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Exploring Expert and Non-Expert Perception of 3D Digital Models of Museum Objects

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Abstract

Increasingly, museum objects are documented as 3D digital models (3dDM) for scientific study, online exhibition, or personal enjoyment; however, 3dDMs invariably exhibit imperfections due to technological limitations and/or the lack of standardisation in museum object digitisation. Little is known how such inaccuracies are perceived and interpreted by users. Through qualitative interviews and deductive thematic analysis this user study first investigates which inaccuracies in 3dDMs lead to misinterpretations by users and then considers six factors based on the concept of Epistemic Vigilance (EV) and to what extend these factors play a role in the users' ability to correctly understand the information presented within 3dDMs. Only one of eight explored inaccuracies was correctly identified by all participants and background knowledge of the museum object and 3D imaging technology (3DIT) had the most influence on correct interpretation of inaccuracies. Furthermore, trust in the museum publishing the 3dDM and in 3DIT also played a role in how the inaccuracies were perceived. Publishing data about the issues present alongside the 3dDM will increase transparency and further work should therefore concentrate on mechanisms that promote correct interpretation of 3dDMs' limitations to enable museum practitioners to make the most of their digitisation efforts.

1 Introduction

In recent years great importance has been placed on creating digital records of museum collections [UK 22, Men17, Mus19]. Increasingly, these records not only include written information and photographs, but also 3D digital models (3dDM) [BKM17, Day18]. 3dDM are three-dimensional digital representations of museum objects which can be viewed and interacted with in designated software. According to [AMS07], "[a 3dDM's] goal is to reliably represent real-world content in a digital form". As such, 3dDMs can be seen as a new medium of communication that conveys information about the appearance – the outward visual condition and state – of their subjects. This includes aspects such as the object's colour, surface texture or geometry.

3dDMs can "enable scientific study and personal enjoyment without the need for direct physical experience of the [tangible museum] object" [AMS07]. While the creation of highly accurate 3dDMs is not impossible, 3DIT is still rapidly evolving and limitations to what is currently achievable exist [GSH*19, MSBV19, RVT*19]. Additionally, although recent attempts have been made to address this , there is still a lack of widely accepted standards in how to create 3dDMs of museum objects . This has resulted in the creation of 3dDMs whose appearance does not fully match that of the object it is representing.

This paper focuses on user perception – the idea the user has of the 3dDM as a result of seeing and interacting with it. First, we investigate to what extent users comprehend that these appearance inaccuracies are inherent to the 3dDM and, whether the inaccuracies lead to participants making incorrect assumptions about the appearance of the original museum objects. It will then look at what factors contribute to the user's ability to correctly identify inaccuracies present in the 3dDMs in order to gain a better understanding of what mechanisms could support the correct interpretation of 3dDM

Specifically, the authors will draw from the field of cognitive science where it has been shown that users cope with the cost of evaluating the accuracy – the correctness and exactness – of information by using strategies that allow quick and effortless decisions making [SCC*10]. The skill to evaluate the accuracy of information is referred to as Epistemic Vigilance (EV) [SCC*10]. According to [SCC*10] the willingness of users to exert EV when evaluating information depends on four factors:

1. How much the user trusts the information source.
2. How much the information matters to the user.
3. What the user's background knowledge about the information is.
4. How much cognitive energy the user must spend to evaluate the information's accuracy.

For this research, the information source is therefore defined as the museum publishing the 3dDM. Furthermore, the information the user is presented with is a 3D digital model which is based

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Model 1, 'King' (*left*): Statuette of an ancient Egyptian king, 1st or 2nd Dynasty, Ivory, 8.8cm x 2.8cm.

Model 2, 'Horus' (*centre*): Statue of seated figure of Horus, Roman Period, Limestone, 55cm x 32cm x 26cm.

Model 3, 'Bust' (*top right*): Head and upper body of a statue, 18th or 19th Dynasty, Limestone, 20cm x 18cm x 15cm.

Figure 1: *Photographs of the original objects whose 3dDMs were used in our study.*

on a real-life museum object. This information can be approached from various angles. For example, if the 3dDM was of an ancient Egyptian limestone statue, then the users background knowledge and interest in either ancient Egyptian history, sculpture or stone types might play a role in how well the user is able to understand the appearance of the 3dDM. Additionally, if the user had prior knowledge of how 3dDM are created and which issues can affect their appearance, then the user's background knowledge will support their understanding of the 3dDM. Lastly, the amount of cognitive energy the user needs depends on the first three factors. If the user is critical of the information source, is very interested in the object captured by the 3dDM and has a lot of background knowledge about the object as well as 3D technology, then the user does not need to spend a lot of energy on evaluating the accuracy of the information presented in the 3dDM.

