

3D Modeling to Reconstruct a Paleontological Site: Museum of Casal de' Pazzi in Rome

Tommaso Empler
tommaso.empler@uniroma1.it

Abstract

Today, 3D modeling allows the creation of sophisticated reconstructions in the field of Paleontology that until a short time ago could only be obtained with traditional techniques and hand-made drawings. An interesting methodological application is the Museum of Casal de' Pazzi in Rome. In this case 3D modeling has allowed the reconstruction, starting from the discovery of some finds, an "Ancient Elephant," a "Urus," and a "Neanderthal Man". Modeling was performed with the help of scientific data and experienced paleontologists and anthropologists. 3D models were completed with the "digital sculpting" technique, allowing a more accurate reconstruction of the shape and appearance of the animals and hominin. The models were subsequently used for multimedia and interactive communication, describing the history of the place where the Museum is located.

Keywords: paleontology, 3D modeling, museums

Introduction

The discovery of the Pleistocene Rebibbia – Casal de' Pazzi complex and its excavation, carried out by the Archaeological Superintendence of Rome from 1981 to 1985, allowed scholars to learn more about the oldest phases of human settlement in Rome and, more generally, in the Italian peninsula (Anzidei and Gioia 1990). The excavation work covered over 1200 square meters. It led to the discovery of a vast Pleistocene deposit, consisting of a portion of the bed of an ancient river. The site is located on the right bank of the Aniene River, at an altitude of 32 m above sea level. Layers of gravel and pyroclastic sand (rock of volcanic origin) characterize the site where scattered lithic elements and fossil bones were recovered.

The bones mainly belonged to large mammals such as the ancient elephant (*Palaeoloxodon antiquus*), the Urus (*Bos primigenius*), Hippopotamus amphibius, *Cervus elaphus*, *Dicerorhinus* sp., and aquatic birds. In the lowest level, almost on the bot-

tom of the river basin, they also found a fragment of parietal bone from a human skull. Overall, about 2,200 bones and over 1,700 lithic tools were recovered. Due to the river nature of the deposit, they show a secondary deposition with different degrees of rounding.

In terms of the number and size of finds, the animal species that symbolizes the site is the ancient elephant (*Palaeoloxodon antiquus*), represented by remains of tusks (25 whole tusks and 50 fragments), molars (60 intact molars, 120 fragments), fragments of the pelvis and skull and the long bones (Gioia 2004).

After arranging the site protection and security measures as early as 2000, a museum path was erected to properly communicate the complex issues resulting from the site. Verbal and visual communication was selected to get the most out of the new technologies (ICT). Visual and/or interactive communication aimed at involving visitors as much as possible to keep their attention.

State of the Art

ICT reconstruction and the interactive and multimedia communication of archaeological areas draws upon some experiences that have been characterizing the city of Rome in recent years. ICT does have a great “democratic” potential due to both its ability to handle a large amount of information and offer new access modes. The digital processing of information allows users to enjoy “worlds” created from paths and ways that they select. Those who curate a museum staging may either establish a guided path or leave the user free to navigate, move, and dive into familiar stories with the desired level of depth. Visitors decide the level of interaction with the scenario, possible mode of navigation, automatic tours, and specific point-of-view details. This freedom to browse a museum is very different from what was available just a few decades ago. Unless they followed a guide, visitors were left alone. They were supposed to have a specific background in order to enjoy and understand the artistic and cultural heritage on exhibition. Today, the amount and quality of information and “views” that the new museum offers can be best enjoyed by any type of user, whatever their level of knowledge. The multimedia reality, with its new communication quality on the one hand, and the ability to accommodate a greater amount of information on the other, turns the museum into a truly novel, indisputably, democratic system.

Some projects have been implemented in Italy to allow visitors to experience archaeological areas in new ways, made possible by the latest multimedia and interactive technologies.

