Virtual Relighting of a Roman Statue Head from Herculaneum: A Case Study

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Figure 1: *An Amazon female warrior statue head in its various forms throughout this paper(left to right): Photograph, Geometry Scanned, Indoor Render, Outdoor Render and a Photograph of a Rapid Prototyping Realisation of the Statue.*

Abstract

High-fidelity computer graphics offer the possibility for archaeologists to put excavated cultural heritage artefacts virtually back into their original setting and illumination conditions. This enables hypotheses about the perception of objects and their environments to be investigated in a safe and controlled manner. This paper presents a case study of the pipeline for the acquisition, modelling, rapid prototyping and virtual relighting of a Roman statue head preserved at Herculaneum in Italy. The statue head was excavated in 2006, after having been buried during the eruption of Mount Vesuvius in AD79.

1 Introduction

Through virtual archaeology we are able to explore the past virtually and gain insights which may not be possible through traditional archaeological means. The virtual archaeological pipeline typically includes: acquiring a digital representation of an excavated artefact, post-processing the acquired data, then visualising the object and illuminating it appropriately (See section 3 for more information on the pipeline). Cultural heritage artefacts may be preserved, while their digital representation can be manipulated, under user-defined conditions, to scientifically extrapolate or interpret new information about the past.

This paper presents a case study of the virtual archaeology pipeline.

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In particular we consider the reconstruction of a Roman statue head from an Amazon female warrior statue from Herculaneum in Italy (in modern Italian: Ercolano). Recently found in 2006 [HCP 2006], the statue head has had great archaeological impact due to the preserved paint still on it. This paint is providing archaeologists greater insight into painted Roman statues.

2 The Statue

Herculaneum was a small town close to Mount Vesuvius. The town was buried in the same catastrophic eruption in AD79 that also overwhelmed nearby towns such as Pompeii. Whereas Pompeii was buried in volcanic ash, Herculaneum became entombed in molten rock, and thus excavation has been a much slower process. In 2006, the statue head of a young Amazon female warrior, probably carved in the late first century BC or early first century AD, was discovered. It was exposed during emergency archaeological interventions at Herculaneum. The work was undertaken by the Herculaneum Conservation Project which has in recent years been engaged in a vital programme of consolidation and recording at Herculaneum. Initial expert analysis of the head identified it as being from a full height statue of a particular type of wounded Amazon of the Sosikles and Sciarra types. This type of Roman statue is commonly attributed as a copy of one or more Classical Greek bronze statues, perhaps from the fifth century BC. Similar statues have been found throughout the nearby area, which means archaeologists know the posture and general appearance of the statue.

The head was discovered in the corner of the so-called Basilica

Noniana, named after a Herculaneum patron. This building is situated on the edge of the public part of the Roman town which still lies buried beneath modern Ercolano. Archaeological interventions in this area have to date been limited to tunnels dug down through 20m of volcanic deposit during the 18th and 19th centuries. The remainder of the statue is presumed to lie within the as yet unexcavated portion of the Basilica. The significance of this statue head is the quality of the painting that is preserved. Although it is known that Romans painted their statues, very few have been found with such levels of pigment in situ. The statue head is made of white marble (Pentelic). It seems to have been sculpted separately from a still missing, presumably marble body.

The combination of stylistic forms in this example may in fact be unique, rendering the successful recording and further analysis vital. It also makes the possibilities of reconstruction both exciting and daunting. For a standard form it would be relatively easy to substitute scanned data for a better preserved (if unpainted) archetype in order to replace the damaged portions and indeed to reunite the head with a possible body. In this case however, the reconstruction through amalgamation of different scanned exemplars may prove an important part in the interpretation of the statue, in addition to a mechanism for sharing ideas, for relighting and contextual interpretation, and for presenting final alternatives to a wider public.

Analysis of sculptural composition has much to do with viewing angle and computer graphic simulation, including authentically modeling Roman light sources, provides for modifications to patterns of light and shade, and to the orientation of viewer and object. For example, analysis based on the relative detail with which parts of a sculpture are rendered in stone do not always account for the interplay of lighting across their surface (a notable exception being [Sturgeon 1995]).