1.1 Related Work

Since 3DIT has become more easily accessible, discussions about 3dDMs and their place in cultural heritage digitisation have increasingly focused on topics such as authenticity, transparency and trust [Hin15, JJM*18, GFGV18, Bru17, BKDB12]. However, little research into requirements of users regarding the appearance of 3dDMs of museum objects is available. In 2015, Hess conducted a survey into 3dDMs stating that correct and detailed geometry and metric accuracy were of importance to heritage professionals [Hes15]. However, the effect that inaccuracies in the 3dDMs had on professionals was not explored. Furthermore, Hindmarch investigated if viewing a 3dDM contributes to the user's understanding of the original museum object [Hin15]. However, the study does not explore what aspects of the 3dDMs' appearance might support the user's understanding of the original object.

In regard to using the concept of EV this has been applied in several studies. These include an evaluation of information sourcing skills of students [SPBB15], how the discussion of ethical implications of scientific results in a science blog influence the blog's readers [HKB16] and whether children link the accuracy of text-based information to the accuracy of its author [VOH18]. In most cases the evaluated information is text-based, however there are studies focusing on visual information such as research into the perception of photographs and videos and their impact on young users' mental development [Gra13].

2 Appearance Inaccuracies

This section briefly discusses inaccuracies commonly present in 3dDMs that can lead to incorrect assumptions about the appearance of the original museum objects. As mentioned, 3dDMs invariably exhibit appearance issues due to technological limitations and/or the lack of standardisation in museum object digitisation. To investigate how such inaccuracies are perceived and interpreted by users, the authors carried out a literature review to identify which inaccuracies are commonly encountered in 3dDMs.

Following the review results, the authors reviewed 3dDMs freely available on Sketchfab and published by heritage institutions to identify 3dDMs that displayed all those inaccuracies. Furthermore, to understand how expert knowledge might play a role in perception of inaccuracies, 3dDMs of objects from the same geographical and historical background had to be selected. These criteria lead to the selection of three 3dDMs which are published by a national museum in Western Europe and are of Ancient Egyptian origin, 'King', 'Horus' and 'Bust', shown in Figure 1.

The metadata and paradata provided alongside the models on

Sketchfab indicated that the 'Bust' model was created using photogrammetry (Agisoft software), whereas the 'Horus' was created using an Artec Spider. It is unknown how the 'King' model was created, and there is also no information about what (if any) post-production was carried out on the 3dDMs.

Eight inaccuracies were identified in the literature review and are present in the 3dDMs used for this research: missing geometry (fine-scale and coarse-scale), misalignments, filled holes, texture inconsistencies and blurring, incorrect colour and brightness issues.

The term 'geometry' is often used to describe the three-dimensional shape of an object's surface including features such as holes or protrusions. Conversely, 'texture' is a term used to describe surface properties such as colour or brightness. Geometry and texture inaccuracies often go hand in hand. For example, regions on 3dDMs with missing geometry also often display inaccuracies in their texture (see Figure 2 and 3) [Day18].

2.1 Missing Geometry (Fine Scale)

The more detailed the geometry and texture of 3dDMs, the larger their file-size, making it very difficult to store and publish these 3dDMs [Day18, Pay18]. To reduce their size the 3dDMs' geometry is simplified. This process can lead to a smoothing or even deletion of surface features. This can be observed on the 'King' 3dDM where the cracks visible on the photograph of the original object (Figure 1, left) appear filled-in on the 3dDM (Figure 4).

2.2 Missing Geometry (Coarse-Scale)

Another common geometry inaccuracy occurs if the capture method is unable to pick up some parts of the surface such as deep holes or occluding elements [GPL16, PHHF16, TCF*18]. For example, the deep indent on top of the Horus statue was only partially captured in the 3dDM (Figure 2 and 3).

2.3 Misalignment

During the capture process it is often necessary to digitise the object in several sections (e.g. the top and sides of the object in one section, the underside in another). These individual sections must be merged during post-processing which can lead to misalignments and the creation of surface features that do not exist on the original object [HMV18, MDP16]. This inaccuracy is highlighted by the 'bust' 3dDM (Figure 5).

