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Using a morph-based animation to visualise the face of Pharaoh Ramesses II ageing from middle to old age

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ABSTRACT

Ramesses II was one of the most important Pharaohs to have presided over Egypt during the New Kingdom period. In 2023 researchers Wilkinson, Saleem, Liu and Roughley produced two digital 3D facial depictions showing Ramesses II at different ages: one around the age-at-death at 90 years old and the other, an age-regression at approximately 45 years old, based CT scans of his mummified remains, photographs, and historical information. The presence of two 3D facial depictions of one ancient individual at different ages affords an opportunity to show how Ramesses II might have looked during key moments of his lifetime and just prior to death. This paper describes the workflow adopted to add realistic textures to the facial depictions, and to use a morph-based animation to represent Ramesses II ageing from 45 to 90 years old.

1. Introduction

The Great King of Egypt named Pharaoh Ramesses II (Kitchen, 1995; Langdon and Gardiner, 1920; Tyldesley, 2001), commonly spelled Rameses II (Norbo'tayev, 2022; Shaw and Bloxam, 2020) or Ramses II (Habicht et al., 2016; Pääbo, 1988; Santillian and Thomas, 2017), and also known as Ramesses the Great (Mihalik and Wing-Vogelbacher, 1993) or Ozymandias in Greek form (Griffiths, 1948; Robinson, 2022), was one of ancient Egypt's most powerful and celebrated pharaohs. He reigned for 66 years, from around 1550 BC to 1069 BC during the New Kingdom period, and was the third pharaoh of the Nineteenth Dynasty (Rowton, 1948). Today, Ramesses II is remembered as one of ancient Egypt's greatest pharaohs, not only for his military prowess and expansive building projects, but also for his lasting impact on Egyptian culture and history (Tyldesley, 2001).

The mummified remains of Ramesses II were discovered in 1881 in the Deir el-Bahri cache (DB320); a tomb in the Valley of the Kings (Tyldesley, 2001), and they are now located in the National Museum of Egyptian Civilization in Cairo, Egypt (https://nmec.gov.eg/mummies-hall/ramses-ii/). Ramesses II is one of the most well-preserved examples of royal mummies ever found (see Fig. 1) and his remains have provided valuable insights into ancient Egyptian funerary practices, including the embalming techniques used during his lifetime (Saleem and Hawass, 2015). Significantly, scientific analysis of the mummified remains revealed information about the health (David et al., 2010; Saleem and Hawass, 2014) and the physical appearance of one of ancient Egypt's most renowned pharaohs (Wilkinson, 2008; Wilkinson et al., 2023).

1.1. Facial depictions of ramesses II

Ramesses II's mummified remains have been the subject of scientific inquiry for decades (David, 1986, 2009; Pääbo, 1988; Saleem and Hawass, 2014, 2015; Wilkinson et al., 2023). Like other well-known Pharaohs, such as Tutankhamun, and fuelled by his popularity and cultural significance, a variety of facial depictions have been produced from his remains using different methods. The exact number of facial depictions may vary as new reconstructions are continually produced by different practitioners. Additionally, the accuracy and level of detail in these depictions can differ based on the available data and the expertise involved. For example, in 2004, a 3D digital facial reconstruction based on cephalograms was produced by Caroline Wilkinson, for a Discovery Channel documentary titled "*Rameses: Wrath of God or Man*?" about tomb (KV5) and the sons of Ramesses I (https://www.nbcnews.com/id/wbna6614215). Then in 2021, digital character artist Curtis Durane produced a likeness (https://curtisdurane.artstation.com/projects/68D9qr) based on photographs of the mummified remains, which gained international media coverage. While the latter did not follow the scientific methods used in the former, both utilise similar

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3D CGI techniques to bring the face of the Pharaoh to life, and both circulate online, reaching audiences to further debate his possible appearance.

In 2023, Wilkinson et al. produced an updated 3D facial depiction of Ramesses II. This built upon the existing 2004 facial depiction, which was created using Geomagic Freeform software (https://uk.3dsystems.com/software/geomagic-freeform) and its accompanying haptic sculpting peripheral almost 20 years ago. The new depiction capitalised on recently available CT imaging of the Pharaoh (Wilkinson et al., 2023). The software and its accompanying haptic interface have continued to be used by Wilkinson since 2004 due to a number of affordances that make it an ideal choice for facial reconstruction (Roughley and Wilkinson, 2019). It was therefore possible to import the new skull model obtained from CT imaging into the same 3D scene in Geomagic Freeform as the original 3D face model. The 3D skull model was used to develop an updated 3D digital facial reconstruction at the age of death; elongated spherical models of 24 mm diameter were set into the eye sockets, at normal protrusion to act as eyeballs (Wilkinson and Mautner, 2003) then, guided by the tissue depth markers, facial muscles from a database were modified to fit the skull (Mahoney and Wilkinson, 2012), and facial features and facial adipose tissues were sculpted following standards and blended to create a skin layer (Rynn et al., 2009; Gerasimov, 1955; Fedosyutkin and Nainys, 1993). This method allows for the production of a facial depiction of Ramesses II with greater accuracy than the 2004 facial depiction (Lee et al., 2012; Wilkinson et al., 2006). The outcomes are shown in Figs. 2 and 3 (see Wilkinson et al., 2023 for detailed description of the facial reconstruction process).

