Title: Comparing 2D pictures with 3D Replicas for the digital preservation and analysis of tangible heritage

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Abstract

In this paper, we present two experiments designed to compare 2D digital pictures and 3D digital replicas of artefacts, to understand how differently these media facilitate the perception and understanding of our past. Archaeologists and museum experts have commonly used 2D digital pictures to preserve and study artefacts. Recently these scholars have also started to use 3D digital archives for their studies. Yet we still need to determine how these two formats (2D vs 3D) affect the perception of our past. Results to our experiments point to 3D digital replicas of artifacts as more effective means to digitally preserve tangible cultural heritage, since 3D multi-visualization augments the perception of physical characteristics of the artifacts allowing a more embodied experience with these objects. Our experiments also suggest that multi-visualization (i.e., point-cloud, mesh, and color information) helps the viewers to overcome their personal conceptualization of specific objects.

Keywords: 2D digital pictures, 3D digital replicas, perception, digital archives, cognition, artefacts.

1. Introduction

Two and three-dimensional images are alternatively used to digitally capture and visualize material heritage; however scholars have yet to determine how these visualizations can differentially promote and/or influence deeper understanding of material culture.

According to Colin Wave, visualization facilitates the understanding of large amounts of data, promoting the perception of objects' affordances, as well as helping us to analyze cultural heritage in various ways (Wave 2004: 3).

Two-dimensional digital pictures are one of the primary methods for visualizing ancient artifacts and creating both off-line and online digital archives for study purposes. Pictures are a fast, simple, and cost-effective way of documenting, preserving and disseminating artifacts that are stored in museums or other remote storage facilities. Although 2D pictures usually provide suitable level of detail for visualizing artifacts, in absence of the real objects, pictures cannot always be considered an ideal means to grasp the physical qualities of objects that are crucial for the understanding of uses of these objects in the past. For this reason, scholars are exploring the potential of 3D reproduction techniques for the creation of off-line and/or online digital archives of artifacts (e.g., Smithsonian X3D 2015). Creating 3D digital archives can be time consuming and require multiple forms of expertise. It is important to understand both *why* and *if* scholars in the field of heritage should concentrate their efforts on the creation and management of 3D digital archives.

In an article on 3D reproductions of prehistoric skeletal collections, anthropologists Susan C. Kuzminsky and museum curator Megan S. Gardiner, highlight the importance of 3D reproductions for preservation purposes. They visited 15 regional and national museums in North and South America and found that many museums still have antiquated or incomplete inventories of both artifacts and skeletal remains (Kuzminsky & Gardiner 2012: 2747). Without accurate information on the artifacts, research becomes both difficult and time consuming, since scholars have to be able to locate and find the original artifact in museum storage to facilitate the completion of an accurate report or study of the objects in question.

The benefit of a 3D digital replica is that it can be easily stored digitally (on a hard drive for example) and researchers can virtually manipulate the objects over time without the risk of damaging the real artifact due to multiple, sometimes unnecessary contact. 3D digital copies of artifacts also have the advantage of being remotely accessible, making them easier for scholars all over the world to analyse and study the same collection (Hermon et al. 2012; Weber and Bookstein 2011; Tocheri 2009; Karasik and Smilansky 2008) and share multiple interpretations of the same artifacts/contexts in real time).

Research on human cognition suggests that pictures are remembered better than words (Tversky 2000: 364), it is our hypothesis that, in the realm of archeological inquiry and examination, 3D media might be preferred over 2D pictures, because interaction with 3D objects mirrors the interactions we have in everyday life. These interactions take advantage of a complex sensory system afforded to researchers everywhere (Levy et al. 1996: 48). Moreover, 3D digital copies of artifacts can be 3D printed, allowing for the creation of comparative physical collections extremely useful for research purposes.

In this paper, we present two experiments designed to clarify how differently people understand artifacts when they are presented either in 2D or 3D digital format. Even though many studies in computer and cognitive sciences have explored how people perceive specific characteristics of objects (e.g., weight, size, density etc.) through visual, tactile, and virtual experiences, little is known about how people perceive past material culture through the senses, and how experiencing ancient artifacts through different media affects the perception of our past. This paper addresses the issue of perception with the aim of providing some suggestions on how to archive information about ancient artifacts.

2. Two and three-dimensional archives for preserving tangible heritage: state of the art

Photography, and more often digital photography, is currently one of the primary methods of documenting, preserving and disseminating artifacts. Photographs are useful for conservation because they provide a fast, simple, and inexpensive way of documenting notable characteristics observed in artifacts. This is perhaps one of the reasons why archaeologists began utilizing photography surprisingly early for recording antiquities (Dorrell 1989:1-2; Harp 1975).

