The Role of Modeler’s Background in Affecting 3D Reconstruction Quality

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Abstract

3D reconstruction is one of the methods for 3D digitalization of artefacts for virtual heritage use. However, since the pipeline relies heavily on human intervention, significant deviations could appear between the physical and digital versions as a result of the modeler’s interpretation. By comparing the modeler’s work, work process, and their understanding of the artefact’s historical significance, we can identify that individual skills, knowledge, and cultural experience play a role in how modelers construct a mental model of the artifact. This subsequently affects the resulting 3D model. This knowledge would be helpful in addressing these factors early on during the production process.

Keywords: *3D reconstruction, 3D modeler, virtual heritage.*

1. INTRODUCTION

CHDR Lab is an academic research laboratory dedicated to the exploration and implementation of animation industry production techniques in the realm of virtual heritage. Among the lab's ongoing projects is the creation of 3D models as the digital archive of physical replicas crafted by skilled artisans, based on archaeologists' interpretations of artefact remains discovered during the excavation of Sila Dynasty tombs in Gyeongju. This project involves a multinational team of undergraduate and graduate students from the Visual Contents department, working as 3D modelers under the guidance of experienced professors with backgrounds in the entertainment industry.

The primary objective of the project is to develop realistic 3D models that closely resemble the physical replicas, serving as digital counterparts for accompanying exhibits. Special attention is given to visual aesthetics, ensuring that the 3D models accurately capture the replica's shape, proportions, elements, color, and textures. Due to the lab's location outside of Gyeongju, the modelers lack direct access to the physical replicas. Instead, a series of photographs depicting the replicas from various angles were provided for analysis. These images serve as references for the initial assessment of the objects' overall dimensions, shapes, elements, materials, and construction.

As 3D reconstruction relies more on human processes, we come to expect that the student individual skill level, approach, and preferences will have significant contribution to the resulting model. This research purpose is to identify contributing factors from a modeler background that affects 3D reconstruction quality of the resulting model.

2. THEORETICAL BACKGROUND

Vaughan defines digital modeling or 3D modeling as the process of creating a mathematical representation of a three-dimensional shape of an object [3]. In practice, the mathematical aspects of the modeling process are handled by specialized 3D modeling software (e.g., Maya, Blender, etc.) that functions as the modeler’s tools for constructing the desired form. As the modeler has an active role in the creation process, the resulting model relies on the modeler’s creativity and spatial skills to perform the required tasks.

3D reconstruction has been used in virtual heritage primarily as a sustainable and affordable tool in performing research, simulations and communicating findings to the public. In the early years of its

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implementation within this field, virtual archaeologists relied on 3D modelers from the creative industry for producing digital reconstruction of artefacts and features. However, with the advent of 3D scanning technologies and algorithms to calculate structure from motion (e.g., photogrammetry), the 3D modeler role is more confined to generating models for communicating findings to the public. Photogrammetry methods for 3D reconstruction is more efficient and effective that 3D modeling [1]. Archaeologists could, by themselves, input a series of artefact's images from various angles into photogrammetry software, to produce an instant and more accurate reconstruction compared to the time-consuming process of subjective interpretation and shape refinement by a 3D modeler [2].

Benardou et. al. states that precision in the digital reproduction of physical artefact is an important consideration to maintain its authenticity on the digital realm [4]. However, Jeffrey argues that authenticity could also be attributed from appeal (aura) [5], a quality of emotional engagement between audience and the artefact (regardless its original or a replica). A 3D modeler could, in theory, attribute appeal to a model through emotional engagement during the 3D reconstruction process.

3. METHODS

We assigned the same project to three different modelers, each given the same brief, without any thorough information of the artefact, apart from the available photographs (as image references) and overall dimension of its replica. The intention was to obtain three distinct results that could be compared and analyzed for any variations. Each modeler was allocated one week (or six working days) to complete the model. Once finished, an interview is conducted for each modeler to collect demographics, psychographics, workflow, problem-solving approach data as well as their insights (their knowledge & interpretation of the artefact).

A comparative analysis of the resulting models (considering aspects such as shape, proportions, mesh structure, elements, assembly, material, & color) is used to assess model precision & appeal (ability to implement personal interpretation). The interview transcript is analyzed using thematic inductive methods to gain insight of their experience engaging with cultural heritage artefacts during the modeling and what sort of creative interpretation they might conjure in the process. Both analyses are cross referenced to find possible correlations that could be used as summary on how modeler's background affects the resulting 3D reconstruction model.