An age regression of the 3D facial depiction was also produced to reverse the signs of aging depicted in the 90-year-old face. Research (Albert et al., 2007) shows that age-related changes occur due to loss of skin elasticity, subcutaneous fat redistribution, buccal fat pad descension, and tooth loss. An older person will tend to have a less upright posture, with narrower shoulders and thinner neck. General soft tissue changes include a less firm lower jawline, more concave profile, hollow cheeks, smaller jaw, longer nose and ears, thinner lips, deeper facial folds and creases and increased wrinkles (Ilankovan, 2014). Geomagic Freeform software's sculpting tools were utilised to move the shoulders and neck, and lift skin around the neck and cheeks; reversing the characteristics and qualities of aged skin to depict a younger face of Ramesses II at approximately 45 years old, as seen in Fig. 4 (Wilkinson et al., 2023). This process was entirely sculptural as the average facial tissue depth data for this population does not distinguish between different adult ages. Sculptural changes were carried out to reflect known ageing patterns in reverse; the younger face was depicted with a stronger, firmer jawline, shorter nose and ears, fuller cheeks and lips, fewer wrinkles, less defined facial folds and creases, and darker, fuller hair.

The presence of two 3D facial depictions of one ancient individual at different ages is uncommon. Two depictions of the same individual allow audiences an opportunity to see how the individual might have looked during key moments of their lifetime. Showing the surface shape and textures of Ramesses II's skin 'ageing' could captivate the public and facilitate a more relatable connection with him; providing a tangible link by depicting him as he might have appeared at different life stages.

However, the 3D model meshes of the faces sculpted in Geomagic Freeform are not conducive for animation and require retopology for blend shapes to be produced. Additionally, the models are untextured with 'smooth' appearance, lacking the realistic skin, eyes and hair (see Figs. 3 and 4), which are noted to increase perceived realism of a facial depiction and for the public to consider the face as 'believable' (Anderson, 2012).

Digital painting of skin and the creation of virtual eyes and hair would increase realism; however, the 3D model meshes generated in Geomagic Freeform are also not suitable for the painting of realistic skin, nor can eyes and hair be generated in the software, therefore work would be needed in additional software to be able to create a realistic appearance and to also animate the depictions. The aesthetic appeal of a facial depiction is often an important aspect for reception of the individual by the public, which is a priority for museums and media companies who commission such works for public encounters (Redfern and Booth, 2023).

Fig. 1. Photographs of the mummy of the pharaoh Ramesses II in Cairo Museum (2008). Image sourced from the "Catalogue General Antiquities Egyptiennes du Musee du Caire: The Royal Mummies" by G. Elliot Smith. Available under Creative Commons licence at: https://commons.wikimedia.org/wiki/File:Mummy_of_Ramesses_II_-_02.JPG.

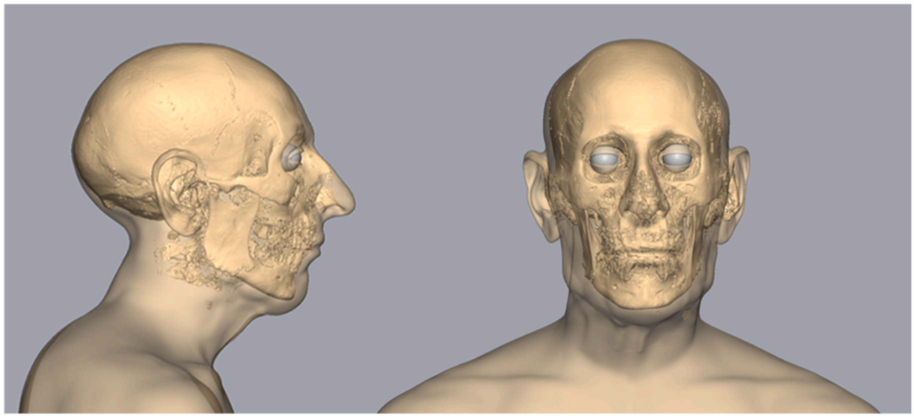

Fig. 2. 3D facial reconstruction of Pharaoh Ramesses II showing the skin layer opaque to see the underlying skull.

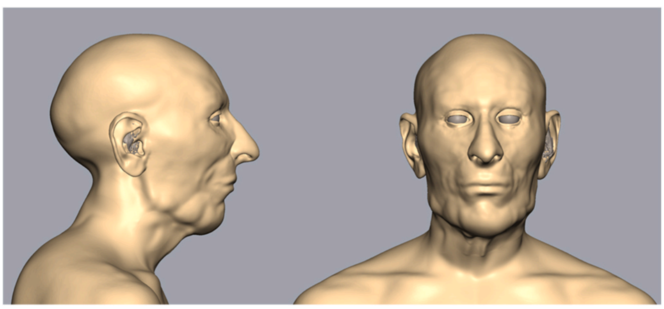

Fig. 3. 3D facial reconstruction of Pharaoh Ramesses II at the age of death, prior to the addition of sculpted skin details and digital painting.

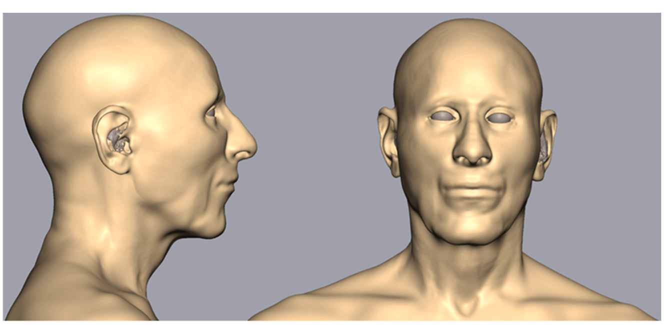

Fig. 4. 3D age regression face model of Pharaoh Ramesses II at approximately age 45, prior to the addition of sculpted skin details and digital painting.