Digital photography provides the advantage of immediate feedback through the display, easy processing, copying and circulating of the digital images compared to images taken using a traditional film camera (for advantages and disadvantages linked to using a digital camera see: Rudolf 2006: 177-209). Moreover, digital photography allows for image editing, such as cutting and scaling, background alteration, or for adding digital scales, symbols, etc., and can be stored on computer hard drives or other inexpensive external backup devices. (Rudolf 2006: 190).

Digital cameras have made it possible to create and manage large collections of digital images and the advent of the Internet has created new opportunities for the use of digital imagery. In the last few years, collections of digital images with appropriate metadata have been recognized as significant resources for heritage management. The

Internet allows immediate access to exemplary bodies of digital images regardless of physical location of the viewer or data source. Some digital collections of pictures integrate information and documentation of excavation projects (e.g., Swedish Pompeii 2015; Çatalhöyük 2015). Other collections give access to digital representations of artifacts stored in museum facilities (e.g., Cuneiform 2015).

Even though photographs provide images of artifacts that work well for documentation, some scholars (e.g., Kuzminsky and Gardiner 2012) argue that 2D images are not ideal replacements, especially when the original artifact is unavailable for "hands on" viewing. As a result, 3D reconstructions of real objects have become a common method to analyze and study artifacts when the real objects are located in storage facilities that are difficult to access due to risk of damage of the real objects, physical distance between the object and the researcher, or institutional conflicts that prevent physical object viewing, etc.

Real object models can be reconstructed automatically using both active and passive methods. Laser scanning and structured light are typical examples of the active methods. One of the most significant advantages of laser scanners is their high geometrical accuracy.

The most used passive method, known as Image-based Modeling technique, uses digital cameras located at different viewpoints to reconstruct a 3D model using a structure-for-motion algorithm (i.e., Photoscan 2015). Passive methods are low-cost and useful when direct access to the object is prohibited.

The use of 3D technologies allow for the replication of real objects without the use of molding techniques, that in many cases can be more expensive, more difficult, or too invasive to be performed; particularly in cases where direct contact of the molding substances to the object could harm the surface of the original artifact.

Given all the technological advancements, 3D reproduction techniques offer affordable options to preserve artifacts and other cultural heritage and create large databases to share 3D digital data (e.g., Smithsonian X3D 2015; MicroPasts 2015).

New databases containing high-resolution 3D digital replicas are innovative tools that can be used by researchers to collect data tailored to specific research questions. (Kuzminsky and Gardiner 2012: 2749). Indeed, many things can be done with the completed 3D digital replicas.

Using software packages (such as Scan Studio 2015; Meshlab 2015, etc.) researchers can take screen shots of images, record points on objects, calculate surface areas and volumes, or make other precise measurements (Weber and Bookstein 2011; Tocheri 2009; Karasik and Smilansky 2008). Scanned images can also be used to reconstruct areas of objects that are structurally incomplete or damaged (Hermon et al.2012). Educational research suggests that digital representations are also effective means by which to introduce aspects of material culture study to large numbers of students, when they cannot access collections of original objects (Doonan and Boyd 2008), but also to introduce methods of the archaeological fieldwork (Di Giuseppantonio Di Franco et al. 2012).

Towards this end, here, we designed two experiments where we compared perception of real-life artifacts through either pictures or 3D virtual replicas. Participants in Experiment 1 were randomly assigned to two condition groups: group 1 viewed digital picture of a statue, while group 2 viewed a snapshot of the 3D point-cloud of the same statue. This experiment was aimed at understanding whether, by augmenting the reality of an object, that is, using different levels of perception of an artifact through digital reproduction, students would perceive this artifact differently. Interaction with digital copies of artifacts was not part of this experiment, since participants only viewed the snapshots/pictures.

Participants in Experiment 2 were divided in three condition groups: participants in group 1 actively interacted with the original artifacts; participants in group 2 viewed pictures of artifacts; and participants in group 3 3D replicas of artifacts. Participants in group 3 could interact with the 3D visualization and also had the option to see the objects with or without original colors applied on it (i.e., texture, mesh, point-cloud, wireframe).

Participants' responses were analyzed for speech content, notably words emphasizing innate qualities of the artifacts (including shape, material, color, weight, texture, and size).

3. Experiment n. 1

3.1. Background

Experiment one examines the perceptual differences between a picture of a statue (3D scanned in Xi'an, China in 2010; see Di Giuseppantonio Di Franco et al. 2013; Forte et al. 2010) with a snapshot of its 3D scanner generated point-cloud. We were interested to see if viewing a 3D point-cloud would be able to enhance the perception of a real-life object, as opposed to viewing a 2D picture and how viewing a 3D point-cloud, versus a 2D picture could be used to improve a museum visitors' experience.