Computer reconstruction of the statue is important for three archaeological reasons: Firstly, provision of a detailed and accessible conservation record. Secondly, spatial and contextual interpretation through lighting. Finally, stylistic analysis. In conservation terms an accurate laser scan will enable construction of armatures and carrying equipment to assist in the preservation and eventual display of the object. The three-dimensional record will in addition offer a stable point of comparison in advance of any further conservation work or in the event of further damage. Successful modelling of the surface texture may also help conservationists in the choice of presentation formats chosen in any display of the artefact and to accurately represent the complex marble/paint surface interactions under authentic Roman lighting conditions.

3   Related Work

Cultural heritage reconstruction is a promising application of geometry acquisition and processing, material properties simulation and authentic relighting for visualising and studying of artefacts and environments of the past. There already exists a vast amount of literature on reconstruction methods and implementations of real-world objects. A few example reconstruction projects of statues and sculptures include [Levoy et al. 2000; Bernardini et al. 2002; Akca et al. 2006; Dellepiane et al. 2008]. Other examples of object and environment reconstruction include [Devlin and Chalmers 2001; Debevec et al. 2004; Balzani et al. 2005; Besora et al. 2008; Gonalves et al. 2008].

[Bernardini and Rushmeier 2002] details the 3d model acquisition pipeline. [Callieri et al. 2005] discusses the emerging issue of how to support the visual presentation of models with interactive rendering. Digital photography can be used as a means to capture texture maps for a 3D laser scanned model. The Macbeth colour chart is a means to compute color compensation based on images as described in [Ward and Shakespeare 1998]. Examples of use of this chart in use include [Debevec et al. 2004; Dellepiane et al. 2008]. While photography allows us to capture the colour of a surface, capturing Bi-directional Reflectance Distribution Functions (BRDF) would enable us to accurately model the physical properties of a material (E.g. see [Debevec et al. 2004]). Image-based lighting (IBL) [Debevec 1998] permits us to light the scene appropriately to how the area is lit today.

4   Pipeline

Figure 2 shows our general virtual reconstruction pipeline. In the following sections we first discuss data acquisition. This includes investigation of the site, preparing for geometry data acquisition, the laser scanning and photography for texture mapping of the model head. Subsequently we describe the reconstruction process involving the laser scanning post-process and applying texture to the model. Finally we detail the visualisation stage including virtually relighting and rendering the head. This section also describes the building of a rapid prototyping realisation of the statue head.
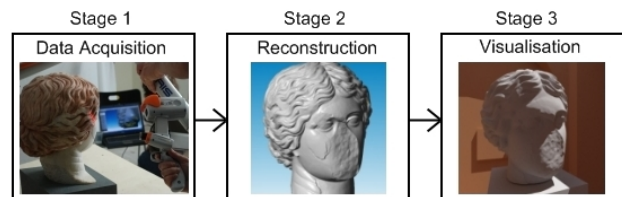

Figure 2: *This case study's pipeline.*

4.1   Stage 1: Data Acquisition

In this section we describe the data acquisition process for our case study. We begin describing our investigation of the physical appearance of the site, and then discuss preparing the scene for acquiring geometry and texture data from the statue head.

4.1.1   Visiting the Site

Due to ongoing excavation at the Herculaneum site, we are currently unable to determine the precise location of the whole statue, and thus unable to visualise it in its original location. During our visit to the excavation site, we took reference photographs of the area for our visualisation stage.

Figure 3 is a photograph from the area where the statue head was initially found at the excavation site, while figure 4 shows the inside of the neighbouring building.

4.1.2   Laser Scanning

We placed the statue head out of its original context and into an open, near diffuse lit room, on top of a table resting on a stone plinth (see Figure 5). We used a Metris Coordinate Measuring Arm [Metris 2008]; a manually articulated measurement system, having seven axis of manipulation, which with the aid of a probing device can detect the spatial coordinates of an artefacts surface (see Figure 5). Its portability provides the measuring arm with the benefit of being able to be used both in laboratory conditions and in several types of field work.