The methods for creating a morph-based animation between two realistic appearances of Ramesses II at both ages are described in the following sections. This includes the workflows used to digitally create skin and hair in Pixologic ZBrush and Autodesk Maya, including the animation of the two new 3D facial depictions of Ramesses II to suggest ageing from 45 to 90 years old. A morph-based animation approach capitalises on the presence of two facial depictions of one individual at different ages, and the technological affordances provided by the digital 3D workflow used to produce the facial depictions.

2. Methods

2.1. Digitally sculpting and painting the skin of the 3D facial depictions using ZBrush

Digital sculpting and painting software are used extensively to 3D model digital characters or digital avatars for public interaction on screen and in games. ZBrush (https://www.maxon.net/en/zbrush) offers several tools that make it a popular choice for artists and researchers producing 3D facial depictions of ancient people as it allows for the addition of high-fidelity textures based on available information from the archaeological record (Aidonis et al., 2023; Martínez-Labarga et al., 2021; Smith et al., 2020). It can also prepare 3D face models for animation. Such tools include.

- ***Intuitive and flexible sculpting tools*:** ZBrush provides a wide array of intuitive sculpting brushes and tools, allowing artists to create intricate skin details and manipulate 3D model meshes with ease (Lindsay et al., 2015; Roughley and Wilkinson, 2019; Roughley, 2020; Roughley and Liu, 2022). This level of control is also essential for accurately representing facial features and expressions.
- ***High-resolution sculpting and dynamic topology*:** ZBrush excels in handling high-resolution models, which is crucial for sculpting fine details on a 3D face. The software's efficient handling of polygon counts allows artists to work on complex facial geometry without significant performance issues (Vernon, 2011). ZBrush also offers dynamic topology, a feature that automatically adjusts the polygon density as you sculpt (Lindsten, 2018). This enables artists to focus on creating organic shapes without worrying about the underlying mesh structure, facilitating a more natural approach to face modelling that is similar to sculpting with clay or wax (Spencer, 2010; Keller, 2011; Kingslien, 2011; Mahoney and Wilkinson, 2012; Kimball, 2019; Roughley and Wilkinson, 2019; Smith et al., 2020). In addition, ZBrush utilizes subdivision surfaces to smooth and refine the model while retaining the high-resolution details and can also be used to generate cleaner meshes from CT data (Erolin, 2023a).
- ***Sculpting layers*:** ZBrush supports sculpting in layers, which enables artists to work non-destructively by adding or removing details on separate layers. This allows for easy experimentation and iteration during the modelling process, and in sculpting skin details; from primary, to secondary and tertiary forms, to create a realistic appearance of human skin (Kingslien, 2011; Spencer, 2011; Roughley, 2020).
- ***Digital painting capabilities*:** ZBrush includes user-friendly digital painting tools that allow artists to add textures, colour, and other surface details directly to the surface of the 3D face model using the 'Polypaint' function or by projecting photographs onto the surface of the model using the 'Spotlight' tool (Johnson, 2014; Erolin et al., 2017; Adams and Erolin, 2021; Erolin, 2023a, Erolin, 2023b). It can also take advantage of a peripheral hardware's pressure sensitivity to paint colour and details with differing intensities e.g. via a drawing tablet (Keller, 2011). This helps in enhancing the fidelity and visual appeal of a 3D face and is akin to painting a portrait using paints.
- ***Morph Targets and Blend Shapes*:** ZBrush allows artists to create Morph Targets and Blend Shapes, which make it easier to pose and

animate 3D character faces with various expressions or to simulate different age groups (Drahoš, 2011; Kingslien, 2011; Spencer, 2010; Spencer, 2011; Patnode, 2012; Ilie et al., 2012; Wisetchat, 2013; Larsson, 2017; Roughley and Liu, 2022; Sarkkomaa, 2022).

The 3D facial depiction models of Ramesses II produced by Wilkinson et al. (2023) were exported from Geomagic Freeform as OBJ files to be prepared for digital sculpting and painting of the skin and the generation of blend shapes for later animation. The OBJ models exported from Freeform have non-standardised or 'messy' meshes, which are unsuitable for high resolution sculpting and animation. In addition, both models need to have the same base topology to allow for animation between them using Morph Targets and Blend Shapes in ZBrush. First, retopology of the surface mesh of the younger face model was undertaken in Autodesk Maya (https://www.autodesk.com/products/maya/) using the Quad Draw tool (https://help.autodesk.com/view/MAYAUL/2024/ENU/?guid=GUID-74867E07-5CCD-4D55-B60B-C90C3AD65DF4) to generate a new low-poly retopologised surface mesh, which was then exported as an OBJ file.

