can be drawn over the image and the best match checked. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

examples as reference, we can deal with the remains of the kiln located during the excavations in 2001. For hypothesizing about the appearance of the kiln and the firing process there are several sources of information that are usually available when dealing with small buildings of industrial nature that were operational in the 19th century, in particular: old photographs and engravings/paintings of the buildings either in use or of the remains, bills and delivery notes regarding the materials used for their construction, textual descriptions done by

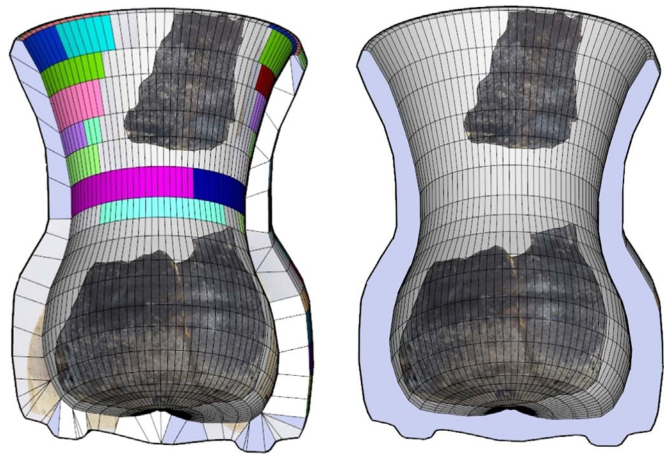

Fig. 4. 3D model of the half of a jar to which the textures from two fragments have been applied. The model on the right shows the use of a generic colour for the areas reconstructed without material evidence.

Fig. 5. Handmade drawing (on top) from which geometry and texture can be obtained (bottom left model). The same geometry can be also wrapped with textures from other sources such as photographs (bottom right model).

witnesses explaining the appearance or the functioning, acts from legal disputes, information about the equipment available inside, direct and indirect data about the production, etc. (Dawson and Kent, 2008; Membrilla et al., 2011). In our specific case, in addition to the archaeological evidences recorded, ethnographical studies of contemporary local productions and early 20th century productions and remains –some still preserved-, including pictures and drawings of similar kilns and pottery productions (Ibabe, 1995), were of high importance throughout the process of defining the hypothesis on the structure of the Orduña kiln.

Virtual models serve as metaphors for the navigation with other kind of data (Apollonio et al., 2012). In the case of the virtual recreation of the kiln, the resulting model permits the relation among the different objects recovered during the excavations, either pottery shards, elements of the kiln (fragments of walls, facing, bricks, etc.) or pieces for the arrangements of kiln during the firing. In virtual reconstruction, it is essential to maintain the references of the existent elements and the hypothetical ones (Pletincks, 2008; Stefani et al., 2011; Favre-Brun, 2015; Pletinckx and Capurro, 2015). To that end, we can resort to different visual variables and graphical resources which allow us to visually identify the level of likelihood of the reconstructive hypotheses, thus the degree of transparency, the schematic rendering, the use of false-colours, the combination of real image and virtual model, etc. Alongside, a common grammar between producer and user is necessary in order to ensure that all this implicit information is communicated with efficiency (Kensek et al., 2004; Barbet, 2008). Finally, more subtle matters, such as the recreation of the soundscape linked to the activity (Kinayoglu, 2008), can be also considered in order to improve the feeling of immersion into the virtual world.

By referring these remains to the historic cartography of the town (Ortega, 2011), it will be possible to interpret the interaction of the local pottery industry with the urbanism and the inhabitants over time. The availability of historic maps with adequate level of detail (usually from cadastral or military sources) varies greatly from a place to another. Consequently, it is not easy to determine beforehand until when it will be possible to take back the analysis, albeit the bibliography counts on some examples in which changes in land uses have been tracked for periods of time encompassing all the 20th century, the 19th and even part of the 18th (Cuca et al., 2011; Skaloš et al., 2011; San-Antonio-Gómez et al., 2014; Kaim, 2016). In addition to the maps, there are several series of orthophotographs of the area of study from mid-20th century, the earliest ones in grey scale with a resolution of several meters and sporadic frequency, the current ones in colour with a resolution of decimetres and on a yearly basis.

In view of the above, the results combine three levels of virtual reconstructions: pottery items, an image of the kiln –as building- and the representation of the spot occupied by the pottery workshop on the ever-changing urban fabric.

Beginning with the models of the pottery items, for two of the selected pieces it was deemed important to record the full 3D geometry as it truly is. The method selected was the imaged-based one (Fig. 6). The geometry of the rest of the pieces was modelled from their profile (Fig. 7).