4. RESULTS & DISCUSSION

Model comparison

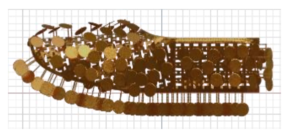
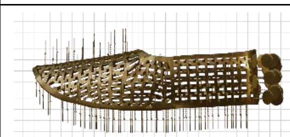
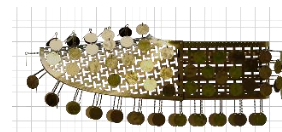
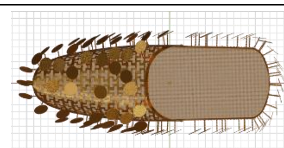
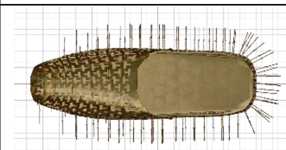
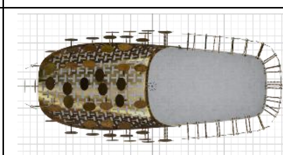
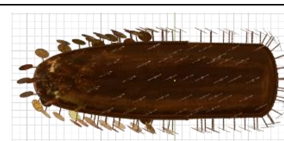
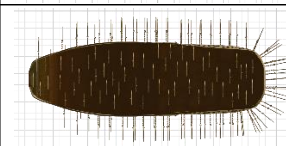
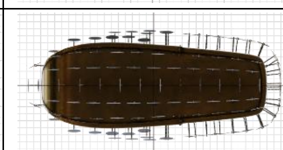
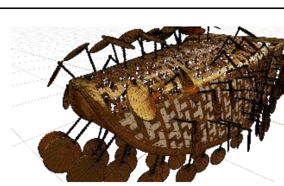
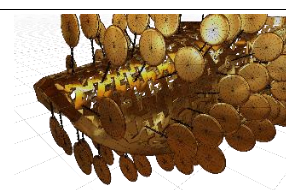
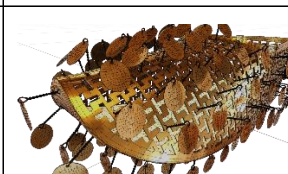
In Table 1, a comparison of each model with the reference images reveals the following observations:

- Overall shape: Student 1's model is the most accurate, while Student 2's model deviates in the front part of the shoes, with a blunt tip and distortions in the hole pattern shape. Student 3's model deviates in the front and mid parts, appearing wider compared to the references.
- Mesh structure: Student 1's model has the cleanest topology, while Student 3's model has the most detail. Student 2's model displays triangular topology in the disc-shaped ornaments, and although the pattern hole shape has some deformations, the topology remains acceptable (consisting of quads). Student 3's model exhibits unclean topology in the pattern hole, but the topologies of other elements are clean. Student 3's model appears smoother as it contains the greatest number of triangles (2,112,856) compared to Student 1 (1,430,436) and Student 2 (539,192).
- Proportion: Student 1's work is the most accurate in terms of proportion, while Student 3's work shows the most deviation. Student 2's model has slight deviations in the tip of the front part and the width of the rear part. In Student 3's model, noticeable deviations can be observed from the middle part to the tip of the front, and the length of the shoes is not proportional to the height.
- Elements & assembly: All models have the same number of major elements. Student 3's model displays more detail in the shoe's elements. Student 1's model misses one set of rivets at the bottom that bind the front, rear, and sole together, while Student 2's model lacks the bottom rivet as well as the edge folds. Students 1 and 3 provide a more logical depiction of element assemblage. Student 2's model omits the bottom edge folds on the front and rear parts, which provide support and stable contact between the sole

and the front/rear parts. However, the width of the folds in Student 1 and 3's models is too wide compared to the image references.

- Arrangement of disc ornaments: Student 1's model displays a random orientation of the disc ornaments, though not exactly matching the reference. Student 2's model also arranges the ornaments in a random pattern, but all the discs are oriented in the same direction. Student 3's model showcases ornaments that are symmetrically oriented and arranged.
- Material and color: Comparing the material and color of the models from the last row of the first table, all models depict the metallic appearance of the reference material to some extent. However, Student 3's model closely matches the lighting and color, while models from Students 1 and 2 appear too dark. The disc ornaments in Student 1's model lack the reflective nature of the material.