Among these, the following are relevant for the purposes of our research: Roman Domus at Palazzo Valentini in Rome; Exhibition ‘Forum of Augustus. 2000 years ago’, Imperial Fora of Rome; Exhibition ‘Journeys into Ancient Rome’, Imperial Fora of Rome. The Roman Domus located beneath Palazzo Valentini (built in 1585) in Rome is an example of the restoration and redevelopment of artistic heritage, enhanced through the use of new technologies as a result of a project carried out in 2010. The enhancement was curated by Piero Angela and a group of technicians and experts, including Paco Lanciano and Gaetano Capasso. The project, through virtual reconstructions and multimedia effects, enabled the reconstruction of the mosaics, decorated walls, polychrome floors, basalt

and other artefacts present in the patrician Domus of the Imperial age, located beneath Palazzo Valentini.

Celebrations for the bi-millenary of Augustus’ death (19th August, 14 AD) helped enhance the Imperial Fora with the exhibition ‘Forum of Augustus. 2000 years ago’, from April 22 to October 21, 2014 (Ministero dei Beni e delle Attività Culturali e del Turismo 2014, 2015, 2016). Here, the communication tool was a multimedia installation with a projection on the walls of the Forum of Augustus, representing the history of Augustus and the Forum with lights, films and projection mapping reconstructions. The success of the 2014 exhibition ‘The Forum of Augustus. 2000 years later’, led to the organization of ‘Journeys into Ancient Rome’ (Viaggio nei Fori 2015 and 2016). Reconstructions and videos take visitors back through the history of the excavations carried out to build Via dei Fori Imperiali, when an army of 1,500 construction workers, labourers and other workers were enlisted in an unprecedented effort, razing an entire neighbourhood to the ground and digging it down to the ancient Roman street levels. The exhibition went further back into the story, starting with the remains of the impressive Temple of Venus, whose construction was ordered by Julius Caesar after his victory over Pompey. It showed the emotional experience of life during Roman times, when officials, commoners, soldiers, matrons, consuls and senators walked beneath the arches of the Forum. Among the remaining colonnades there were the tabernae, namely offices and shops and, among these, a nummularius, a kind of currency exchange office. There was also a large public lavatory, with some remains still in existence. The tour tried to recapture the role of the Forum in the life of Romans, as well as the figure of Julius Caesar. To build this great public work, Caesar expropriated and demolished an entire neighbourhood and the overall cost was 100 million aurei, today’s equivalent of at least 300 million Euros. He also wanted the new home of the Roman Senate, the Curia, to be built right next to his Forum. The Curia still exists, and virtual reconstructions show us what it looked like in Roman times.

Research Objectives and Development

Our research aims at identifying one or more representation/reconstruction methods, in lieu of the traditional drawings of animals that lived in the Pleisto-