Three-dimensional models have varied uses such as archiving, conducting studies or the communication and virtual exhibition. Each one of them will require adaptation both of the file formats and in order to support the interaction with different kinds of users and media (desktop computers, mobile devices, exhibition panes, etc.) (Fig. 8).

Considering now the kiln, the basic dimensions were taken from the notes and the scaled drawings and plans generated during the excavation in graph paper. From the few photographs that were available, it was possible to infer the conservation status of the structure and, as a result, the starting point for the hypothetical reconstruction. The elements that compose the virtual model were organized according to their real function (internal and external walls, floor covering, etc.) so that the users can focus on particular parts of the building (Lee et al., 2014) (Fig. 9).

Finally, the following figure shows the area where the remains of the kiln were discovered over three different backgrounds corresponding to three epochs (Fig. 10). The figure on the left corresponds to the orthoimage of the year 2014, in which the quarter is urbanized. In the middle the orthoimage of the year 1990 is shown, with indication of the current urban pattern (red lines) and the place where the remains of the kiln were found (yellow lines). At that moment, the area was occupied by plots with some small auxiliary buildings. Finally, on the right a cadastral plan from the 19th century is presented in which two buildings with the handwritten inscription "*Alfar*[a] *Ortes Velasco*" (translated as "pottery workshop of Ortes Velasco") alongside can be seen. This plan is georeferenced and –as the image in the middle- includes the current urban pattern (red lines).

5. Conclusions

The present work seeks to contextualize the pottery production of the town during the pre-industrial era on the grounds of the virtual recreation of the pieces, the buildings and the vision of the surrounding spaces over time. All of them have been modelled from different sources of fragmentary information.