This file was imported into ZBrush as a Subtool. In the same document, the un-retopologised surface mesh of the older face model from Freeform was imported as a second Subtool (see Fig. 5). The models were then positioned on top of each other and, using the 'Projection Master' in the Subtool panel, the topology from the younger face model was projected onto the older face model. This creates two low polygon meshes with the same polygon count and layout but with different appearances (Fig. 6). The next step was to subdivide the meshes by choosing 'Subdivde' from the Geometry panel and to repeat the 'Project' and 'Subdivde' steps until a higher subdivision count was present on both models for digital sculpting of high-resolution details or 'tertiary forms' (Roughley, 2020). In total, 7 subdivisions were generated for both models and a UV map was generated in the ZPlugin > 'UV Master' for the younger face model, choosing 'Symmetry' and using control painting to ensure that any seams generated were located on the back of the head, away from any facial features.

Before any digital sculpting or painting could take place, the 3D models needed to be stored as Morph Targets for later animation using Blend Shapes. To do this, each low poly mesh was exported from ZBrush as OBJs (taking the UV map with the younger face model). A new ZBrush document was opened, and the younger low-poly mesh was imported as a Subtool. With the model selected in the Subtool panel, in the Morph Target panel 'StoreMT' was selected. Next, with the younger face model still selected in the Subtool panel, the older retopologised mesh was imported over the younger face model subtool. In the Layers panel, layer one could be altered to enable a morph between both young and old model meshes; by altering the values of the stored morph target on layer one from 0 to 1 and back.

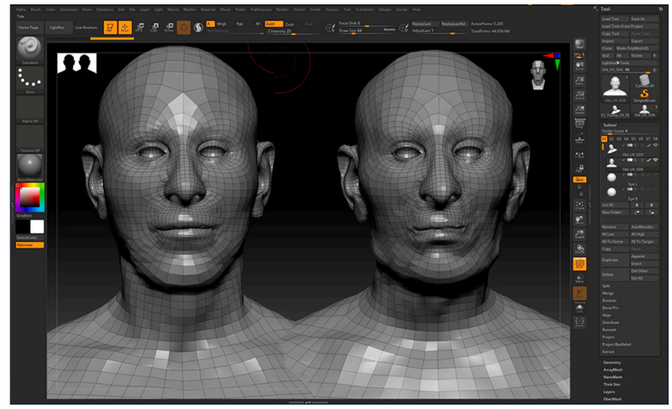

Fig. 6. ZBrush screenshot showing the low-resolution retopologized younger and older face models after topology projection.

With the layer one value set to 0, the highest subdivision selected, and the Zadd or Zsub sculpting option chosen in the toolbar, sculpting the skin for the younger face could begin. Following methods outlined by Roughley (2020) and Roughley and Liu (2022), and using the human skin digital brush pack available from character artist, Pablo Munez (https://pablander.selz.com/item/zbrush-skin-brushes-pack/), high resolution microdetails were sculpted, altering intensity and brush size throughout. Tertiary details were added, including the criss-cross patterning of the skin, mostly around the eyes, and stretched pores/-larger pores around the forehead, nose and mouth regions appropriate for this age (Neave, 1998; Wilkinson, 2005; Naini, 2011) and based on visual review of images and CT scans of the mummified remains (Wilkinson et al., 2023) (see Fig. 7). As some sculpted details from Geomagic Freeform were lost during the retopology process, some additional secondary forms were sculpted using the 'Dam Standard' brush and additional skin alphas and brushes available from ZBrush Guides (https://www.zbrushguides.com/resources/zbrush-skin-brushes-pack), such as the 'Wrinkle' and 'Lip Detailer' brushes. Some areas were masked to allow for more focused micro-sculpting and to not add unwanted details to the surrounding areas of the face.

In the Layers panel, the value of layer one was toggled from 0 to 1. The model then morphed to the older face model, bringing with it the sculpted skin details. Now, at an older age, further tertiary and secondary skin details could be added until the face appeared to be that of a 90-year-old, including the deepening of wrinkles, increased skin roughness and sagging tissues around the neck, nasolabial folds and neck (Neave, 1998; Wilkinson, 2005; Naini, 2011) (see Fig. 8).

The next step was to paint the skin colour. Following the same

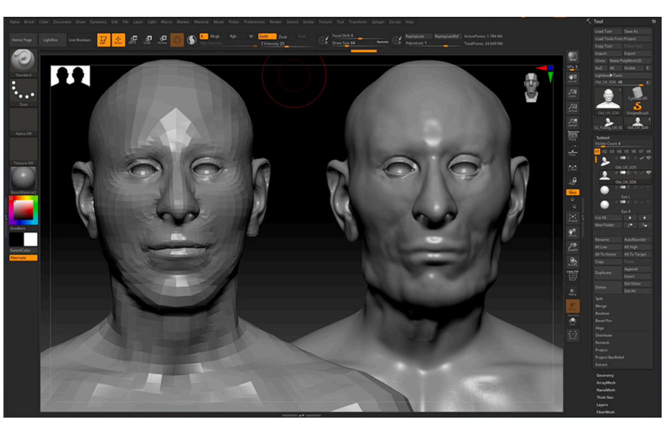

Fig. 5. ZBrush screenshot showing the low-resolution retopologized younger face model from Maya, adjacent to the un-retopologized older face model from Freeform, prior to topology projection.