There are a number of probing solutions which can be used with a Coordinate Measuring Arm which include touch-trigger; contin-

Figure 3: *A photograph from where the statue head was recovered.*

Figure 5: *A photograph of the scanning process.*

4.1.3 Digital Photography for Texture Capture

An initial texturing and relighting has been possible via photographs taken on site. These photographic textures, although crude provide an impression of the statue under varying lighting conditions. The head was covered as away far as possible by several white sheets in order to eliminate as much specular lighting as possible. We captured the photographs in order to eventually compute color compensation based on the Macbeth chart via the *macbethcal* function in the Radiance rendering software [Ward and Shakespeare 1998] (see Figure 6).

Figure 4: *Inside a nearby building to where the head was found.*

Figure 6: *A photograph of the statue head with the Macbeth chart.*

More physically correct methods can be used to capture the material properties, such as BRDF [Debevec et al. 2004] or Subsuface Scattering [Jensen et al. 2001]. However, this would have required greater access to the statue head over a longer period of time than our initial case study would allow.

uous touch-scanning and non-contact laser-scanning probing devices. The probing system that was selected to gather the geometrical data for the statue head was the emerging non-contact laser-scanning probe. Laser-scanning is able to define a numeric representation of the statue's surface through sets of 3D points [Lartigue et al. 2002]. It can gather up to 80,000 measurement points per second in concentrated proximity and therefore has a much faster and denser data acquisition rate than that of traditional probing solutions which makes it ideal for recording surface information and visualising archaeological artefacts.

The laser probe utilises an image-sensing camera and a focussed laser line to gather points using a process known as active triangulation [Feng et al. 2001; Lartigue et al. 2002]. This allows surface topology to be determined without having to contact the objects surface, vital for maintaining the structural integrity of delicate archaeological excavations. Instead, the focussed laser line is projected onto the statue and the diffuse laser light that is reflected back from the surface is detected. As the laser line was moved across the surface of the statue a detailed 3D point cloud emerged. The point cloud was generated by using the high resolution Metris laser scanning probe in combination with the manual measuring arm, had a system accuracy of between 50-60μm, producing a realistic virtual representation of the statue.
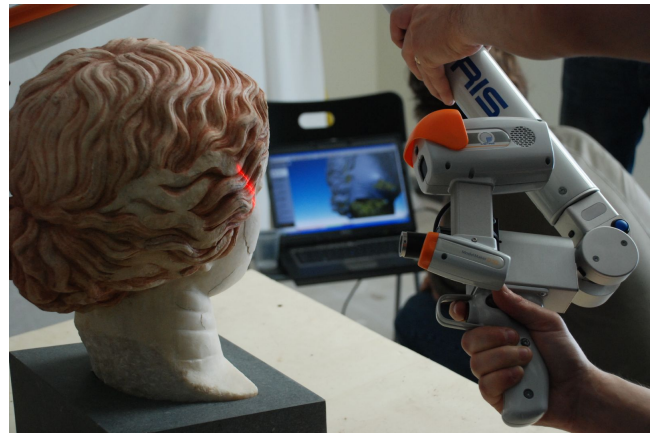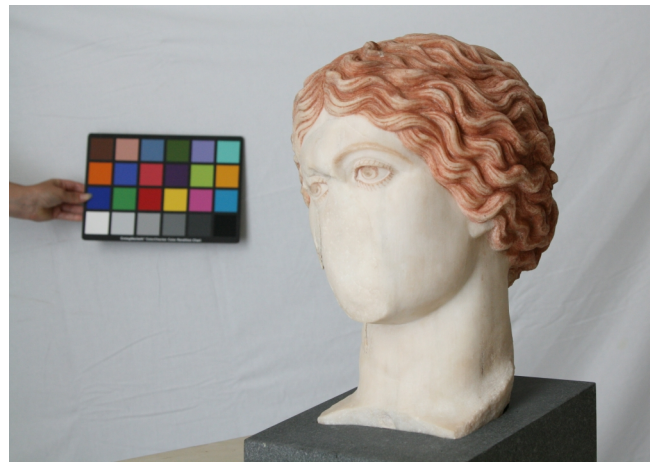
4.2 Stage 2: Reconstruction

In this section we discuss our approach to reconstructing the statue head, covering the laser scanning post-process and the initial texturing of the statue head.