2.4 Filled Hole

Another inaccuracy explored through the 'Horus' 3dDM is visible on the underside of the 3dDM which was not captured during the digitisation process and the hole was later filled with a made-up digital surface (Figure 6).

2.5 Texture Inconsistency

If not enough texture data was captured during the scanning or photographing of the original object or the texture of the original object is very homogenous, texture inconsistencies can occur on the 3dDM [BTM*16, JU16]. Figure 7 shows this texture inconsistency both on the 'Horus' statue's lap and the plinth.

2.6 Blurring

Localised blurring of texture is caused by the use of out-of-focus photographs during the creation of 3dDMs or excessive magnification during the texture mapping process [MDP16, NNMR14]. Both the 'King' and 'Bust' 3dDM highlighted this issue (Figure 8).

2.7 Colour

Little research has been carried out to understand how to colour-manage 3dDM [GLS04, JKYK13, SAX*18, XSS*16]. As a result, the colour of a 3dDM can differ – sometimes substantially – from the colour of the original object [NNMR14]. Both 'Horus' and 'King' differ in colour from their original objects, with 'Horus' having a greener tint and 'King' being whiter than the original.

2.8 Brightness

If the original object is not captured in a controlled lighting situation, the final 3dDM will have shadows and/or highlights present on the

Figure 2: *Head of 'Horus' 3dDM showing a square hole whose geometry was only partially captured.*

Figure 3: *'Horus' 3dDM showing texture inaccuracies due to missing geometry.*

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Figure 4: *Cracks as displayed in the 3dDM's geometry.*

Figure 5: *Misalignment on the chin area of the 'Bust' 3dDM.*

Figure 6: *Underside of the 'Horus' 3dDM showing the made-up digital surface.*

Figure 7: *Texture inconsistency on the 'Horus' 3dDM.*

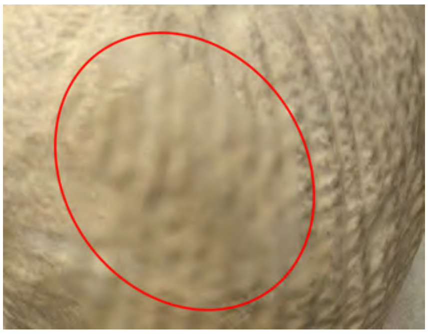

Figure 8: *Localised blurring on the surface of the 'Bust' 3dDM.*

Figure 9: *Overexposed area on the side of the base of the 'Horus' 3dDM.*

object during capture (e.g. gallery light, harsh sunlight) permanently baked into its texture [PHHF16]. Similarly, if equipment such as a structured light scanner is used for acquiring the 3dDM, artificial brightness differences on the 3dDM's texture can occur if the scanner was held too closely to the object's surface. Brightness inaccuracies can be observed on the base and the plinth of 'Horus' (Figure 9).

3 Methodology

Qualitative interview techniques are proven to be very effective at exploring the relationship between variables, in our case between participants and 3dDM [KRST22, Cre14, Opp05, Bar15]. As such, semi-structured qualitative interviews were chosen to provide detailed responses from experts and non-experts about their perceptions of 3dDM of museum objects. 15 interviews with an average length of about one hour were conducted.

All interviews were transcribed allowing the author to become familiar with the data. Using statistics software NVivo Pro 12, a deductive thematic analysis was conducted in four main stages broadly following the approach adapted by [Bra06]. First, the authors identified interesting features of the data and coded them in a systematic fashion across the entire dataset. Second, the collated data for each code was gathered into potential themes. Third, each theme was checked against both the data within each theme, as well as against the entire data set. Fourth, clear definitions and names for each theme were generated (e.g. background knowledge, inaccuracies, trust, etc.) through continuous analysis and refinement of the specifics of each theme and the overarching story the analysis tells.

3.1 Participants

Three groups of 5 participants each were selected: general members of the public, 3DIT experts, and content experts. Gender distribution was balanced, and the average age varied between 37.4 (public), 39.0 (technology experts) and 44.6 (content experts). All participants had visited on or more museums in Western Europe in the 12 months prior to being interviewed.

Members of the public were selected amongst people who had no specialist knowledge of 3DIT and ancient Egypt and neither have been, nor are currently working in the cultural heritage sector. Technology experts were selected amongst professionals creating 3dDMs within a heritage setting. Content experts were selected amongst professionals working in the field of Egyptology either in higher education or the cultural heritage sector. The three groups were chosen as representative of the types of users who are likely to engage with 3dDM's online.