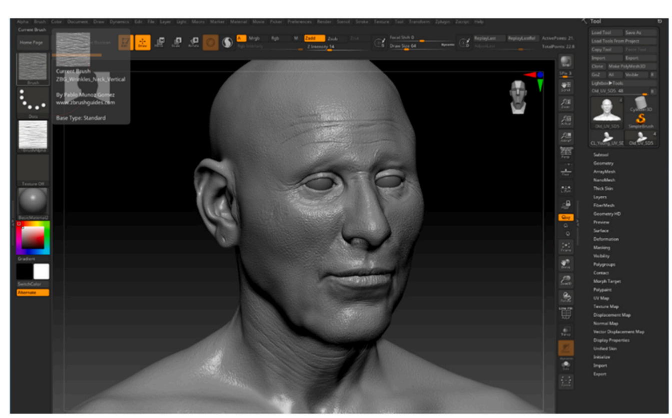

Fig. 7. Sculpting skin surface details onto the younger facial depiction of Ramesses II in ZBrush.

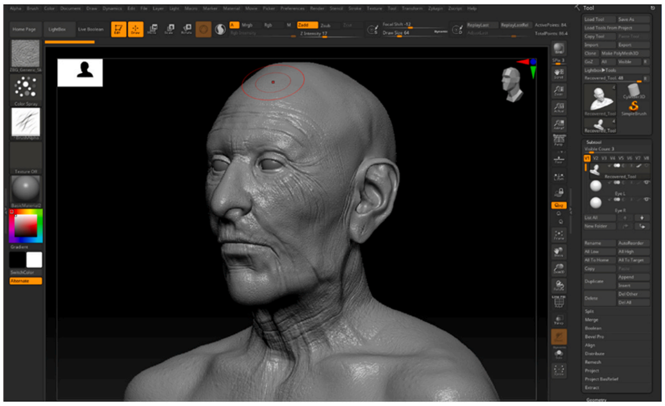

Fig. 8. Sculpting skin surface details onto the older facial depiction of Ramesses II in ZBrush.

process, the layer one value was set to 0 and using the same skin brushes and alphas but with Zadd/Zsub turned off and RBG Polypaint selected in the toolbar, skin colour and textures were painted based upon the well-preserved soft tissues of the Ramesses II's mummy that exhibited a honey-brown skin tone base (Wilkinson et al., 2023), with some adjustments made to present a skin texture appropriate for an individual at middle age (see Fig. 9).

In the Layers panel, the value of layer one was again toggled from 0 to 1. The model mesh morphed to the older model but with the painted younger skin visible on the surface of the older face model. Here, age-related skin discolouration and marks were added carefully to suggest advanced age (Fig. 10). Toggling layer one between 0 and 1 allowed for comparison between both ages at a glance, and further painting where required was added until a consensus was reached, and the model could be prepared for export.

A Texture Map and Displacement Map were generated while layer one was set at a value of 0 and the lowest subdivision selected. These maps were then exported using the ZPlugin > 'Multi-Map Exporter'. The same process was followed while layer one was set at a value of 1, creating maps for both the older and younger faces. The Subtool was then exported to Autodesk Maya using GoZ.

2.2. Animating the 3D facial depictions using Autodesk Maya

There are a range of 3D software that can be used to animate digital humans and 'bring them to life'. Autodesk Maya (https://www.autodesk.com/products/maya/)is one software that allows for modelling, animation, simulation and rendering. Its versatility and realism capabilities make it a popular choice for character artists and animators in the entertainment industries, including video game development, film, and TV production. When it comes to 3D face modelling and animation, it offers several key tools.

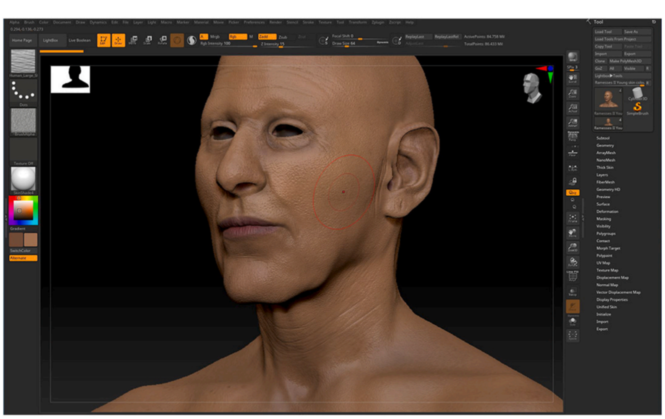

Fig. 9. Digitally painted face model of Ramesses II at 45 years old.

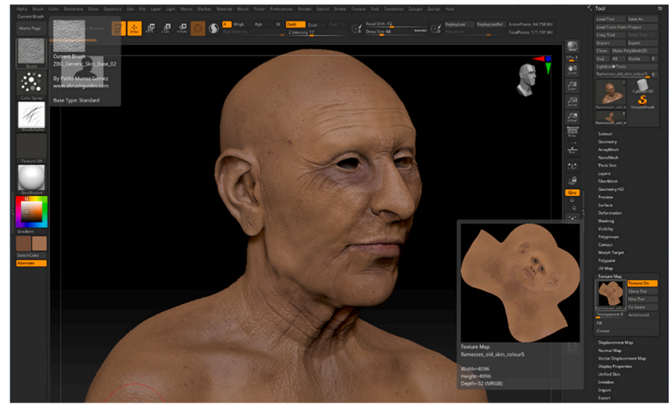

Fig. 10. Digitally painted face model of Ramesses II at 90 years old, with sculpting brushes and UV map highlighted.