3.2. Participants, materials, and methods

Participants in this experiment were undergraduate students who were randomly assigned to view one of two images of the Maoling Museum's horse statue [Fig. 1 near here]: 1. Image 1 was a picture of the statue as exhibited on-site (i.e., in the Mausoleum; [Fig. 1a]). 2. The second image was a snapshot of the 3D point-cloud acquired during the 3D laser scanning acquisition campaign [Fig. 1b]. The level of detail of the 3D point-cloud was between 6 and 8 millimeters. In this experiment, students were asked to analyze the 2D images, but they did not really visualize the object in the 3D space.

One-hundred-fifteen students volunteered to participate in this study for course related extra credit. All were proficient speakers of English, either native speakers of English or bilinguals with dominant English experience. All had normal or corrected vision. Data were collected online using a web-based survey application. After consenting to participate and reading the instructions (see text below) displayed on the computer screen, the students pressed a START button on the screen to start the experiment. Participants were randomly assigned to either the 2D picture condition (58 students) or to the 3D point-cloud condition (57 students). The task was as follows: "In this task, your job is to look at the picture and answer the questions below. Take as much time as you need. Thank you for your cooperation". All participants answered 14 questions, one by one, while viewing the associated image (either 2D picture or 3D point-cloud snapshot). All questions focused on innate qualities of objects (materiality, shape, texture and spatiality) in the attempt to understand if the perception of these qualities differed between the two conditions.

3.3. Results

For this experiment, we conducted a preliminary analysis of verbal responses for each of the following questions:

Q1. What is the figure?

Question 1 aimed at understanding if the participants were able to recognize all features characterizing the sculpture. The results showed that most subjects (95.7%) were able to recognize the horse, but no one described the figure underneath it, with no difference between the 2 experimental conditions: X^2 $(4, N = 115) = 5.14$, $p = .27$.

Q2. Please use the scale provided (1-7) to answer the question. How easy is it to recognize the image in this sculpture (1 being difficult; 7 being easy)?

On average, the majority of students felt confident about their level of perception and understanding of the artifact as a whole. The difference between the two groups was not statistically significant, $t(115) = 1.91$, $p = 0.06$ [Table 1]. Participant confidence judgments in the 2D picture condition did not reliably differ from participant confidence judgments in the 3D point-cloud condition.

Q3. What is the figure made out of?

This question aimed to understand how participants in the 3D point-cloud condition would overcome the absence of texture (color) to elaborate upon the material of the statue. Findings show a statistical difference between the two groups, X^2 (6, N = 115) = 19.57, p = 0.003, even though the percentages of students in the two conditions who recognized that that the statue was made of stone were close (3D point-cloud: 63.2%; 2D picture: 69%).

Even if the majority of participants in the 2D picture condition recognized that the statue was made of stone, 25.9% of them indicated that it could be made of cement, possibly due to the color of the limestone. The second most frequent response of the 3D point-cloud group was clay (24.6%).

Q4. How sure are you that this is the right material?

To calculate uncertainty (hedging) about the material, all cases in which students gave multiple answers were considered. Results of this question show a statistical difference between answers given in the 2D picture condition and the 3D point-cloud condition (93.1% vs 78.9): X^2 (1, N = 115) = 4.81, p 0.028. 93.1% of those who viewed the 2D picture of the horse gave a single answer, however, only 78.9% of those who viewed the 3D point-cloud gave a single answer. This statistical difference was to be expected, since the 3D point-cloud group worked with an image lacking original colors.

Q5. Please use the scale provided (1-7) to answer the question. What is your impression of the image?

a. *(1 being weak; 7 being strong)*
b. *(1 being passive; 7 being aggressive)*
c. *(1 being cowardly; 7 being brave)*

A significant difference was found only in Q5c, t(115)=2.94, p=0.004. The 2D picture of the horse was judged as being more brave (M=5.60, SD=1.26) than the 3D point-cloud of the horse (M=4.82, SD=1.57). While not statistically significant, it is possible to observe a trend, as participants in the 2D picture group also described the statue as stronger and more aggressive than participants in the 3D point-cloud group [Table 1].

Q6. Please use the scale provided (1-7) to answer the question. What is your impression of the image? (1 being light; 7 being heavy)

Results show that both groups expressed their preference toward the adjective *heavy*. Nonetheless, participants in the 3D point-cloud condition perceived the statue as significantly heavier when compared to the participants in the 2D picture condition, $t(115) = 2.232$, $p = 0.03$ [Table 1].

Q7. Please use the scale provided (1-7) to answer the question. What is your impression of the image? (1 being lifeless; 7 being lively)

Examination of these data show a reliable difference between the two groups, $t(115) = 2.46$, $p = 0.015$ [Table 1]. Participants viewing the 3D point-cloud judged the statue as more lively (M=3.96, SD=1.57), than those viewing the 2D photograph (M=3.24, SD=1.58).