3.2 Presentation

To ensure participants were not influenced by contextual information available on the host-platform, the 3dDM were embedded into a website created for the purpose of this research. Except for the model name, the name and logo of the publishing museum and the Sketchfab logo all contextual information could be removed. The background of the website was set to 255 white, the website menu was removed, and a neutral domain name was chosen (www.researchproject.xxx). The 3dDM were embedded at 1080 by 720 pixels and participants were asked to activate the fullscreen view (1920 by 1080). During the interviews, the 3dDM were streamed through the Internet using a Dell XPS 15 with Bluetooth mouse. The monitor brightness was set to 100% and the positioning of the screen was such that no reflections interfered with the screen surface. In four instances (participant 8, 9, 13, 14) it was not possible for the interviewer and the participant to meet in person. Instead, the interviews were conducted via skype with participants using their personal computers.

3.3 Interview Protocol and Data Collection

The semi-structured interview protocol consisted of five stages (1.–5. below). Open-ended questions and non-directive probing was used where necessary to clarify views and opinions [KRST22, Cre14, Opp05] c.–k. below). The interviewer was careful not to introduce bias when probing by avoiding leading words and using the participants own words were possible. The interview was conversational in tone and based on the following questions.

1. Questions about participants' background and their interest in museums and historical objects.
    a. What gender do you identify with?
    b. How old are you?
    c. What sector do you work in?
    d. Have you visited a museum in the last year and if so, how many times?
    e. What is it that you are interested in when you visit a museum?
    f. Do you have a favourite type of historical objects you are interested in?
2. Participant is read a definition of 3dDM: "For the purpose of this research a 3D digital copy is defined as a three-dimensional representation of an object that exists in real life. When viewed on a screen in designated software or online it is possible to interact with 3D digital copies to view it from all sides and angles and zoom in and out."
3. Participant is shown how to navigate the model using a mouse. They then proceed to interact with the 3dDM before answering the next questions.
    g. Please tell me what you are seeing and if anything catches your eye?
    h. Would you be interested in having access to museum objects online in form of a 3dDM? And if so, why?
    i. Can you tell me a bit about the museum that published these 3dDM?
4. 3dDM is shown alongside Collections Online webpages containing descriptions and photographs of the respective museum objects.
    j. Could you tell me what your thoughts are seeing the 3dDM side by side with the information on Collections Online?
5. Participant is made aware of the purpose of the study and the issues present in the 3dDM.
    k. If museums asked you for feedback on the 3dDM you have just seen and the experience you have had interacting with them, what would you say?

Questions c.–h. were designed to gain insight into how much the presented information (here the 3dDMs and the museum objects captured by the 3dDM) mattered to the participant and to understand the participant's background knowledge about the information. Question i. and j. were asked to explore the participant's trust in the information source and how much cognitive energy they had to spend to evaluate the information's accuracy. Question k. was asked after stage 5 of the protocol and allowed the authors to gather valuable feedback about the participant's experience using the 3dDM.

4 Emerging Findings and Discussion

Using direct quotes, this section reports the participants' thoughts and reactions to the 3dDMs and how they interpreted the inaccuracies therein. Adopting the approach by [HS14, KRST22], each quote is put into context and discussed to illustrate how they form the basis for the findings. Following on from this, and in direct reference to the quotes and initial findings, is a discussion of which EV factors contribute to the participants' ability to correctly identify the inaccuracies. Where segments from the interview transcript are cited, the participant's number is included in brackets. Table 1 shows a numeric summary of the results by participants and gives insight into how inaccuracies were understood and what areas were commented on more frequently. Avergage scores and standard deviations between participant groups are presented in Table 2.

4.1 Missing Geometry (Fine Scale)

Of the geometry inaccuracies addressed in this study only one was interpreted correctly by all participants: the cracks affecting the