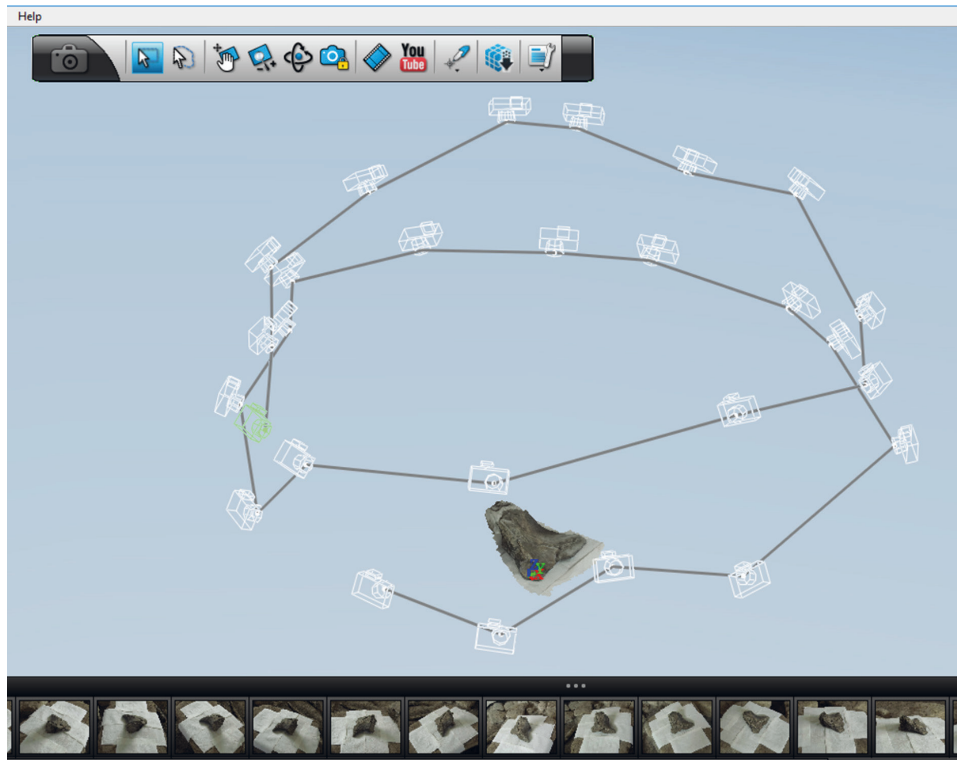


Figure 1. Stereometric frames obtained with 123D Catch (Image processed by M. Camicioli).

cene Deposits (Manzi, Salvadei, & Passarello 1990). In particular, our attention focused on the Pleistocene Museum of Casal de' Pazzi in Rome, where remains from 200,000 years ago had been found. The first part of this research focuses on the 3D reconstruction of the animals, the second one on the use of 3D models for multimedia communication outputs describing the history of the site (e.g., Lock 2003). Given the presence of some artifacts and fossils, 3D modeling allows us to reconstruct the animals that lived in the bed of the river (Emler 2006). In particular, the reconstruction process focuses on an "Ancient Elephant", a "Urus" and "Neanderthal Man". Modeling is based on scientific data and, when those data were absent, the models benefited from the expertise of paleontologists and anthropologists, who had followed the whole 3D procedure.

The research consists of the following phases:

- Identification of "references";
- Survey of objects present in the deposit;
- Realization of models based on low resolution "low-poly";
- "High-poly" modeling through "digital sculpting";
- Retopology and reprojection of details;
- Texturing;

- UV mapping;
- Rendering.

Identification of References

The first part of the reconstruction process is based on the identification of "references." These should be reliable in terms of the size and shape of the animals under study. In most cases, the "references" of an object to be modeled are assumptions previously hypothesized by other scholars who have had the opportunity to define and redefine based on new discoveries the most plausible appearance of any animal being studied. To make 3D models of the most important finds in the areas of Casal de' Pazzi, such as the ancient elephant, the urus, and the Neanderthal, reliable reconstructions had to be put together. They needed to show the following views:

- image of the animal, front view;
- image of the animal, perspective view;
- image of the animal, 3/4 view.

The type of "references" can be of a varying nature, such as a graphic reconstruction or a photograph. Most importantly, they need to be as reliable and consistent as possible with respect to the number of views listed above. Where there is an inconsistency



Figure 2. Low-poly models of the finds (Image processed by M. Camicioli).

or reconstruction gaps, the opinion of paleontologists or anthropologists becomes crucial.

Survey of Objects Present in the Deposit

In regards to the 3D survey of the finds existing in the site, a photomodelling (Sammarco 2012) procedure was used. It consists of taking photos following some specific techniques:

- Take photos in a circular pattern;
- Take pictures at a minimum of 2 different levels in height;
- Take pictures at the same angle from one another (30/45°);
- Have an adequate ambient lighting (not too much light, not too much shade);
- Take several photos (at least 50) and some additional pictures for poorly visible details.

Before the shots, it is advisable to surround the finds with white cloths or paper sheets, to distinguish them from the surrounding environment. At the end of the “shooting”, photomodelling can be obtained with appropriate applications like Autodesk “123D CATCH” (Meneses 2013), among others. The photomodelling software generally returns files in .obj format, which can be used by most 3D modeling applications (Figure 1).