Table 1. Model Comparison

	Reference Images	Comparison		
		Student 1	Student 2	Student 3
Side view				
Top View				
Bottom View				
Perspective				
Details				

Workflow comparison

In general, all students follow the same workflow (Figure 1), with difference in practice details as noted below:

- Collecting references: Student 1 only relies on the available images handed out during project briefing as reference, while Students 2 & 3 gathered further information and references from the internet. Student 3 even created several sketches to create hypothetical representation of the artefact's parts that are not visible from the available image references.
- Adjusting references: All students select several images that closely matched the top, side, front, rear, and bottom orthographic views from the available photographs as tracing references. Selected images are scaled and aligned accordingly within the 3D modeling software to match the artefact's dimensions and form. Other images are used as visual references to refine contour and minute details.

- Model construction: Students 1 construct the model geometry using the polygon & sculpting modeling technique, Student 2 uses the patch modeling technique (lofting), while Student 3 only relies on polygon modeling technique. They also choose a different technique for creating details (hole pattern). Student 1 uses texture masking technique, Student 2 build mesh pattern and applies wrap tools to shape the mesh according to the artefact's surface, while Student 3 chooses the Boolean operators to create the hole. Students 1 & 2's goal is to create a clean topology, while Student 3 prefer to replicate the artefact's physical features (hole is cut out from the surface). Each student encountered modeling challenges that differ according to the technique they choose; however, they managed to find a solution and learn new software skills in the process.
- UV Mapping: Students 1 & 2 have difficulties during this stage as the technique they choose requires refined adjustments of the model's UV map.
- Material & Texture: All students utilize separate software to create surface textures based on the UV map. The resulting textures are then imported back to the 3D modeling software as PBR (physically based rendering) material textures. Each student has a different opinion on the value for base color, metallic, roughness & normal properties as can be evident from Table 1.

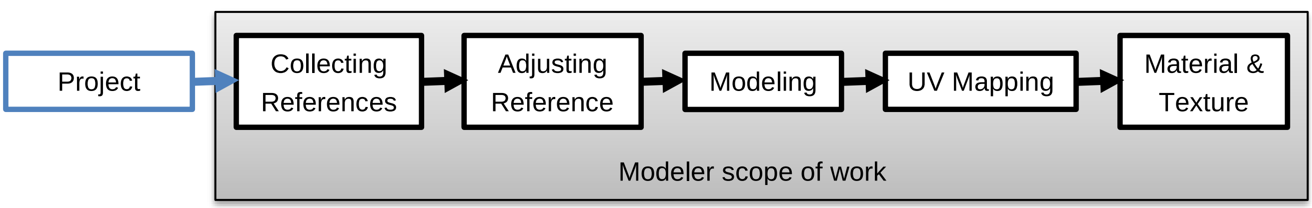


Figure 1. Modeling Workflow

All the models could not reconstruct the replica accurately, which is to be expected from using the 3D reconstruction techniques instead of the more mechanically inclined methods (e.g., photogrammetry). However, Student 1 fares better than the others in terms of precision, while Student 3's model, although has the most distortion, is more appealing (Table 2).

Table 2. Model Quality

Model Quality	Student 1	Student 2	Student 3
Precision	High	Low	Low
Appeal	Low	Low	High

Interview Analysis

Based on the description as outlined in the above paragraphs, the modeler's respond to the interview could be codify into the following keywords: experience, persistence, attentive, inquisitive, efficient, functional, symbolic, exclusive (Table 3). Each student could be then analyzed as follows:

- Student 1 experience is in between Student 2 & 3. Attentive to the task given and persistent to achieve the required goal. Prefer efficient methods in completing tasks. Views the artefact as exclusive and symbolic based on preference from personal interest (hobby).
- Student 2 has the least experience but has the persistence to improve skills. Attentive as well as inquisitive, willing to explore using inefficient technique to achieve better results. Views the artefact as exclusive and symbolic object based on preference from cultural background.
- Student 3 has the most experience, however not as persistent and attentive as the other students. Inquisitive, prefer to use inefficient methods to achieve desired outcomes. Views the artefact as exclusive yet has functional aspect to it based on preference shaped by educational backgrounds.

The reconstructed artefacts provide problem solving challenges for students to come up with the best approaches, as evident by the fact that each modeler chooses a different method. They have no knowledge of best practices that best meet the task. The least experienced student learns new knowledge to help solve the task problem, while the other students need to relearn and familiarize themselves with techniques that they have learned before in order to perform the task. Extensive examination of the artefacts provides students with new information, not only the artefact is no longer available in modern times (there is no shoes like it today) but as it also serves a different purpose, having features that are not common for a product like it.