This research succeeds in visually an important part of the

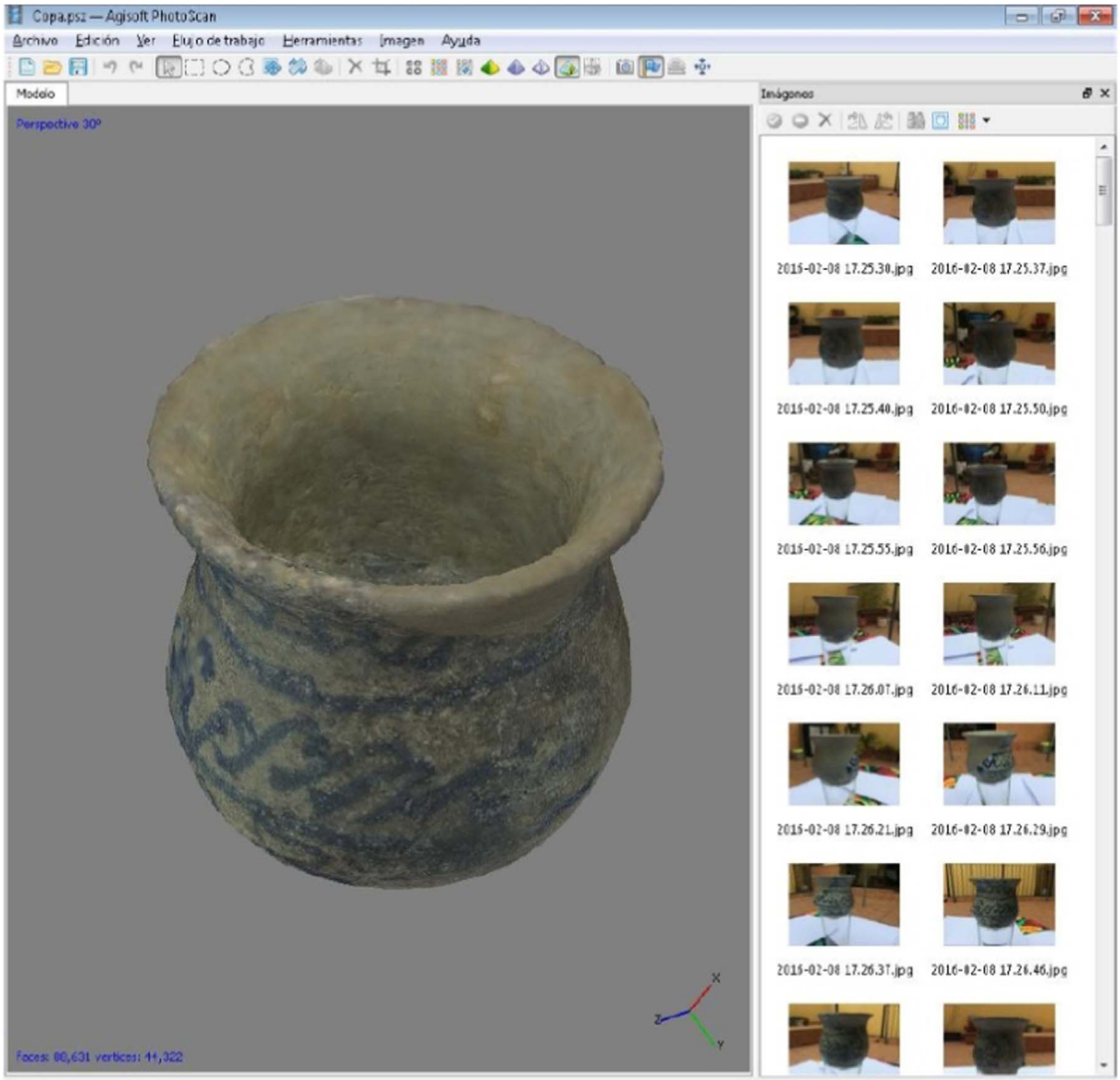

Fig. 6. Vessel of a pottery goblet from the collection studied in the project. Outcome of the 3D modelling by means of image-based techniques (software: *Agisoft Photoscan®*).

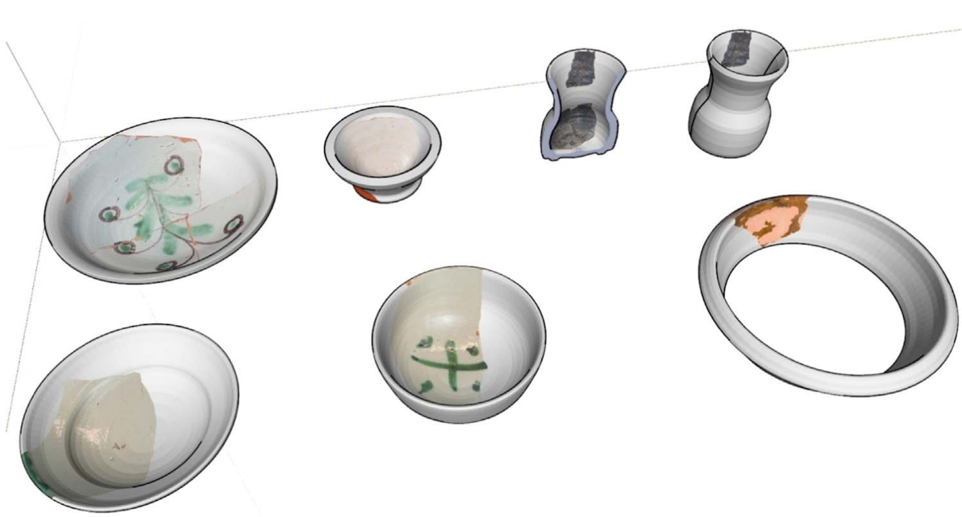

Fig. 7. Group of pieces reconstructed in 3D from the profile and with photographic texture applied following the procedure explained.

Fig. 8. The image on the left shows one of the models imported in an environment for graphic design (*Unity 3D®*) from which the application shown in the image of the right was created. This application permits haptic interaction with the virtual object through a tablet.

knowledge about the matter, which allows for the dissemination and use by a wide range of people and purposes encompassing the historical study, the virtual display inside museums (or through their websites), tourism, etc. It goes without saying that the features of the 3D models have to be adapted to the expected users and uses, being the latter what will define the accuracy of the geometric reconstruction, whether real texture is required or not, as well as any other feature considered.

Taking into account the number of fragments that are deposited in museums, this study also bolsters the need to establish methodologies for the generation of collection of 3D virtual models in a quick and cost effective way. Furthermore, interoperability will be required between the 3D models of the pieces to which physical access is possible and the models that are obtained only from derived information (sketches, photographs, etc.).

These facts clearly emphasise that, in the current context of digital technologies, it is not possible to untie the success in the physical conservation and exhibition of the archaeological pieces and the strategies for the recording, preservation, management and use of the information related to them.