Realization of Models Based on Low Resolution “Low Poly”

The first phase of 3D modeling provides for the gen-

eration of models based on low resolution “low-poly” (an abbreviation for “low polygon”, i.e., a 3D model consisting of few polygons).

The procedure involves the following steps using 3D Studio Max (Segatto 2016):

1. alignment of front and perspective “references” in their respective views (front and side, right or left), so as to form a right angle between them;
2. insertion of the 3D model of a parallelepiped (Box), positioned between the two images and scaled in such a way as to have its sides aligned with the contours of the figures, both in the front and perspective view;
3. duplication of “edges”, i.e. of the sides, of the “Box” and alignment along the contours of the figure, alternating the front view and the perspective (the greater the number of duplications of the sides, the more precise the border alignment). The “symmetry” command allows choosing an axis to reflect the modeling operation and minimize 3D modeling (Figure 2);
4. division of internal “edges”, i.e. the sides of the polygon faces, to increase the “density” of the mesh and make it “softer”.

This phase yields a low-poly model with the following characteristics: Low-poly Ancient Elephant: 37,800 polygons; Low-poly Urus: 1,208 polygons; Low-poly Neanderthal: 1,348 polygons.

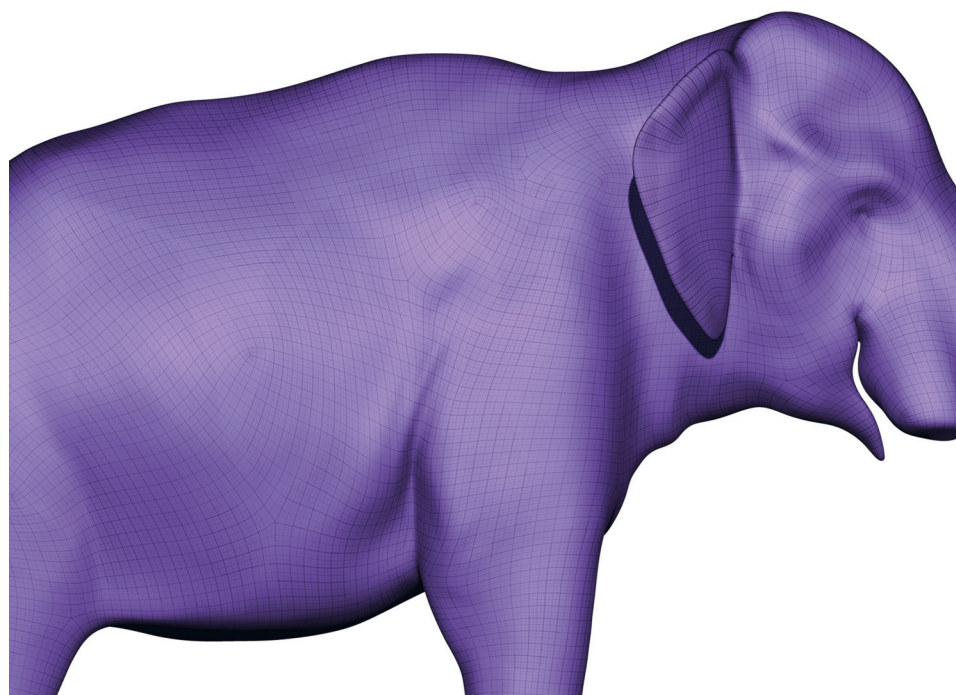


Figure 3. Levels of subdivision: Level 1: 20,000 polygons ca.; Level 3: 350,000 polygons ca.; Level 5: approx. 6,000,000 polygons (in the image) (Image processed by M. Camicioli).

“High-poly” Modeling Through “Digital Sculpting”

At the end of the low-poly modelling step, with models made up of a small number of polygons, high-poly modeling increases the number of polygons of the mesh. This phase takes longer, given the higher complexity of the mesh resulting from the additional quantity and quality of details needed to make the model more “realistic”. It is necessary to import low-poly models into a different software for “artistic” modeling, such as Zbrush (Keller 2011). Zbrush has a number of “tools” that allow one to “sculpt” very fine and complex details on the surface of the model (this is why it is called “digital sculpting”). To generate a video output, some parts of the models should be modeled separately rather than sculpted inside the mesh; for example, the eyes and clothing of the Neanderthal must be modeled as separate “tools”, albeit being part of the mesh. In this way, they can be animated independently.