After reading the results of the last question, all open-ended descriptions of the statue were analyzed, to see if the provided figures were described with an emphasis on space. The participants in the 3D point-cloud condition exhibited an increased sense of spatiality in describing the statue when compared to participants in the 2D photograph group (76.9% of the 3D point-cloud group described the object stressing its spatiality versus just 23.1% of the 2D picture group; [Fig. 2 near here]): X^2 (1, N = 115) = 10.06, p = 0.002.

Q8. What do you see under the horse? Is what you see easy to recognize?

Here, students were requested to recognize the figure under the horse: most of the participants in the 3D point-cloud condition were able to recognize the human figure (70.2%), while less than a quarter (24.1%) of the participants in the 2D photograph condition readily recognized the figure under the horse, this difference was reliable, X^2 (1, N = 115) = 24.46, p < 0.001. When asked if it was easy to recognize this figure, most students, regardless of condition answered that they were unsure (3D point-cloud: 78.9% unsure, photograph: 72.4% unsure): X^2(1, N = 115) = 0.666, p = 0.41.

Q9. Does the figure under the horse looks like it is moving?

Answers to this questions show that the majority of students independent of condition did not recognize any motion in the figure (3D point-cloud: 58.3%, 2D photograph: 41.7%): X^2 (1, N = 115) = 0.93, p = 0.334.

4. Experiment 2

4.1. Background

In Experiment 2, participants were videotaped while they interacted with selected artifacts through different forms of media. This experiment aimed to understand how the medium (e.g. tactile experience, viewing of 2D pictures, and interaction with 3D virtual copies) influences the way people describe and understand objects (Di Giuseppantonio Di Franco et al. 2015a; Di Giuseppantonio Di Franco et al. 2015b).

4.2. Participants, materials, and methods

A total of 32 participants volunteered to take part in this study. Half were undergraduate students, who received extra course credit in exchange for their involvement; the other half were expert archaeologists (i.e., either academics or contract archaeologists) who also volunteered for the study. All were proficient speakers of English, either native speakers of English or bilinguals with dominant English experience. All had normal or corrected vision.

All students were videotaped in a large, well lit laboratory room and after signing a consent form they were asked to stand in front of either real objects or their reproductions (made using different media), located on a table together with a succinct caption providing information of the object's provenience and age [Fig. 3 near here]. A video camera, fixed to a tripod, was positioned opposite the participant on the other side of the table, about 120 inches (3 m) from participants. Some archaeologists were interviewed in the same lab used for the students, but most were interviewed, based on their availability, in their personal offices or labs, where the authors of this paper reproduced, to the best of their ability, the conditions and atmosphere experienced by the other participants. Participants were given verbal instructions by a researcher (detailed below). The researcher then left the lab leaving the participant alone during the experiment. This was done to reduce nervousness of the participants.

Participants were randomly assigned to the following conditions: Touch (haptic experience with real objects, 8 participants); 2D picture (2D visual, 8 participants); 3D screen (3D virtual visual, 8 participants).

For this study we analyzed and compared all interviews in the three conditions, to see how 2D and 3D digital reproductions differentially enhance and/or influence the understanding of ancient material culture in absent of tactile experience with real-life objects.

4.3. Results

4.3.1. Quantitative analysis of verbal descriptions

First, we compared the total average number of words participants produced in the Touch, 2D picture, and 3D screen conditions to see if differences existed in the length of discourse produced by both students and archaeologists [Table 2 near here]. Overall, archaeologists produced more words while touching the objects (M=322.62) than they did while viewing 2D pictures of the objects (M=160.62), $t(6) = 1.97$, $p = 0.02$.

When comparing the Touch and 3D screen conditions, we found that Touch and 3D screen participants produce very similar amounts of words, which were higher than the amount of words used by participants in the 2D picture condition. When comparing students to archaeologists, results show that archeologists in the 3D screen condition used more words than their peers in the 2D picture condition, $t(6) = 2.81$, $p = 0.03$.

The three groups were then compared to see how differently participants perceived innate qualities of objects. The analysis was aimed at understanding if specific media would better stress some qualities over others, and how media would influence the overall perception of ancient artifacts and their functions in the past. The analysis included: material, color, shape, size, and weight.

Participant responses were categorized into four possible response types: correct, incorrect, uncertain, and absent. The uncertain category included all cases in which participants were not sure about the material of an object, but eventually indicated the correct one [Table 2]. The *absent* response was not considered an incorrect answer, since multiple factors could explain why people did not mentioned material or other characteristics of an object. For instance, it could be that the medium does not stress/afford/enhance a specific characteristic; or that some people do not consider a specific characteristic crucial for their description of an object. In addition, some participants might have felt that the perception of a characteristic is so obvious, that they did not need to provide a description of it. For all other categories, correct vs incorrect answers were not considered, since determining weight and size of an object, for instance, could be challenging in any given condition; the analysis thus aimed at examining when participants either mentioned or did not mention each characteristic and the frequency with which they did. All graphs include answers for all objects described.