4.2.1 Laser Scanning Post-process

From the complete point cloud produced from scanning the entirety of the artefact's surface, a finite element mesh was constructed. This is a 3D model based from small triangular facets, all scans taken were optimised to ensure that there were no stepped surfaces and the point cloud was filtered to a point spacing of 0.3mm. Boundary points were inserted to ensure surface definition and small holes in the mesh was filled using curvature analysis. This was achieved using Metris Kube software [Metris 2008]. Figure 7 shows the geometry captured.
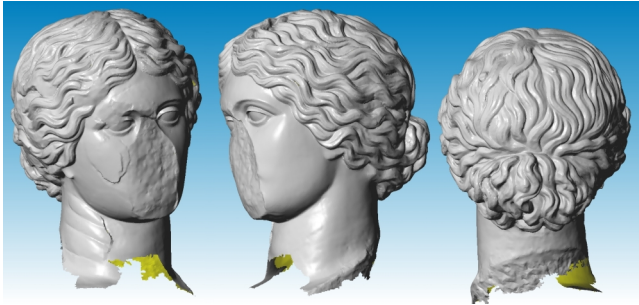

Figure 7: *Screen capture of the post-process of the geometry acquisition stage.*

4.2.2 Texture Mapping

Appropriate texturing of the model is a vital and complex operation. The initial examination of the data involved the application of several techniques photographic texturing using the 3D modelling package Maya 8.5 [Autodesk 2007] and also the development of procedural materials using the 3D modelling package 3DS Max 2009 [Autodesk 2008] (see Figure 12) designed to simulate the surface properties of the head. Both of these techniques have proven competent and enable authentic relighting. Whilst being successful as a method of visualising and presenting the data, the potential of using procedural materials will be more fully realised during the next phase of the project during which we will capture and incorporate additional surface detail. This will enable the behaviour of the materials to more accurately simulate the behaviours of the statue surface.

4.3 Stage 3: Visualisation

In this section we discuss our approach to visualising the statue head. We discuss relighting, rendering and the rapid prototyping realisation of the Statue Head.

4.3.1 Re-lighting the Statue Head

The necessity to relight cultural heritage objects with historically correct illumination is of increasing importance for authentic representation of those objects and environments [Devlin and Chalmers 2001; Roussos and Chalmers 2003; Gonalves et al. 2008]. For the purpose of this paper our relighting reconstruction uses textures captured from digital photography and scanned geometry.

Not knowing the original position of the statue poses difficulty in relighting the virtual model in an authentic manner. We captured a spherical High Dynamic Range (HDR) photograph [Debevec 1998] on top of Mount Vesuvius using a Spheron HDR camera [Spheron 2007]. We use IBL from an light probe to relight the statue head. Due to weather circumstances during our visit to Herculaneum the HDR image is on a cloudy day.

Figure 8: *A spherical HDR capture on top of Mount Vesuvius.*

4.3.2 Rendering

Due to the complications with determining the exact position of the statue head, we render the head in two distinct approaches. The first is an outdoor scene of the statue head, using a simple base plinth with the HDR spherical image as the scene backdrop (see Figure 9).