First Step of “Sculpting”: Subdivision of the Mesh |

To sculpt very complex details on the mesh, such as wrinkles, creases or the micro-details of the skin of the elephant, it is necessary to increase the number of low-poly polygons through the “split” command. Upon each subdivision, the number of polygons qua-

druples. Polygons become increasingly smaller and more compact, increasing the density of the mesh.

Second “Sculpting” Step: Modeling and Progressive Sculpture |

As a rule, the mesh should not be split too many times all together; subdivisions should be performed from time to time, depending on the type of detail to sculpt: at the lowest levels of subdivision, the ‘larger’ details can be modeled. For example, the anatomical features (limbs, fingers, tails, and so on) whereas at higher levels, smaller and finer details are applied. This avoids a “pixel-looking” mesh, which should rather appear clean and uniform. As to sculpting and modeling, ZBrush offers the “brushes” tool that provides a great variety of features and options (Figure 3).

Third “Sculpting” Step: Micro-Sculpture Through “Alpha” Brushes |

After modeling the general structure of a character, micro-details are subject to the final sculpting, such as the sculpture of the porosity of the skin, wrinkles, creases, and hair. Zbrush offers special brushes called Alpha. Unlike normal brushes, Alpha brushes sculpt directly on the mesh through the transparency channel. In this case, to create the full pattern of the creases of the elephant skin, or the fur of the Urus, the brush uses an image of a portion of real elephant folds; the brush is then passed over

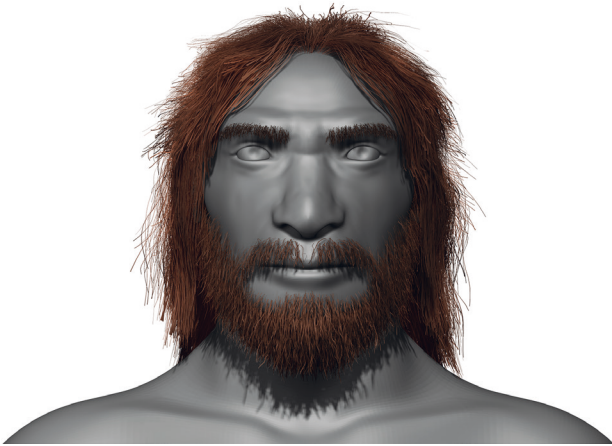


Figure 4. Fibermesh: Neanderthal hair and beard (Image processed by M. Camicioli).

the whole surface to sculpt according to the same fold pattern and a different orientation and scale. This process ends with the creation of a complete pattern.

Fourth “Sculpting” Step: Fibermesh, Creation of the Hair | To confer more realism to animal models (excluding fossils), the Fibermesh command generates the fur of animals and humans (Figure 4). This tool sets the shape, color, type and appearance of the hair to be applied to a selected area of the mesh (the human skull, for example, or the tip of the tail of the two animals). Fibermesh consists of polygons. This makes the file heavier, sometimes compromising the hardware computing performance. We recommend to properly assess the Fibermesh settings, seeking a balance between the fur realistic appearance and the lightness tool. After completing the high-poly phase of the models, through separate tools and Fibermesh, retopology helps prepare the models for the subsequent animation phase.

Retopology and Reprojection of Details

With the described method, the high-poly model goes back to the low-poly step, albeit with different structural characteristics. These are essential to enable an effective animation of the 3D model. At any rate, the high-poly quality is not lost with Retopology, thanks to its subsequent phase of details reprojection. The retopology model allows the rearrangement and decrease in the number of polygons of the mesh. When using a 3D model for animation,

the high-poly model is discarded. In fact, the quality and density of polygons do not allow a smooth walk-through. The low-poly, retopologized model is low-poly like the initial one, but it exhibits different characteristics. The rearrangement and decreased density (quantity) of polygons allows an efficient animation of the critical points of the model, especially the joints.