Material. No reliable differences were found between the Touch, 2D picture, and 3D screen conditions: X^2 (2, N = 96) = 2.4, p = 0.3. Therefore, we analyzed archeologists and students independently [Figs. 4, 5] and found reliable difference between conditions controlling for participant type: Archaeologists: X^2 (2, N = 48) = 1.79, p = 0.4; Students: X^2 (2, N =48) = 10.14, p = 0.006.

Analysis revealed that students in the 3D screen condition mentioned the material of the objects more frequently than their peers in the Touch condition, X^2 (1, N = 32) = 5.24, p = 0.02. Similar results were found when comparing students in the 2D picture condition to their peers in the Touch condition, X^2 (1, N = 32), p = 0.015. We did not find any reliable differences when comparing archaeologists in the three different conditions. These results suggest that experiencing objects in the 3D screen and 2D picture media tend to increase the interest toward *material*.

Texture. A reliable difference was found in how participants mentioned texture across the three categories of analysis (Touch, 2D picture, and 3D screen): X^2 (2, N = 96) = 8.59, p = 0.01.

Analyses showed how archaeologists in the 3D screen condition mentioned more utterances related to texture qualities of the objects than their peers in the 2D picture condition, X^2 (1, N = 32) = 6.15, p = 0.01. No reliable difference was found when comparing students in the 3D screen and 2D picture conditions.

Color. A reliable difference was found in how participants mentioned color across the three conditions (Touch, 2D picture, and 3D screen): X^2 (2, N = 96) = 7.93, p. = 0.02. Individual comparisons show how archaeologists in the Touch condition produced significantly more words related to color than their peers in the 2D picture condition, X^2 (1, N = 32) = 10.16, p. <.0001, and 3D screen condition, X^2 (1, N = 32) = 4.8, p = 0.03. No reliable difference was found when comparing student responses across conditions.

Shape. No reliable differences in participant responses were found with regard to shape across the three conditions: Touch, 2D picture, and 3D screen: X^2 (2, N = 96) = 5.59, p = 0.06. The difference was no reliable also when we compared students and archaeologists' responses independently.

Size. A reliable difference was found in how participants mentioned size across the three conditions: X^2 (2, N = 96) = 6.34, p = 0.04. Individual comparisons [Figs 6, 7 near here] show how students in the Touch condition produced significantly more words related to size than their peers in the 2D picture condition, X^2 (1, N = 32) = 5.08, p = 0.02 and in the 3D condition, X^2 (1, N = 32) = 5.24, p 0.02.

Archaeologists who interacted with 3D digital replicas (i.e., 3D screen condition) mentioned the size of the objects marginally more frequently than participants who viewed 2D pictures, but this difference is not statistically significant.

4.3.2. Qualitative analysis of verbal descriptions

Material. The qualitative analysis reinforces the idea that both students and archaeologists struggle to discern the material of 3D replicas of artifacts. The following example, for instance, shows one archaeologist's response while interacting with the 3D digital replica of the Buddhist ritual object (i.e., 3D screen condition): "Uhm other than that uhm I can't even say what material it is/ It's probably ceramic uh could be stone uh" (#34). "So what it is is/ It looks like it's maybe made from rock" (#1, student looking at the 2D picture of the Buddhist object, which is made of wood).

It's interesting that in absence of direct tactile experience, participants use several other visual cues to discern the material of an object, such as color, texture, and shape cues:

- Color: "S[o] this is what I'm guessing it is for and it's again like it's flat and it's white and maybe made out a rock, bone, or it was an animals teeth at a point" (#1, students, looking at the 2D picture of the projectile point). "And, uh, it looks like there is some sort so yeah the color of this thing is/ uh sort uh dark brown kind of mottled with lighter brown or tan it could well be wood" (#28, archaeologist, looking at a 2D picture of the Buddhist ritual object in the case);
- Texture: "Uhm, it has you know marks on it that look like it was chiseled on wood and uhm" (#33, archaeologist, interacting with the 3D digital replica of the Buddhist object). "Uhm I say that it's made of wood uhm from what I could tell

uh it looks as though uhm it has you can see marks where it's been uhm chiseled away by hand" (#36 archaeologist, interacting with the 3D digital replica of the Buddhist object).

- Shape: "The structure of this uh/ Of this thing would be made up of some type of metal/ Uhm as you can see/ Uhm as I infer that this darker spot her uhm inside of the sphere/… It I was originally thought like a grenade or something like that" (#15, student, interacting with the 3D digital replica of the pot -3D screen condition).