Figure 9: *Outdoor render of the statue head.*

In the second scene we attempt to visualise how the head appears under more enclosed conditions. We relight the scene using the same HDR image, some light penetrates through an open ceiling. All the rendering was done utilsing a standard path tracer [Kajiya 1986] and calculating using approximately 2500 samples per pixel. HDR IBL was used to try to faithfully re-create the lighting conditions.
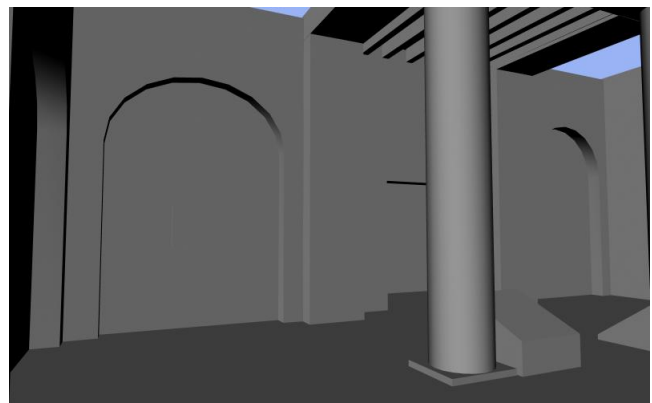

Figure 10: *Room reconstruction for relighting.*

Figure 10 and 11 illustrate our test attempt at placing the statue

Figure 11: *Indoor render of the statue head.*

head in an appropriate indoor environment. Our virtual environment, based on figure 4, was modelled using Maya.

Figure 12: *A screen capture of the texture mapping process.*

The image of the head textured with procedural materials was rendered in 3DS Max 2009 using the Mental Ray renderer (see Figure 12). The statue was set within a simplistically simulated white room with artificial lighting. This scene was designed in order to provide a rough simulation of the environment to be replaced when the image is set within other simulated contexts.

Figure 15 at the end of this paper consists of multiple sub-figures which detail additional results.

4.3.3 Rapid Prototyping Realisation of the Statue Head

Prior to Rapid Prototype (RP) manufacture of the statue head, the triangulated mesh representation of the head obtained from 3D scanning was surfaced to generate a 3D triangulated surface model. The model was then prepared for RP by recreating any missing surface data not captured by the scanning process. This was achieved using the Kube software, which allowed 3D surface geometry to be added to the model.

Preparation also included constructing a surface at the bottom of the neck to create a single enclosed surface, necessary for RP; this would also form a base on which the sculpture would stand. Stereolithography (SLA), which constructs models by the layer-wise solidification of a light-sensitive resin using a laser, was chosen as the

most appropriate RP system, as this provides an appropriate surface finish, and is capable of replicating the fine detail contained within the model.

Manipulation of the model was performed in Magics RP (Materialise n.v). To prepare the model for SLA, the surface model was hollowed to create a 3mm wall thickness shell in order to reduce RP build time and weight of the model. A hole was then created in the base surface to allow resin to drain from the hollow part after construction. The RP model was realised using a SLA 5000 (3D Systems Inc) system in Watershed 11122 XC resin (DSM Somos). See Figure 13 for a photograph of the process. The final real world model of the statue can be seen in Figure 14. This model can for future reference be used for validation of our reconstruction as an existing copy of the original real world model.
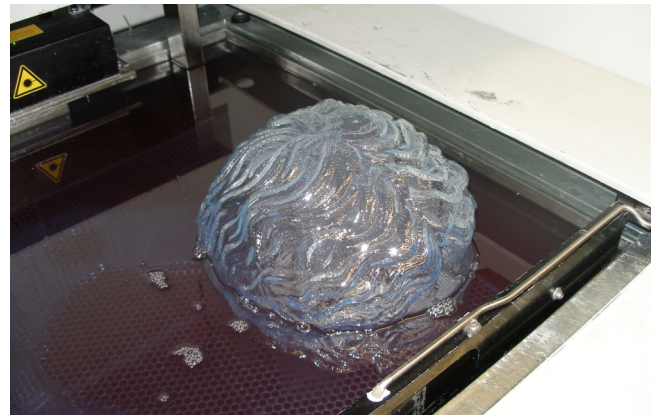

Figure 13: *Photograph of the Process of Making the Rapid Prototyping Realisation of the Head.*

Figure 14: *Photograph of the Rapid Prototyping Realisation of the Head.*

5 Discussion and Conclusion

In this paper we have presented a case study of the virtual archaeology pipeline from capture to display of the head of an Amazon female warrior statue excavated at Herculaneum in 2006. The unique nature of this statue and the quality of the pigment preservation offers archaeologists the potential to gain significant new insights into Roman painted statues.