- ***Polygonal and subdivision surface modelling***: Maya provides powerful tools for creating 3D models using polygonal and subdivision surface modelling techniques. Artists can shape and sculpt facial geometry, defining facial features and expressions with precision (Gruber et al., 2020; Navic et al., 2022).
- ***UV mapping***: Maya includes tools for texture painting and UV mapping, allowing artists to add colour, textures, and fine details to a 3D face model. Controlled UV mapping is crucial for ensuring that textures are applied accurately to the face model's surface (Šulek et al., 2020; Roughley and Liu, 2022).
- ***Virtual lighting, material shaders and rendering***: Maya's GPU rendering engine 'Arnold', ray tracing-based renderer, uses physically-based material shaders that simulate the properties of materials (Emerson, 2023), including visualisation of the translucency and specularity of human skin and hair. Lighting simulations and ability to edit material shader properties for both skin, eyes and hair, contribute to realism of the final rendered set of still images or video (Roughley and Liu, 2022).
- ***Hair simulation***: Hair and hairstyles play a critical role in self-expression, cultural identity and social identification, and it is important that digital reproductions of hair are able to be styled to meet certain parameters and do not appear stiff, flat or unnatural (Emerson, 2023). The XGen plugin for Maya is a geometry instancer that offers interactive and procedural grooming of primitives to simulate hair (Autdodesk, n. d.). Tools, like brushes and clump modifiers, can manipulate the appearance, positioning and behaviour of hair strands, yielding lifelike outcomes bespoke to the individual (Emerson, 2023).
- ***Animation tools and blend shapes***: Maya offers specialized tools for facial animation such as Pose and Time Editor. These tools streamline the animation workflow and enable animators to work efficiently on complex facial performances (Orvalho et al., 2012; Abdrashitov, 2022). Artists can also create a system of Blend Shapes (also known as shape keys or morph targets) that allow for different facial expressions to be created, keyframed and easily animated between (Lewis et al., 2014; Ma et al., 2015; Cetinaslan and Orvalho, 2020).

Autodesk Maya is therefore a comprehensive 3D animation package that provides a wide range of tools and features for 3D face modelling and animation. For the depictions of Ramesses II, the ability for Maya to receive Morph Targets from ZBrush as Blend Shapes would allow for seamless creation of a key-framed morph animation between two face models at different ages.

Upon export of the Ramesses II Subtool from ZBrush using GoZ, Autodesk Maya automatically opens, and the 3D model is imported into an empty scene. The 'Blend Shape' menu also opens allowing the user to easily test if the exported morph targets have imported correctly by changing the slider from 1 to 0. This is demonstrated in Fig. 11. The duration of the final animation was set to 240 frames using the Timeline. At frame 0 the Blend Shape was set to level 1 and keyframed by clicking on the 'Key All' button. The Timeline slider was moved to frame 120 and the Blend Shape level set to 0.5 then keyframed. The Timeline slider was then set to frame 240, the Blend Shape level set to 0, and then keyframed. The morph animation could now be previewed in the Timeline.

A virtual studio was set up using a plane with a Lambert material shader assigned plus two directional point lights and a directional Camera and Aim. The lights were positioned equidistant from each other, pointing towards the temples of the Ramesses II head model. The lights were set with uneven intensity to ensure a soft shadow was present on one side of the head model, plus a soft blue and red hue to soften the starkness of the lighting. Eye models from Autodesk (https://www.autodesk.in/campaigns/arnold/asset-3d-eye) downloaded and imported into the scene and move into anatomical position. The 3D head and eye models were selected in the Outliner and an aiStandardSurface material with default settings was assigned to each model using the Hypershade window. Test renders using the Arnold rendering engine allowed for tweaks to the settings until a desirable material appearance was reached, with specularity akin to human skin (Roughley, 2020) (see results in Fig. 12).