One archaeologist even stressed the importance of certain visual cues combined with her familiarity of the projectile point, as strong affordances that help determine the function of this particular object:

> Uh this is a stone projectile point uh in this case it's uh in part because of my familiarity with the object and also in part because of the surface characteristics that are visible both in the visual scan and then also uh in the data points uh in the underlying layers it's clearly uhm it's very easy to see clearly visible uh flaking scars uh stone and uh glass uhm are two materials that uh respond that way to uh certain kinds of impact pressure so we can actually get a pretty good clue about the material from these visual cues because I have familiar familiarity with/ uhm stone tools and how the materials they're made of/ uh work in this situation (#35, interacting with the 3D digital replica of the projectile point -3D screen condition).

3D seems more problematic than 2D pictures, since the texture reproduced by the scanner is somewhat low in resolution and due to this, some visual cues can be misleading:

> Uh it seems in my estimation/ although it's difficult because I can't actually see or touch the material but it's likely made out of clay/ Ceramic object uh/… Alternatively uhm it could also be a metal object there's some sheen and some other discolorations on there that are reminiscent of uh metals known from archaeological contexts especially those in dry areas/ I don't know if it's I don't work with metal very often in my own work uh/ Also it's something I don't uhm have a lot of experience reading visually/ If I could get my hands on it uhm I could tell you for sure (#35 archaeologist, interacting with the 3D digital replica of the ceramic pot -3D screen condition).

Texture. The qualitative analysis shows how quite a few participants (both students and archaeologists) in the 3D group focused on *texture* while describing the artifact. These participants stressed the importance of removing original colors from the replicas (i.e., 3D screen condition), to better understand texture and detail of the objects under analysis. For instance, a student interacting with the 3D digital replica of the grinding stone, noticed:

> But uhm another interesting thing is the fact of how/ Many points it has or the geometry I think is what uhm this button and this button is for/ Uhm it is very very intricate and very small things that make these indents/ Uhm very small changes which is not easy to do on purpose/ Uhm so that would lead me to think that the the water itself from the ocean uhm/ Would've hit or just would've deformed the rock in these subtle ways/ Uhm making this overall structure of the rock and this uhm the texture of this rock (#15).

Similar observations of the grinding stone were made by another 3D student participant: “Okay uhm when I remove the texture/ from this the texture seems to be kind of like rough (#16).

Archaeologists’ responses similarly stress the importance of removing original colors from digital reproductions to better understand and perceive the surface of an object: “even if we take away the color it still it looks like a rock itself was uhm/ incised with little holes in it and so those little pits could be just natural or it have had some wear on the uhm on the tips (#33, interacting with the 3D digital replica of the grinding stone - 3D screen condition).

Other responses highlight, more directly, the importance of the mesh and/or 3D point-cloud for a sophisticated analysis. Particularly, some examples point to the possibility of removing original colors from the digital artifacts as an added value for the perception of specific physical cues that facilitate the inquiry process:

> Uhm looking at it from the visual uhm visual spectrum uh it’s very clear that uhm it is uh likely made out of stone/ And if we take away the visual uh layer uhm the texture below uhm in the next layer in the image also uh supports that uh that inference/ Uhm this object most likely is a grinding stone/…With this technology we can actually take away the visual uh spectrum and you can basically do the same thing/ Uhm see what the underlying surface looks like so I’ll do that/ In this case there’s no indication uhm uh that the discolored area we can see in the visual uh image uh is actually uh a different level than the surrounding area (#35, interacting with the 3D digital replica of the grinding stone -3D screen condition).

In this case, looking at the mesh (i.e., surface) of the grinding stone, the archaeologist was attempting to discern if an area of the stone showing red stains coincided with changes in texture (e.g., a smoother texture indicating signs of wear). Similar observations are addressed by another archaeologist interacting with the 3D digital replica of the projectile point (i.e., 3D screen condition):

> Uhm and the reproduction the reproduction is interesting in its regard because/ Uhm when I turn off the sort of skin of color I can actually see things I can see the the fine texture of the object better than uhm when it's on an this is the first time that's happened in the three objects that I've been shown/… And when I turn off the color actually there's a certain a a certain amount of roughness uhm in that place and so I'm wondering if this is a a uhm if this is a leer a layer of stone and that there's this is a place where the top layer is missing and so I'm catching glimpses of the layer of of stone underneath uhm (#36).

Color. The analyses of the transcripts of the interview shows that both the 3D screen and 2D picture conditions elicit very detailed descriptions of color in the artifacts, as shown in this example of a student viewing the 2D picture of the grinding stone: "But it's definitely gradi[ent] ah and you can see different colors in here it goes from brown and right here is grey" (#1); similar examples can be provided for the 3D screen condition: "Uh looking at it you can see again much like the last object we saw a sort of you know dark uhm muddle-brown color" (#35, archaeologist describing a brownish variation in color in the 3D digital replica of the projectile point).