Group	Geometry and Texture Inaccuracies								Average
	Fine-Scale	*Coarse-Scale*	*Misalignment*	*Filled Hole*	*Texture Inconsistency*	*Blurring*	*Colour*	*Brightness*	
Public									
Participant 1	1	1	0	0	0	1	N/A	1	0.50
Participant 2	1	N/A	0	0	0	0.5	N/A	0.5	0.30
Participant 3	1	N/A	0	0	0	0	N/A	N/A	0.20
Participant 4	1	1	0	0	0	1	N/A	N/A	0.50
Participant 5	1	1	0	0	0	1	N/A	N/A	0.50
Technology									
Participant 6	1	0	1	1	1	1	1	N/A	0.83
Participant 7	1	0.5	1	1	N/A	1	N/A	1	0.90
Participant 8	1	0.5	0.5	1	1	0.5	0.5	1	0.75
Participant 9	1	N/A	1	N/A	1	1	1	N/A	1.00
Participant 10	1	0.5	1	1	1	1	N/A	1	0.92
Content									
Participant 11	1	1	0	0	0	1	N/A	N/A	0.50
Participant 12	1	1	0	0	N/A	1	N/A	N/A	0.60
Participant 13	1	1	1	1	1	1	1	1	1.00
Participant 14	1	1	0	0	0	0	N/A	N/A	0.33
Participant 15	1	1	0	0	N/A	1	N/A	N/A	0.60

Table 1: *Numeric Summary of Results per Participant. 0 = Inaccuracy not correctly interpreted, 0.5 = Unsure about how to interpret inaccuracy, 1 = Inaccuracy correctly interpreted, N/A = Did not comment on inaccuracy. Average scores exclude colour and brightness as less than half of all participants commented on this issue.*

Group	Average						Overall Average
	Fine-Scale	*Coarse-Scale*	*Misalign-ment*	*Filled Hole*	*Texture Inconsis-tency*	*Blurring*	
Public	1.0	1.0	0.0	0.0	0.0	0.7	0.40
Technology	1.0	0.4	0.9	1.0	1.0	0.9	0.88
Content	1.0	1.0	0.2	0.2	0.3	0.8	0.61
Overall Avg.	1.00	0.79	0.37	0.40	0.43	0.80	

Table 2: *Comparison of Average Scores between Participant Groups. Brightness and colour scores are excluded, as less than half of all participants commented on these issues.*

surface of the 3dDM 'King' (Figure 4). Most participants drew their conclusion based on their background knowledge of the material:

> "If it were wood, then some cracking from age. If it is bone or ivory, then I would think it is more inherent from the material." (10)

> "I just assume it's cracks, as old organic material tends to crack when it dries out." (14)

This background knowledge allowed the participants to understand, that the lines on the 'King' were indeed three-dimensional cracks and not dark lines painted onto the surface of the model. Participant 13 commented on the depth of the cracks and how some of them appeared to be filled in:

> "The grey in the lines… as a viewer they slightly puzzle me. And also remembering the object it puzzles me. It looks as if a sort of white plaster has been rubbed into the object." (13)

This 'filling-in' was caused by the lack of fine detail in the underlying geometry, an issue referred to by two of the technology experts:

> "They don't look very three-dimensional. They look like they are the actual texture map, the photograph. It seems very smooth rather than it actually dipping in. But it gives a sense that there was something." (6)

> "The geometry sort of hints at them but the deepness of them, that impression comes from the photograph." (10)

These statements illustrate, that the participants' understanding of depth might not only be supported by their background knowledge of the material, but also by how depth is perceived. According to [CWE04], "particular patterns of shadow can provide information about the relative shape of solid objects". Thus, the darkness of the cracks in comparison to the lighter surface of the ivory might also have aided the participants to understand their three-dimensionality. When looking at the photograph (Figure 1, left) of the original object during stage 5 of the protocol, several participants stated that the cracks looked deeper in the photograph:

> "The photograph, the lines look deeper. [. . .] The model almost looks smoothed over. The photo looks genuinely damaged. In the model the lines almost disappear in places. They almost look filled in." (4)

> "The photograph is clearer. Because here you can actually see the cracks are deeper and it is easier to see the facial features." (14)

4.2 Missing Geometry (Coarse scale)

The hole in the head of the 'Horus' 3dDM (Figure 2) was interpreted correctly as indicating a hole in the head of the original object by all members of the public, who did not question what they were seeing. All content experts were aware that the hole indicates a missing head-dress that originally would have been positioned on top of the original statue and secured by being slotted into the hole. Technology experts were less certain about how to interpret the hole as their background knowledge in 3D imaging made them question whether the hole was caused by the creators of the model not being able to capture the top of the head, or whether the hole existed on the original object:

> "I think either they couldn't get the camera on top or there was some kind of mount stuck in there." (7)

> "There is this area on the head where I don't quite know what is going on. Maybe the statue actually has a hole. Maybe they couldn't image it. I don't know." (8)

In this case, background knowledge about the object was more beneficial than background knowledge about 3DIT to draw the correct conclusion, as demonstrated by participant 13:

> "The hole at the top of the head looks slightly bizarre. It's for a headpiece of sorts I presume. But it rather looks like there is a hole in the top of the digital model as opposed to it being a hole on the statue." (13)

4.3 Misalignment

All members of the public and four out of five content experts made incorrect assumptions about the appearance of the original objects based on the misalignment on the 'Bust' 3dDM (Figure 5).