Except for Student 2, they understand the advantages of using a certain technique and the consequences of implementing them. For Student 1, the most efficient way is more desirable even if it means compromising the realism of visual appearance in detail, while for Student 3, high number of triangles and an unclean topology is acceptable to achieve the hyper realistic details.

Artefact interpretation

All the students have no prior knowledge of the artefact besides as given during the brief (image references). Each student builds their own interpretation as noted below:

- Student 1:
    - Student 1 believes the artifact is primarily for display, showcasing wealth and the creator's ability to make complex items.
    - It is not considered practical to be worn and may be inspired by intricate objects from medieval Europe.
    - If worn, it could be by royalty to avoid touching the ground or by a girl with revered status.
- Student 2:
    - Student 2 interprets the artifact as being worn by aristocratic women during large gathering occasions.
    - The golden color symbolizes the owner's wealth, and the shoes are seen as inconvenient for everyday wear.
- Student 3:
    - Student 3 believes the shoes are only for official appearances and not meant for walking to preserve the ornamental elements.
    - The shoes are worn by sliding the feet in, possibly with socks or some form of covering for comfort.
    - The disc ornaments on the surface create the illusion of sparkling, perhaps to elevate the wearer visual appearances as to having a glowing (holy) aura.
- Furthermore, all students assumed that the artifact was crafted by skilled craftsmen, with Student 1 and Student 3 specifically mentioning goldsmiths as the creators, with Student 1 goes even further by elaborating the tools and techniques used, such as hammering, stamping, and suggesting the use of a special machinery to create the intricate patterns.

Table 3. Codifying Interview Transcript

Code	Student 1	Student 2	Student 3
Experience	4 years	< 2 years	> 10 years
Persistency	High	High	Low
Attentive	High	High	Low
Inquisitive	Low	High	High
Efficient	High	Low	Low
Functional	No	No	Yes
Symbolic	Yes	Yes	No
Exclusive	Yes	Yes	Yes

If we cross referenced analysis of the interview with the resulting quality of model created, we could deduce that the modeler who cultivates persistency and attentiveness is likely to provide a more accurate reconstruction.

They strive to be faithful to the task given. While the inquisitive student has the tendency to question even the apparent data, prefers to explore the possibility of making the product better by forcing their own interpretation, resulting in a distorted rendition of the original object.

Even though students have the same opinion that the artefact has a special place in its time, each has different creative interpretations that could be attributed to their background difference. Student 1 examines that the shoe is impractical and uncomfortable, decides that it only serves as a decorative item (not to be used), as it is not an effective and efficient form of footwear. The student preference of modern rendition of medieval art in digital games also strengthens his arguments, as in the rendition, complexity, and elaborate item, though not practical, has a special value and symbols of superiority. However, this student provides an interesting creative interpretation, describing in detail the tools and process to create the artefact, an indication of fascination for the creation of the artefact. Student 2 interpretation is based on cultural background, appropriating symbol common in the student's culture to something foreign, an effort to make sense of something previously unknown. While Student 3 interpretation focuses on the relationship between artefact and its usage, describing how it should be used, inquisitive of the world surrounding the artefact. This interpretation is possibly affected by educational backgrounds and character. This creative interpretation could be attributed to the student's model as the most distorted. An examination of the model shows that there is an "effort" to make the artefact appear more comfortable to use, spreading the front part of the model. As well as giving artificial defects in the model surface to mimic product that is affected by wear and tear of usage and environmental conditions.

5. CONCLUSION

The background of a modeler, encompassing demographics, psychographics, and skill level, influences the modeling process and the resulting model. In a 3D reconstruction project that seeks to create a precise digital replica of the original, mechanical reproduction methods such as photogrammetry are more suitable. This is because the 3D modeling method necessitates preliminary steps to mitigate these influencing factors, such as understanding the artefact, standardizing basic skills, modeling techniques, and workflow. However, additional research is needed to evaluate the effectiveness of these preliminary steps in reducing the subjective nature of the 3D modeling method.

Interestingly, this research inadvertently revealed that the 3D modeling process has potential as a medium for enhancing a modeler's understanding, knowledge, and interest in cultural heritage artefacts through virtual engagement in reconstruction. This provides an initial concept for investigating the use of 3D modeling as a medium in cultural heritage artefact education.

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