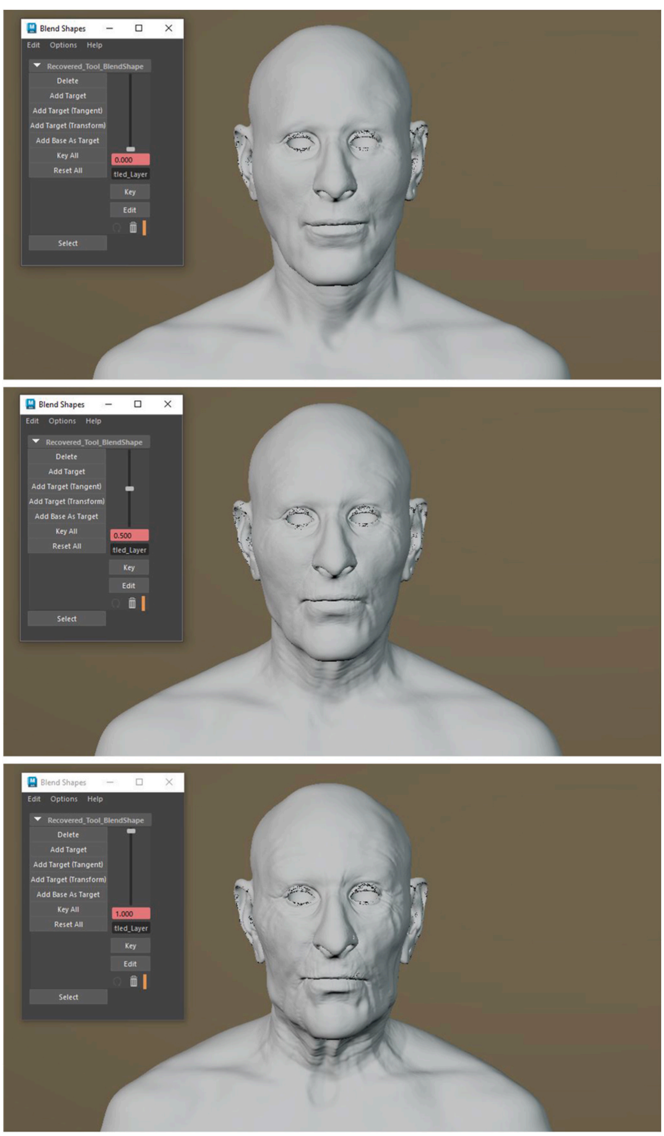

Fig. 11. Three images showing the same 3D head model of Ramesses II but at different blend levels: (R) Blend level 1 showing Ramesses II at 90 years old, (L). Blend level 0 showing Ramesses II at 45 years old, (M) Blend level 0.5 showing the model of Ramesses II blended in between the two ages.

The Texture Maps for the eyes were added to Subsurface Colour in the aiStandardSurface material assigned to each eyeball. To enable the Displacement and Texture Maps for both the 90-year-old and 45-year-old face to appear on the 3D head model at the right time during the blend animation, an aiLayerShader was used in conjunction with aiStandardSurface materials. The aiStandardSurface material assigned to the 3D head model was activated and changed to a 'Skin' preset, with the older face Texture Map assigned to Subsurface Colour. An additional aiStandardSurface material with a 'Skin' preset was generated in the Hypershade with the Texture Map for the younger face attached to the Subsurface Colour. Both materials were plugged into 'Surface Shader' channel in 'Input 1' and Input 2′ on the aiLayerShader. To attach Displacement Maps to the correct shaders, an aiLayerRgba shader was generated in the Hypershade. This was plugged into the aiLayerShader's 'Displacement Shader' channel. Two 'Displacement' shaders were then created, and the Displacement Maps for both the older and younger face added. Each 'Displacement' shader was then plugged into 'Input 1' and Input 2′ on the aiLayerRgba shader (see Fig. 13 for the final node tree).

With the aiLayerShader selected in the Hypershade, the 'Mix' values could be altered to show either the older or younger appearance. With Layer 1 set to a Mix value of 1.000 and Layer 2 set to a mix value of 0.000, the same values applied in the aiLayerRgba shader, and the Blend Shape value set to 1, once rendered in Arnold, the older face appears (see Fig. 14). This was then keyframed by right clicking on the 'Mix' values in each shader with frame 1 selected in the Timeline. Following the same process but with the values switched, the younger face appears (see Fig. 15). This was then keyframed by right clicking on the 'Mix' values in each shader with frame 240 selected in the Timeline. Playing the Timeline showed the morph animation preview in the viewport.

2.3. *Adding simulated hair to the 3D facial depictions using Autodesk Maya*

Henna pigments were found on the mummified hair of Ramesses II and the hair pattern and length was also well preserved (Wilkinson et al., 2023), therefore we were able to depict the Pharaoh's hair based on the mummified remains. Using the XGen geometry instance, hair was generated and styled. Hair can be created using 'XGen Descriptions' and numerous tutorials can be found online (Creature Garage n.d.) as a great learning resource. To create a description, the surface (faces) of the head model must be selected to indicate the area of hair 'growth'. For Ramesses II, seven hair descriptions were created for different areas of the face, this includes: head hair, upper eyelashes, lower eyelashes, eyebrows, sideburns, facial hair, and nose and ear hairs. Each area described has different properties such as colour, length, density, texture, and coarseness. 'Placing and Shaping Guides' control were selected to shape the hair, this control allows users to place individual guides on the surface using 'Add or Move Guide' to sculpt the shape of the hair and the 'Sculpt guides' tool to manipulate the shape of the guide (see Fig. 16).

After all guides were placed, the XGen Preview can be visualised with '*Update*' and '*Clear*' icon. Hair density, length and width can be adjusted under '*Primitives*' (see Fig. 17). To create variable width of each individual hair strands, a random expression '*rand (0.1, 0.2)*' was used in the '*XGen Expression Editor: Width*' (Autodesk, nd). Naturally, hair tapers off towards the tip, and '*Width Ramp*' controls the width from the proximal and distal ends of the hair strands. The curvature of the individual hair strands was increased using the '*Modifier CV Count*', for example, straight hair will require a lower CV count in comparison to curly hair.