Shape. The qualitative analysis helps clarify the importance of 3D multi-visualization for the analysis of artifacts' digital replicas. More than one participant underlined the importance of geometric properties with no colors applied to better understand the shape of the objects. The following example shows how a student copes with the difficulty of describing the shape of the Buddhist object: "If you look at the the topography (i.e., *mesh*) of it you can see that there is in fact some type of horseshoe sized indent uhm (#13, student, interacting with the 3D digital replica of the Buddhist object -3D screen condition). Similar answers are given by archaeologists:

> Uhm looking at just the visual or the uh the optical uh image of it uh here on the screen/ It actually to me looked quite flat uhm/ but if we take away uh the optical scan you can see that it's actually uhm got quite a concave uh surface on the front side of the object and I'll show you that now/ A you can see from that earlier obser[ved] underlying scan without the color data/ Uhm it's concave uh and it sort of moves in uh in its concavity uh from the outer edges towards the center (#35, interacting with the 3D copy of the buddhist object).

Interestingly, focusing on specific objects, it was possible to notice that both archeologists and students find it difficult recognizing the internal part of the pot. This is mentioned by one of the archaeologists and shown in figure 8 [near here]. The 3D replica with colors applied gives the perception of the pot as a solid object and makes it difficult to understand that the object is, in fact, hollow: "I would say that I can't see very well into the object and so it almost looks as though uhm from the the reconstruction it's as though it's solid uhm so it's hard to get a sense of uhm how it functioned as a as a container uhm (#36).

While archaeologists have both the professional experience and background knowledge to overcome this challenge and recognize exact shape and function of the pot, students can be misled and can make incorrect assumptions about object details concerning shape, function, and even material:

> The structure of this uh/ Of this thing would be made up of some type of metal/ Uhm as you can see/ Uhm as I infer that this darker spot her uhm inside of the sphere/… It I was originally thought like a grenade or something like that/… So I would have to say maybe uh uh a very primitive form of a grenade/ That uhm will go off when you throw it uhm with the gun powder in it/ Uhm that seems to be the only likely way of forming these outside bumps/ on the outside of this sphere uhm/ And it must have exploded the top letting out most of the explosion/ Uhm yet still having some on the sides though the little bumps here uhm/ It would have to've been blown out from the top and a little on the sides (#15).

Size. When examining the way participants mention object size, we noticed that, while Touch participants used adjectives and exact measures to provide size information, participants in the 2D picture and 3D screen conditions often used gestures to relay this information [Fig. 9 near here].

The qualitative analysis helps us understand how people perceive size in absence of original artifacts. For instance, some participants in the 3D condition thought that some objects seemed bigger on the screen: “Uhm and uh the object is I guess in some ways it th[e] the uhm the reproduction makes it somehow seem bigger than it is but in fact it’s we’re told it’s the size of a hand/ Uhm so uh I have to keep re-imagining it to be a little smaller than it actually is” (#36, talking about the 3D replica of the Buddhist object).

Similar observations were found in descriptions made by participants in the 2D picture condition: “it’s about of the size of a hand so uhm maybe the size of mine but I think the picture got stretched out (#1, student, talking about the Buddhist object).

5. Discussion and conclusions

Two experiments were conducted to investigate how modality of presentation influences participant understanding of artifacts. Specifically, how do people, interact with, understand, and describe objects differently when presented in three unique modalities: touching real artefacts, looking at 2D pictures, interacting with 3D digital replicas on a computer screen? In both studies, participants were asked to describe ancient artifacts in detail. In the first experiment, participant descriptions were elicited using self-guided question sets including a combination of multiple choice, likert scale, and open-ended questions. In the second experiment, participants (students and professionals in the field of archaeology) were asked to verbally describe objects, alone, in front of a video camera.

Results from Experiment 1 reveal insights into how people perceive artifacts through digital copies and how they cope with the absence of authentic, real-life, objects. In general, it was found that background knowledge guided some of the students' answers. In particular, when students who viewed a 3D point-cloud were asked to determine the material of an object, in absence of original colors (Q3), the most frequent response was clay (24.6%). It seems apparent that students relied on their personal conceptualization, which was most likely influenced by their real-life experience with these types of representations (statue of a horse). Even more surprisingly, most students who experienced objects through 3D point-cloud felt confident about their answers on the material of the statues, reinforcing the idea that background knowledge can influence perceptual and interpretative processes (Holden 2004; Bransford et al. 2000; Mazur 1997).

With regard to the use of different media types, results show that overall, students in the 3D point-cloud condition demonstrated a better understanding of particular details of the statue (Q8, Q9), including features of the warrior underneath the horse, suggesting participants in this condition had a more complete understanding of statue texture and shape through the use of 3D point-clouds. Moreover, students in the 3D point-cloud group defined the statue as heavy (Q6), even heavier than what their peers in the 2D picture group indicated. This finding suggests that the 3D point-cloud as an efficient way to reproduce density and solidity.