Retopology must always be carried out from a copy of the high-poly model and can operate in two ways: 1) manual method: polygons are arranged manually one by one (the “symmetry” function halves the work); 2) “fixated” automatic method: polygons are rearranged and decreased through the ZRemesher automatic control; later, some critical points are manually adjusted through the ZModeler command. During the animation phase, the movable parts of the model structure (arms, legs, tail, and proboscis) need a specific topology of polygons for an efficient animation: this is possible thanks to the creation of the edge-loops.

The edge-loops, in a “retopologized” model, are the portions of mesh that connect the mobile section to the whole body. Hence, they indicate the real anatomical joints (junction of arms, legs, tail). An edge-loop must have a higher density of polygons at the attachment of each joint and have a uniform arrangement of polygons (square or rectangles only). The edge-loops allow a smooth and realistic animation of joints. Once the model retopology has been completed, the quality of details of the original high-poly model must be reprojected on to it. To do this 1) the retopology is selected and only the high-poly model is visible, bringing it to the lowest level of subdivision. 2) In retopology you must use the Projects command to reproject on its surface the details of the first layer of the high-poly model. 3) The high-poly model moves to the second level of subdivision while retopology is split; then, the Projects command is activated again. You repeat the last step until retopology has the same number of subdivision levels of the high-poly model (in the case of characters, you can get up to 6 levels). Reprojection returns a single model. At the lowest level, you have a re-topologized model; at the highest level, you have the high-poly model, exhibiting the same quality as the first high-poly model previously generated. At this time the original high-poly model is no longer used.

Texturing

Having the retopology and high-poly in a single model by simply changing the level of subdivision (from 1 to 6 and vice versa) represents another key step for the final realization of the model - the exportation of maps. The texturing step characterizes the mesh through a Polypaint procedure for characters, and Spot Light for bone finds. Polypaint is the command used to color the mesh. It makes use of a standard brush, with the sculpting functions disabled and RGB color enabled. The RGB standard panel spreads the prevailing color consistently across the surface, such as the gray color of the elephant skin. On the other hand, to draw the small details of the skin, tusks and other areas, the Alpha Channel, renamed Alpha RGB is used. As with sculpting, these allow one to repeatedly draw the same module on several parts of the mesh (for example, a portion of skin folds or pores) to finally put together a single pattern.

In this case, the Symmetry function is disabled. Asymmetry of micro-details is not necessary to confer true realism to the model. The Spot Light is the most common way to apply the texture. This technique allows the texturing of fossils. Photos taken to create them in 123D CATCH (Meneses 2013) also allow originating Bitmap Textures, for an extremely accurate coloring, as in the original finds.

The steps involved are as follows:

1. import model and pictures for a clear display of the 6 main views (plant, side prospectuses and bottom);
2. overlay of one of the photos on the view corresponding to that of the model;
3. via the Spot Light function, the model is colored with the picture as a layer above;
4. reduce the photo size to see the result;
5. repeat the above steps for any other available views.

UV mapping

After creating the texture, with a single model in-

cluding a retopologized low-poly model for animation as well as a high-poly, you can get the same high quality of detail of the high-poly model (subdivision level 6) on the low-poly retopologized model (subdivision level 1) through the UV mapping. The generation of UV coordinates, known as UV mapping, is a process to apply a texture or any type of two-dimensional image on a 3D model. Coordinates and the relevant X and Y values are generated on a Cartesian plane (automatically, manually or a combination of both). These are then assigned to each polygon of the mesh; in this way, each polygon has the required coordinates for the assignment of a certain portion of the 2D image. By putting together all polygons in a two-dimensional Cartesian space, one gets the overall space in which the image is applied, or from which the maps of the various characteristics of the mesh are exported.