Most explained the misalignment as a cracking or flaking off the stone. When participants were presented with the Collections Online description and photograph of the bust, several believed that the reason they could not see the crack on the photograph was due to the angle and lighting of the photo:

> "I can't even see that there is a crack [. . .] because I just can't move the photo around to see where the cracks are." (2)

> "From the photo you would have never seen the bit under the chin, whatever that is. I am not seeing that in the photograph because it is static." (5)

> "Here you don't see the crack [. . .]. Because of the angle and the shadow [. . .]. Obviously with the chin thing, you could just put an extra photo of that." (14)

One participant believed they could see evidence of the crack on the photograph:

> "You can still see that [the museum object] has had some reconstruction, but it looks like it has been repainted" (11)

4.4 Filled Hole and Texture Inconsistency

Regarding the artificially filled-in underside of the 'Horus' 3dDM, all public participants and four content experts (except participant 13) assumed that the object had a protective layer of different appearance added. Similarly, the texture inconsistency was explained as a modern material showing a repair of the object. In comparison, all technology experts understood that they were looking at inaccuracies present in the 3dDM:

> "[The underside] has just been filled with a fake texture." (6)

> "There are a few issues with the textures, like here on the lap." (6)

4.5 Blurring

The blurring of texture as seen on the 'Bust' and 'King' 3dDM (Figure 8) was interpreted correctly by eleven participants. Those who misinterpreted it most commonly thought the blurring was a sign of weathering or abrasion. Specialist knowledge in 3DIT in turn allowed four of the technology experts to correctly interpret the blurred areas. Their use of language ("render" (6), "interpolating" (10), "masking" (9)) suggests that they are drawing from their background knowledge to explain what they are seeing.

4.6 Colour and Brightness

Only 6 references questioning colour accuracy and 10 references about brightness issues were made. Half of the statements on colour and two of the statements on brightness were made by participant 13. From the beginning this participant expressed substantial doubt in the capabilities of 3DIT to deliver 3dDMs that were suitable for their needs. This included the following statement about colour accuracy:

> "I don't entirely trust the colour. Parts of the rendering seem to me not fully accurate and realised." (13)

Additionally, the participant appeared very familiar with the original objects using their background knowledge to ascertain whether the colour and brightness of the 3dDM is accurate:

> "I find the texture and colour of this more as I remember the object." (13)

> "I think the texture and the colour on this, from what I remember from seeing the original object is less convincing. [...] The back and the sides have a very different colour. Which puzzles me. I think it may partly be the lighting." (13)

4.7 Other inaccuracies

Two additional issues that had not been anticipated by the authors, as they had not been mentioned in the reviewed literature, were highlighted during the interviews: the lack of scale and the hollowness of the 3dDMs. The lack of scale was mentioned by 10 out of the 15 participants (3 public, 4 technology experts and 3 content experts) with 26 comments about scale in total. Comments by the technology experts and public group focused on guessing the correct size:

> "I can't tell whether it's an absolutely massive statue or whether it is tiny in real life." (3)

> "It is a what I would imagine quite a large statue. But I don't know as there is no scale." (8)

In comparison, content experts expressed mainly concern for the lack of scale:

> "I am irritated by the fact that I do not have scale information." (12)

> "[I know that] it is quite a small item, and how it is displayed now, you would not have any appreciation of how large it is." (14)

Content experts used more emotional language than other groups commenting on lack of scale and participants 12 and 15 specifically mentioned the lack of scale as one of the main reasons why they were not satisfied with the 3dDM.