Notes

Authors bear no relationship with any of the companies that produce or commercialize the pieces of software mentioned along the text; they are included just for the sake of illustration. The following list refers to their websites:

- Autodesk 3DS Max. http://www.autodesk.com/products/3ds-max/overview
- SketchUp. http://www.sketchup.com
- Meshlab. http://meshlab.sourceforge.net/
- Agisoft Photoscan. http://www.agisoft.com/
- Unity 3D. https://unity3d.com

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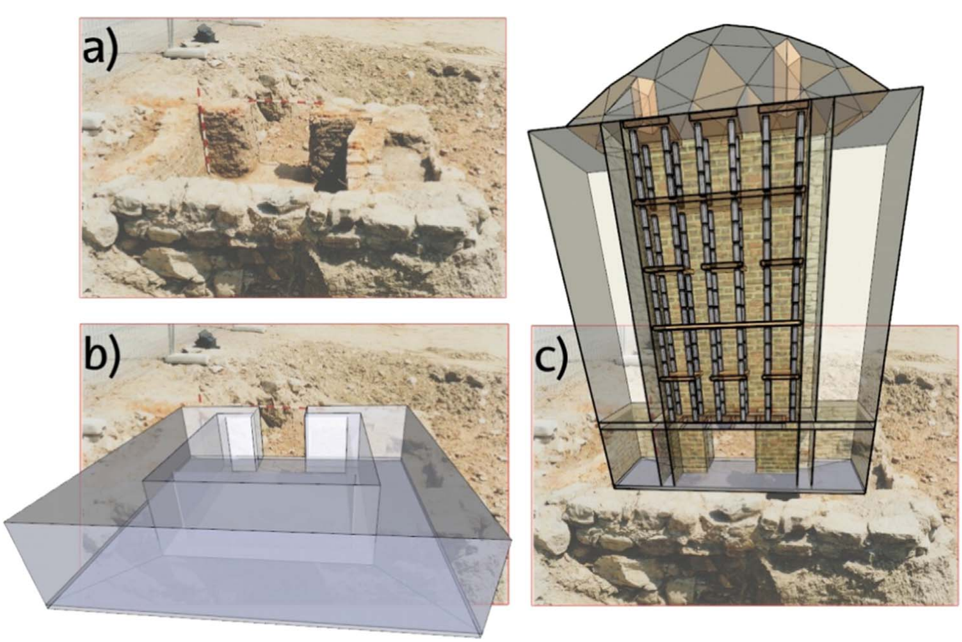

Fig. 9. The image shows, in (a) a photograph taken in 2001 in which the remains of the combustion chamber of the kiln located during the excavations; (b) over this photograph the 3D model is superimposed representing the existent remains; and (c) the representation of a cross-section of the virtual reconstruction of the complete kiln with the internal partition during the loading.

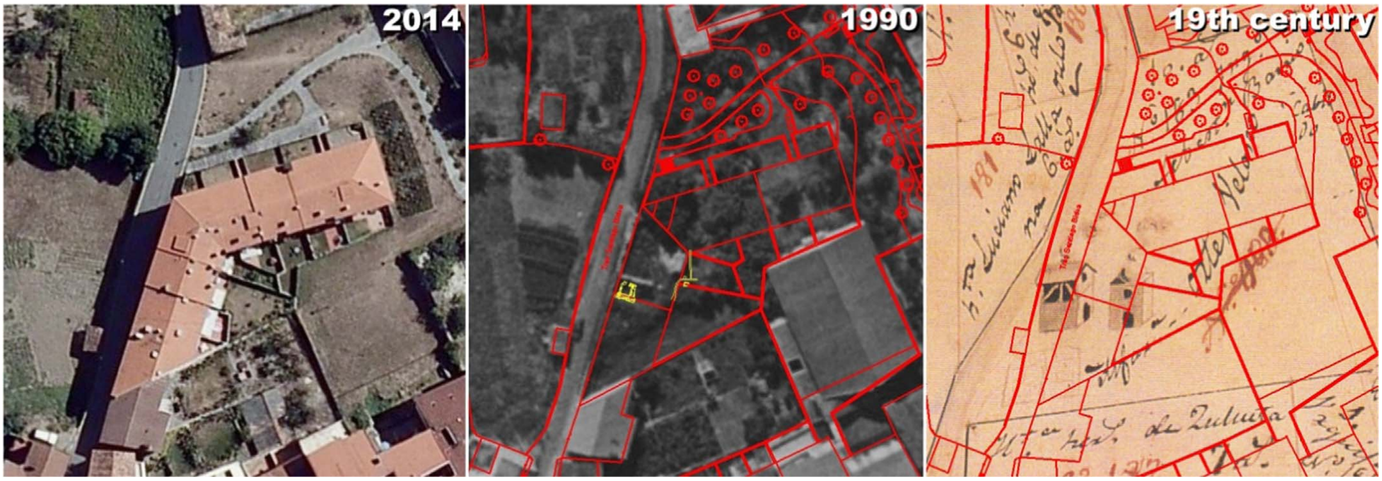

Fig. 10. Area where the remains of the kiln were discovered over maps from different moments: 2014, 1990 and 19th century (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.).

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