From an archaeological study standpoint, the ideal working virtual environment for study of historical objects includes accurate modelling of geometry, materials and lighting in virtual space. A problem with existing computer graphics research is the limited amount of precision available. Models in object space and image space can be either sampled or approximated. This is in complete contrast to the real, continuous world. Furthermore, rendering high-fidelity reconstructions is difficult at interactive frame rates due to their complexity, and in several cases not possible using current hardware. In the future, we hope our case study may be used as an inspiration to implement a fully robust platform for relighting and studying artefacts in authentic lighting for future reconstruction pipelines.

Production of the rapid prototype physical model has provided an opportunity to experiment with physical analogues to the digital representations as they are developed. The work undertaken by the Musei Vaticani, the Gliptoteca di Monaco, the Ny Carlsberg Glyptotek and others has shown the potential for combined physical and graphical repainting of surrogate polichrome statues [d'Arte 2005]. Our application of physical repainting will build upon this work but concentrate on the potential for computer graphics to produce physically-based representations suitable for analysis. The repainting to be undertaken in coming months will allow for a systematic comparison between reality and simulation and in particular for the exposure of both the physical and the digital surrogates to luminaires such as oil lamps and hearths in a way not possible with the original.

Authentic relighting of the statue is fundamental to investigating how the statue may have been perceived in the past. HDR imagery is one means to achieve the necessary level of accuracy in lighting. Furthermore appropriate Roman architectural contexts must be recreated and a series of hypothetical models for its original appearance produced. Recent studies of the statue by the project team and by a range of other experts have begun to provide a more nuanced understanding of both aspects. Firstly, the potential Roman contexts are being digitally recorded [Brizzi et al. 2006]. Secondly, initial examination of the statue suggest that its digital restoration must take into account the possibility of the surviving statue representing a hitherto unseen amalgam of 'standard' wounded Amazon statues. Further collaboration with experts from the Soprintendenza and the Herculaneum Conservation project will enable careful additions to be made to the digital model. In particular, the damaged face will be digitally repaired in a number of different ways and alternative bodies will be constructed based in part on scan data captured of 'type' statuary and in part on the extant Roman painted record.

Virtual archaeology now offers archaeologists the potential to recreate the city and its artefacts and investigate how they may have appeared before the eruption. Evidence, such as that obtained from the Amazon statue head, provide vital clues to ensure the authenticity of any reconstruction. To avoid the danger of misrepresenting the past, all stages of the virtual archaeology pipeline need to be as accurate as modern technology will allow.

The virtual archaeology pipeline we use needs to be extended further to allow the archaeologists to fully explore theories concerning the statue head and painted Roman statues. In the next stage of this project we will incorporate further elements. These will include adding to the surface records available of the statue by capturing high resolution Polynomial Texture Mapping surface data for the sculpture. This will augment the photographic and topological data gathered during the scanning phase [Malzbender et al. 2001]. Unable to acquire the BRDF of the statue head for this case study, we hope to add this to the model in the future. In addition, careful decomposition of the surface properties of the sculpture will be modelled procedurally, with particular emphasis on subsurface scattering [Jensen et al. 2001] within the upper portion of the marble surface, the interaction zone between the pigment and marble, and the physical properties of the paint itself, allowing for chemical decomposition and photodegradation [Dorsey et al. 2008]. In this way we will be able to visualise the Roman pigments as they would have appeared when they were first applied to the statue.

A spectrophotometer [PhotoResearch 2008] was used to sample colour values for the face and hair in order to assist repainting and relighting. Although the conditions of the eruption and subsequent burial of the statue will have significantly impacted the colour values of the head it is only through detailed calibrated colour capture that any interpretation of the original colours can be made. Subsequent work will extrapolate these colours via known Roman comparative pigment data.