This process is similar to an unwinding of the 3D mesh on a two-dimensional plane, with contours corresponding to the cuts applied to the model for 2D unwinding. The Polypaint Texture or Spot Light can be created irrespective of the UV maps; in other words, they can be created on the model even before UV mapping, but cannot be exported as image files to be reapplied to the model. This can be done (for other types of maps, too) only after generating the UV coordinates. The UV positioning in a model including both low-poly and high-poly (on two different levels of subdivision) is a prerequisite to transfer the quality of detail of the high-poly to the low-poly model, since the UV coordinates are the same. This transfer of the detail quality occurs during the so-called “baking.”

In this phase, the model achieves its highest high-poly quality to export the various types of maps, each referring to a specific characteristic of the mesh: Texture Map (color map); Normal Map (map of normals); Displacement Map (map of polygonal deformation); Cavity Map (map of “excavated” details); Ambient Occlusion Map (shadow application map). After exporting these maps from the high-poly model and applying them to the low-poly (thanks to their shared UV), the latter acquires the properties and quality of detail of the high-poly model, while the number of polygons remains unchanged. Therefore, the resulting model has a high-poly quality and the low density of polygons of a low-poly. This is the type of model required to proceed with animation.

Rendering

During the animation phase, the maps are applied after the various sequences, to maintain the file light, without compromising the fluidity of the animation process (Empler 2006). However, to get an idea from the outset of how the model will appear during rendering, maps are applied for an initial preview, and once applied, can be edited (Brito 2010). Each map includes a series of editable parameters (e.g., a higher or lower intensity, or a different brightness or color range). By implementing various combinations of the map parameters, and the various maps, the model can take on a completely new look, since it is influenced by the interplay of several factors.

Finally, the choice of material to apply to the mesh (Siddi 2010) is equally important for the final quality of the model; a suitable choice allows an ideal simulation of “real” parameters, like the bounces of light on the surface, or the quality of shadows between the various parts of the model. Once the low-poly, retopologized model is complete with the high-poly maps to apply on top, the model is ready for preparation for the animation. However, if you also need to realize explicative rendering images of definitive models, you can also use a simple high-poly model. The low-poly and its textured maps do not exceed the high quality of detail of a high-poly model. The rendering output results from the retopologized model. It is brought to the highest level of subdivision of the high-poly, i.e. the maximum quality. After “baking” maps and exporting the low-poly, retopologized model as an .obj file, preparation for the model animation begins. This step precedes the animation proper and includes a number of steps to make the model fully mobile.

Instead of Zbrush (Keller 2011) modeling software, Maya offers a better performance during animation. Since the video is not complete yet, we will analyze only the phases immediately preceding the animation, to get a preview of the result.

First Step: Creation of Joints | Once you have imported the low-poly model into the Maya animation software, the skeleton, consisting of joints, is created. The skeleton, composed of various joints and individual bones, should not necessarily be too faithful to the true skeleton of the real animal; however, while

limiting the number of joints, they should be placed properly, for example in the junctions, to faithfully reflect the junction points of the true skeleton. Several graphic reconstructions of the skeleton of the two animals and the Neanderthal have been collected for this purpose.

Second Step: Orientation of the Joints | Once the skeleton is ready, it is necessary to orient every single joint, to obtain an accurate rotation. Specifically, the axis (X, Y and Z) of each joint must be aligned with those of the other joints, especially those that are part of the same chain. A chain, in this context, is a series of joints arranged along the same direction until they are interrupted by another chain that is connected but oriented in a different direction. In other words, there exists a chain for the arms, one for the legs, one for the bust, and so forth.

Third Step: Skinning | After preparing the skeleton and orienting each joint, the so called “skinning” begins. A given portion of the mesh is assigned to a matching joint. This connection between joint and portion of the mesh is performed by painting that portion of the mesh. The edges are colored in blue (zero influence) while the central body is red (maximum influence). They are then shaded with hues of green and yellow. To begin skinning, you need to push the Smooth Bind command. It performs a first automatic skinning that can be manually changed according to your needs.