The hollowness of the 3dDM was commented on by all public participants and three of the content experts. All other participants understood that when zooming inside the 3dDM, the viewer is presented with the inverted view of the 3dDM and not the actual inside of the museum object. The content experts who did zoom into the 3dDM expressed doubts over whether they were indeed inside the model, drawing from their background knowledge of the original objects:

> "I know that object [...] But it is not a hollow object, so I would think it's the model. At least I don't think it is hollow." (11)

> "I did not know there was a cavity. In the statue. It looks as if it is, or is it not? I thought it was out of limestone. This is the inside, right?" (14)

All members of the public in comparison believed that the museum objects were hollow. Participants 2 and 5 went further and used their perception of the museum objects being hollow to make assumptions about their materiality:

> "It's hollow [...]. And looking at this edge, I'm seeing how thick the object is." (2)

> "I can see inside him. Unbelievable. [...] So, this could be a hollow cast. Perhaps it's not stone, perhaps it's just a cast." (5)

4.8 Epistemic Vigilance Factors

The previous sections have shown that EV factors can indeed be associated with many of the participants' statements. The use of background knowledge, both about material properties, the original objects and 3DIT was identified as a common theme during the analysis. All participants understood that the dark lines on the 'King' 3dDM were indicative of cracks in the original object. This is likely due to a combination of the participants' background knowledge of the material and human depth perception which allows particular patterns of shadows to provide information about the surface of a solid object [CWE04]. Misalignment inaccuracies, filled holes and texture inconsistencies, however lead to incorrect assumptions about the appearance of the original object by almost all public participants and content experts, regardless of any background knowledge.

Background knowledge about 3DIT seemed to have the most impact on how well participants understood what they were seeing, as technology experts had an overall average score of 0.88 (Table 2). This knowledge about 3DIT was only outperformed by knowledge about the original object in the case of the hole in the head of the 'Horus' 3dDM.

Content experts (overall average score: 0.61) performed better than public participants (overall average score: 0.40) mainly due to participant 13 who was the only participant who commented on all inaccuracies and interpreted all of them correctly. To verify whether the performance of participant 13 was indeed significant, statistical tests using ANOVA Single Factor analysis were performed. Results confirmed statistical significance both in comparison to the overall average within the content expert group (p-value 0.03) as well as in comparison to the overall average of all participants (p-value 0.007).

Participant 13 is most critical of 3DIT, mentioning "trust" six times and "convincing" in a negative context eight times. Two of their comments also referred to a greater trust in digital photographs in comparison to 3dDM:

> [Upon seeing a photograph] "I feel much happier looking at that. I can read that as a three-dimensional object. With much greater assurance. Because there I feel like there is a balance between the detail, the form and the structure, which I felt like was lost in the 3D model." (13)

> "I would trust the digital photographs more than I would trust those digital models." (13)

However, the participant is not completely dismissive of 3DIT stating:

> "If one wanted to examine certain details, that would be incredibly useful [...]. But I think, to get an aesthetic appreciation for the whole thing, that is where I have the most reservations." (13)

Aside from their low level of trust in the appearance of the 3dDM, the participant is also personally familiar with the original 'Horus' and 'King' objects, thus bringing a lot of background knowledge to their evaluation of the 3dDM. Additionally, participant 13 states that they have "used [3dDM] a lot. Quite a lot", thus highlighting their familiarity with the technology.

Trust was a recurring theme within the analysis. Participants showed a tendency to put trust in the 3dDM they were presented with and in 3DIT in general. This trust is only questioned once participants learned about the inaccuracies present in the 3dDM:

> "You trust the model, like you would a photograph." (1)

> "If I had to use these models for my own studies I would have been really annoyed and felt cheated if I had misinterpreted it." (2)

> "How many of us would really understand what we are looking at? Would we be able to identify issues in the 3D model that are caused by the technology? If we don't recognize them, they could be misleading." (15)

Participants who made correct assumptions about the inaccuracies also referenced trust in several comments:

> "There is a certain level of distrust with it. Because it obviously is a 3D render and a reproduction." (6)

> "That is slightly misleading, because you could not see that in the 3D model. I trust the photograph more." (7)

> "I think if I didn't know the object, I wouldn't know how much the object was damaged and smoothed. How much it is part of the model and how much it is part of the original object. That would make me feel a bit distrustful." (13)

That members of the public deem museums a credible source of information was demonstrated by [AZC*09] who carried out a survey involving 57 participants. The results showed that all three museums used in the study were given a credibility score of 4.05 or higher out of 5. Trust in the museum publishing the 3dDM used in this study was also present amongst the involved participants:

> "You had to sort of trust what [the museum] said." (4)

> "[The museum] has a lot of different kinds of research [...]. I think they are better than most universities" (14)

> "We often direct our students to [the museum's Collections Online website] as a resource." (15)

4.9 Limitations

The main limitation of this study is its exploratory nature. The small sample size led to an underrepresentation of participants below 30 and above 50. Furthermore, the participant pool was too small to report statistical deviation or any other statistical information regarding age. Additionally, the educational level was above average, with all participants having completed university degrees [Off16]. Future studies should therefore consider larger more varied sample size to complement this study and add quantitative data to this qualitative exploration.