Accurate modelling of these factors is vital in provision of a record for subsequent comparison with the object, including the impact of any subsequent conservation treatments. Physical procedural modelling should also provide the potential to simulate subsequent degredation. Successful modelling of the surface texture may also help conservatives in the choice of presentation formats chosen in any display of the artefact. In addition we would hope that the digital imagery could assist in dissemination of information regarding this piece of Herculaneum's history.

Acknowledgements

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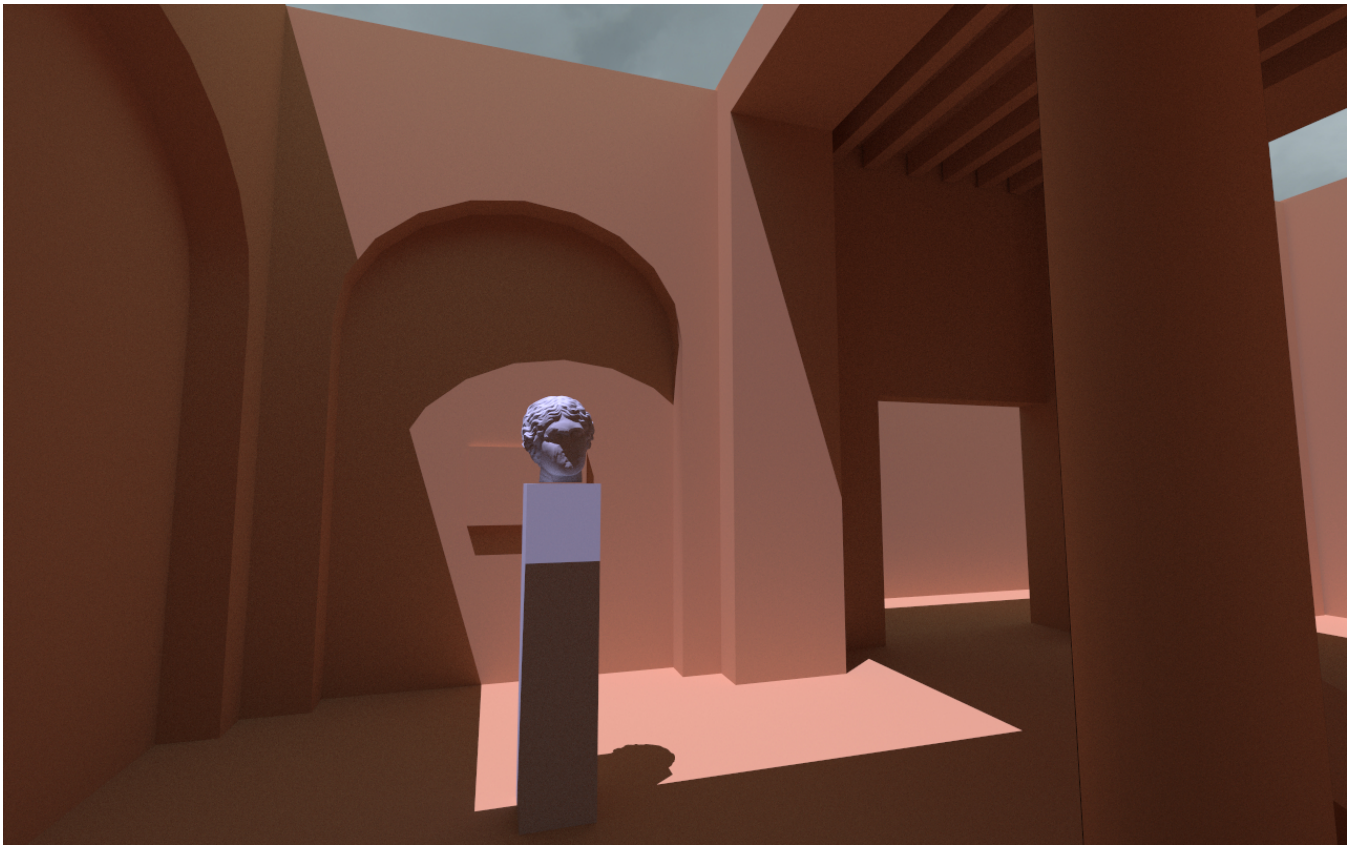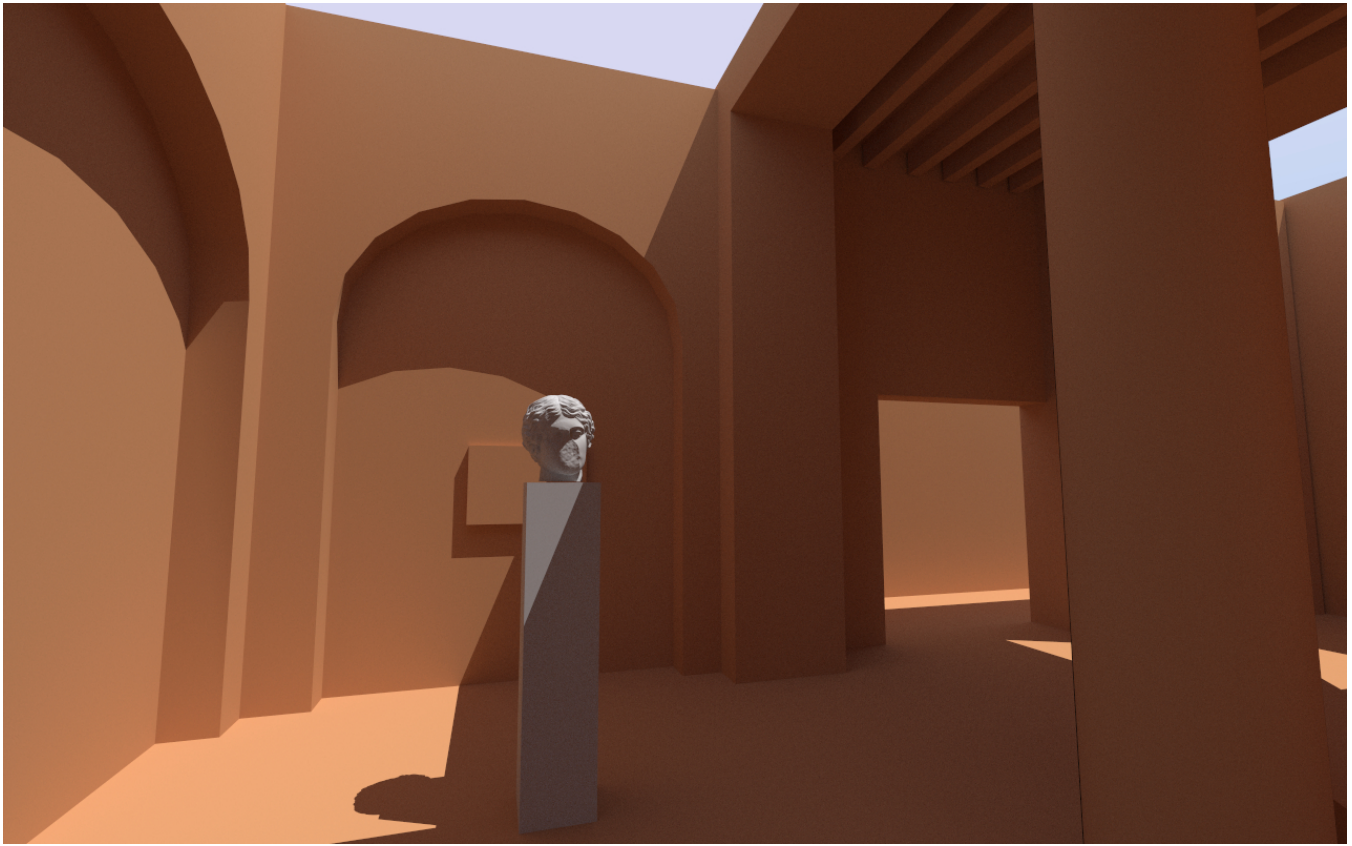
Figure 15: *A compilation of various renders related to this paper of the statue head.*