Additional observations can be made with regard to emotional qualities elicited by the artifacts. Students in the 2D picture condition described the statue as stronger, more aggressive, and braver (Q5). This finding has two possible explanations: perhaps the 3D point-cloud group, which seemed to better recognize the warrior under the horse (Q8), focused more on the whole representation, without favoring the dominant figure of the horse. Conversely, the 2D picture group, which favored the horse over the whole representation, defined the statue with adjectives that were more related to this dominant figure and/or to a common idea we have on the horse as symbol of wildness, freedom, regality, and power. Another explanation for this finding could be that, since the 2D picture is more realistic than the 3D point-cloud, it was better at enhancing force, aggressiveness, and bravery that are characteristics commonly associated to the horse.

The 3D point-cloud group perceived the statue as more lively (Q7), indicating that something as simple as media type can highlight tension represented in the scene of the fight (muscular structure of the horse, horse prevailing over the warrior, etc.). Experiencing the artifact as a 3D point-cloud seems to enhance the sense of spatiality that the statue physically convey. Interestingly, participants in neither conditions perceived a sense of motion that the representation of the fight seems to suggest (Q9).

Results from Experiment 2 compliment results from Experiment 1, giving important insights on how people perceive artifacts in absence of a real-life tactile experience. While Experiment 1 showed that point-clouds of 3D digital replicas improve the perception of physical details and increase the sense of spatiality of complex shapes, Experiment 2 further clarifies how individuals perceive important physical characteristics of objects; characteristics such as material, texture, color, shape, and size. Examining individual characteristics reveals that while 2D pictures and 3D digital copies invoke similar participant responses for material, color, and size, we cannot say the same for shape and texture. A significant number of participants in the 3D screen group stressed the importance of multi-visualizations (i.e., object with or without original colors) to grasp textural information, a detail highly associated with tactile experience. Texture cues can help participants successfully determine both object material and function. In the case of the grinding stone, people often look at signs of wear to determine its function. For many participants, the Buddhist object's material was only identifiable through the use of texture to determine its material.

With regard to shape, both students and archaeologists in the 3D screen condition mentioned and described the shape of the object more consistently and frequently than those in other experimental conditions (2D picture and Touch). As noted earlier, the shape of 3D digital replicas can be difficult to recognize when color information is applied to the model. For this reason, the visualization of 3D models with no colors applied can be crucial for recognizing *shape* information. The importance of removing original colors from the 3D models was highlighted by several participants, but this observation is usually only made following the second, or sometimes even third 3D model they interact with during the experiment. This observation is not trivial, since it indicates that 3D model users needed experience to understand the tool and to fully benefit from the 3D model medium. Once participants in the 3D model condition understood how the tool functioned, the possibility to remove colors from the 3D model was seen as a valuable tool to perceive the object. The experience with multiple layers of the 3D digital replicas on the screen activated a constructivist sensory-motor learning sequence that allowed participants to actively create knowledge about the artifacts while simultaneously interacting with their environment (i.e., 3D copies) in seek for meanings (Huba, 2000, p. 37).

In summary the results of these experiments point to 3D digital replicas of artifacts as more effective means to digitally preserve tangible cultural heritage since 3D multi-visualization augments the perception of physical characteristics of the artifacts allowing a more embodied experience with these objects. Real-time 3D experiences using multiple informational layers (texture, mesh, vertexes, wireframe) simulate, to some extent, real-life experiences better than 2D pictures, since the perception of texture/surface compensate for the lack of a tactile experience with original artifacts.

In conclusion, the results of the proposed experiment can be considered a valuable former assessment to design future 3D viewers for the analysis and visualization of 3D digital data. These results suggest how 3D viewers should always include multi-visualization (i.e., point-cloud, mesh, and color information), since shape and texture qualities of an object are easier to recognize when colors are not applied to 3D models. Moreover, different layers of information should always compliment the 3D models. These might include the possibility to magnify an object, change light settings, measure, section an object, etc., but also the possibility to access multimedia information regarding the object directly from the 3D viewer. These multimedia information might take the form of metadata and other formats to visualize an object (e.g., x-rays and 2D visualization formats) and will help the viewers to overcome their personal conceptualization of specific objects (which might influence their interpretation), allowing an increased perception and understanding of our material past.

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Tables

Table 1. Average number and Standard Deviation values from likert scale results.

	3D point-cloud		2D picture	
Condition	**M**	**SD**	**M**	**SD**
Q2	5.74	1.55	6.24	1.27
Q5a	4.53	1.2	4.93	1.54
Q5b	3.56	1.52	3.67	1.49
Q5c	4.82	1.57	5.6	1.26
Q6	4.33	1.62	5.3	1.75
Q7	3.96	1.57	3.24	1.58

Table 2. Average number of words produced by archaeologists and students while talking about the artifacts.

	Archaeologists	Students
Condition	**Words**	**Words**
Touch	322.62	177.69
2D picture	160.62	131
3D screen	400	217.7

Figures