5 Conclusion

This study represents an initial exploration into whether different user groups perceive inaccuracies in 3D digital models of museum objects as relating to the model or to the object itself. Several inaccuracies commonly encountered during the creation of 3dDM were covered: lack of detail, misalignments, filled holes, texture inconsistency, surface blurring and colour, brightness inaccuracies, lack of scale and perceived hollowness of the 3dDM. Analysis of the gathered data showed that technology experts had the least problems understanding the issues present in the 3dDM, followed by content experts and then members of the public. Missing geometry and surface blurring were correctly interpreted by the majority of participants, whereas misalignment, filled holes and texture inconsistency caused the most problems.

Both trust in the museum publishing the 3dDM, as well as trust in 3DIT played a role in how the inaccuracies present in the 3dDM were perceived. Moreover, knowledge about the original objects and 3DIT influenced whether participants perceived inaccuracies in the 3dDM as relating to the model or to the original object.

This study confirms that the concept of EV contributes to how users evaluate the accuracy of information. Trust in the information source (here the museum publishing the 3dDM) and background knowledge about the information itself (here the 3dDM of an original object) played an important part in this study. While trust in the information source has been discussed in literature on EV, trust in the technology used to relay the information, in this case 3D imaging, has not. Yet, as illustrated not only trust in the museum publishing the 3dDM, but also trust in 3DIT played a role in how participants perceived the inaccuracies. Likewise, not just background knowledge about the original object, but also background knowledge of 3DIT influenced participants' perception. This study suggests that the presence of EV in users of information is enhanced when it includes background knowledge about the medium (here 3dDM and 3DIT), a subject area where public or professional knowledge may change as this technology becomes more common.

Given the exploratory nature of this research there is considerable scope for future research. Apart from using larger and more varied sample sizes and gathering quantitative data, one could also investigate how 3dDMs and their inaccuracies are perceived in different environments, such as virtual or augmented reality. Furthermore, with the advances made in artificial intelligence (AI) research, perception of AI-generated or improved models could also be explored.

5.1 Recommendations

The previous discussion of the results highlighted that background knowledge about the original object, background knowledge about the 3DIT and trust in the information source and 3DIT played an important role in the participants' ability to correctly identify the inaccuracies. These results contribute to our understanding of the usefulness of 3dDMs of cultural heritage objects and – alongside feedback given by participants during stage 5 of the interview protocol – allow us to formulate recommendations that cultural heritage institutions might consider to provide users of 3dDMs with tools they need to correctly interpret the 3dDMs they are presented with.

Background knowledge about the original object could be improved by:

- Linking all publicly available 3dDMs to their respective Collections Online pages.
- Updating Collections Online pages with information about the appearance of the object (incl. scale) and professional photographs.
- If the museum does not have a Collections Online website, all information mentioned above should be included on the platform through which the 3dDM is published.

Background knowledge about 3DIT can be improved by:

- Including information about issues present in the 3dDM as a text description or as annotations on the 3dDM itself.
- Including a disclaimer in the description of the model stating that the 3dDM is solely representational and should not be used for research where applicable.
- Sharing platforms for 3dDM, such as Sketchfab, do offer a feature that limits users' ability to zoom inside the 3dDM [Ske19]. It is highly recommended that museums make use of this feature.

Adding information about the issues present in the 3dDM will increase transparency and trust, the theme most often referenced by participants. As [HKB16] have shown, transparency has a positive effect on the user's trust in the information source, especially if this transparency is introduced by the information source itself. Moreover, adding information about the 3D imaging technology as well as the content broadens the audience museums can reach from members of the public, who are solely interested in the content, to those who might be drawn in through an interest in 3D imaging technology. Increasing user's access to knowledge concerning both the content as well as 3D imaging technology will enable museums to make the most of their digitisation efforts and feel confident that their user's expectations are met.

5.2 Notes

At the time of writing many guidelines and recommendations on how to create 3dDMs exist [3D 14, Bed17, BB18, Fro18, HR13, MFS19, MMSL06] but there is no widely accepted standard.

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