Fourth Step: Rigging | The last step to prepare the model for the animation is the composition of the rigging. The creation of manual commands (called “handles”) connected to the joints, through the previous skinning, allow the various parts of the model to move. The rigging phase is essential to allow the widest range of movements of the various parts of the model. From here onwards, the model is moved, or better, posed for the different frames, until animation ends (see Figs. 5-7).

The completion of the rigging of characters starts the animation proper. First of all, it is necessary to preset certain elements such as the creation of the background, the screen resolution, and the lighting. The preview, in the form of Animatics, shows its structure and the surrounding scenery.

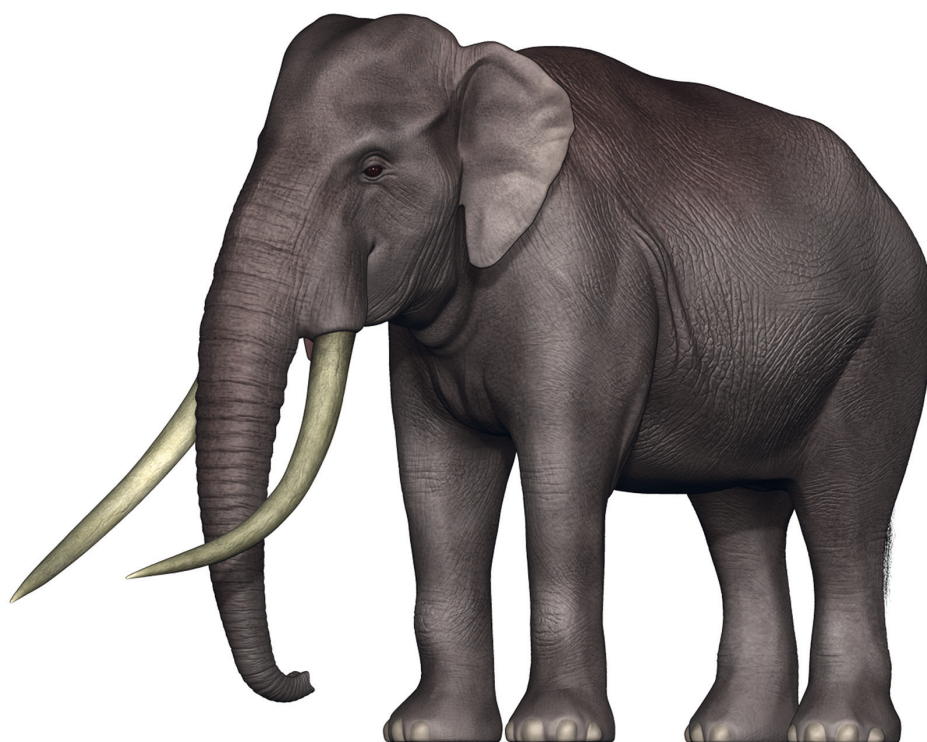


Figure 5. Rendering of the ancient elephant (Image processed by M. Camicioli).



Figure 6. Urus rendering (Image processed by M. Camicioli).

Conclusions

As we have seen, the potential of 3D modeling in the field of Paleontology is considerable. It is possible

to reconstruct the appearance of an animal starting with the fossils recovered in a prehistoric deposit and integrating data with elements on the muscles and skin taken from the literature or from references



Figure 7. Rendering of Neanderthal (Image processed by M. Camicioli).

found at other sites. When this is not sufficient, paleontologists and anthropologists give their advice. 3D models, as previously illustrated, can generate videos in which the life of animals in the environments in which they lived has been reconstructed. A further important aspect relates to 3D printing. In this case, research can follow two directions. On the one hand, the production of 3D prints of reconstructed animals

(with muscles and skin) produces physical objects. In turn, they can undergo a manual transformation in the event experts believe that some parts need to be modified in the light of new findings or new research outcomes. The second option is the reconstruction of the missing parts of bone finds. Bone and muscle reconstruction assumptions can be tested differently from traditional techniques.

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