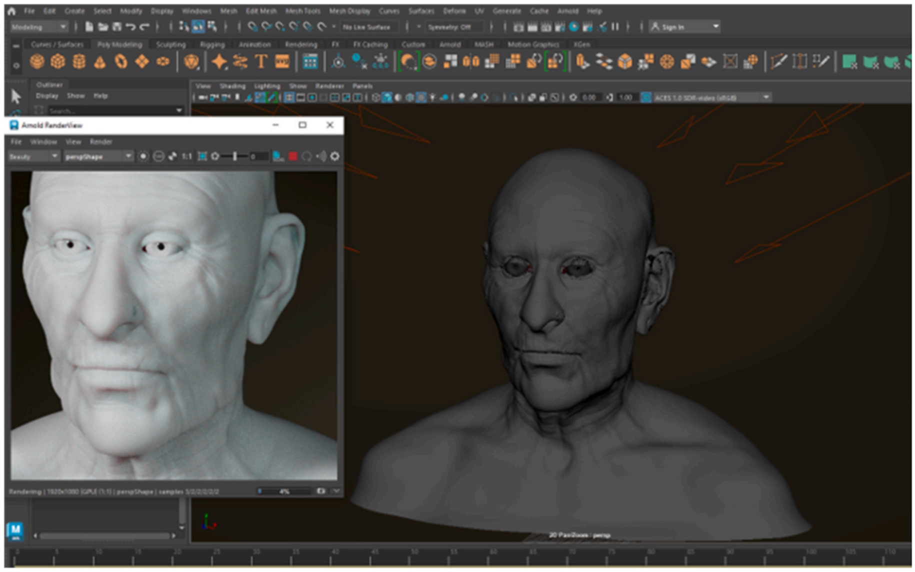

Fig. 12. Results of the lighting, studio and material shader setup in Autodesk Maya, rendered in Arnold.

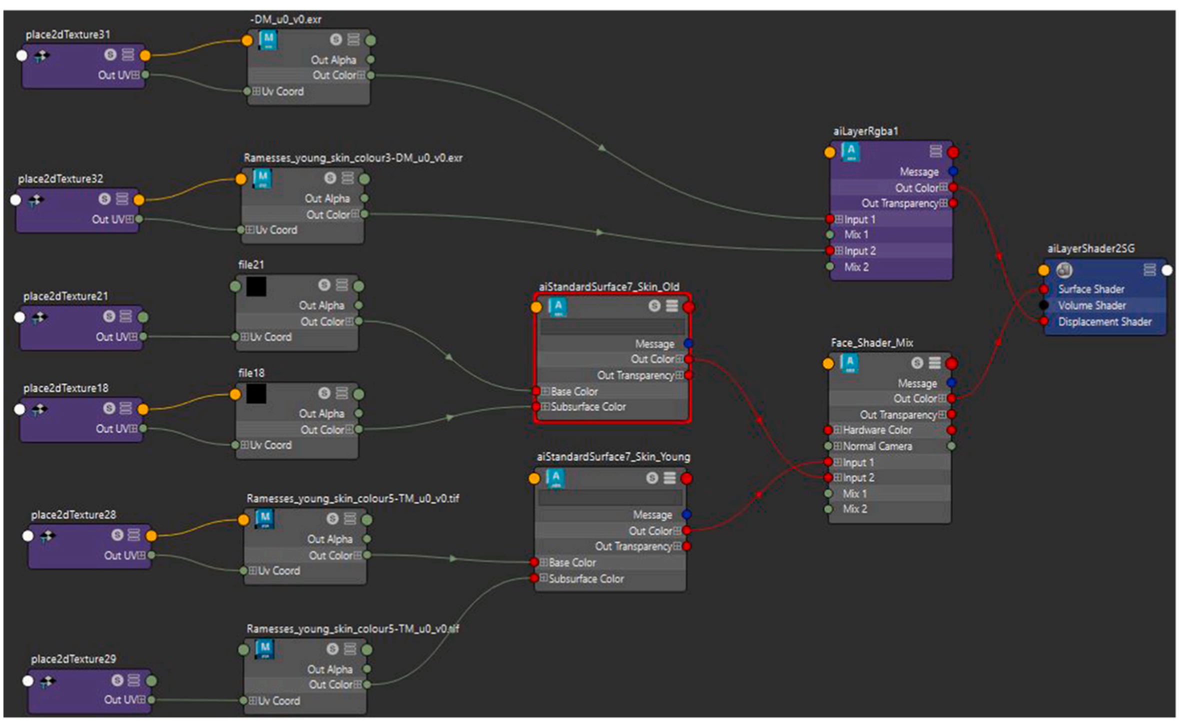

Fig. 13. Node tree with layer mixers for skin shaders and displacement maps.

In this case, a CV count of 100 was used for wavy hair. Generally, this number should be kept as low as possible to reduce computational time. It is important to adjust the CV Count before adding modifiers and noise, so the details of the noise can be visible.

Different areas of the head can have different density. After adjusting the desirable overall density, a mask was applied, black to mask out hair, white to 'grow' the hair. Different brushes were selected to create a variation of density in certain areas of the hairline (Fig. 18).

Modifiers were used to add clumps and noise to create texture to the hair. For the head hair, 3 clumps and 2 noise modifiers were added. The first clump (Clumping 1) follows the guides, and the second and third are set at different density levels (0.03 and 0.01). This modifier dictates the density of the clumping of the hair. The '*Clump Scale*' indicates the strength of the clump form proximal to distal ends of the hair strands, 0.5 is no expression, 0 is strong expression (see Fig. 19).

The first noise added an overall texture to the individual hair strands. '*Frequency*', '*Magnitude*' and the '*Magnitude Scale*' can be adjusted. In this case, a 'random' expression was used to create variation on the waviness of the hair strands. The proximal end of the hair strand had less noise when compared to the distal end of the hair strand (see Fig. 20). The second noise created stray hairs; an expression was used to control the percentage of 'Fly Aways' as described by Creature Garage (n.d.). This expression turns the 'Mask' into a slider for adjustment. The magnitude for stray hairs should be high to create the 'Fly Aways' (see Fig. 19).

Similar techniques were used for the eyebrows and eyelashes (Fig. 21). No clumping was used for these two areas. Short facial hair/

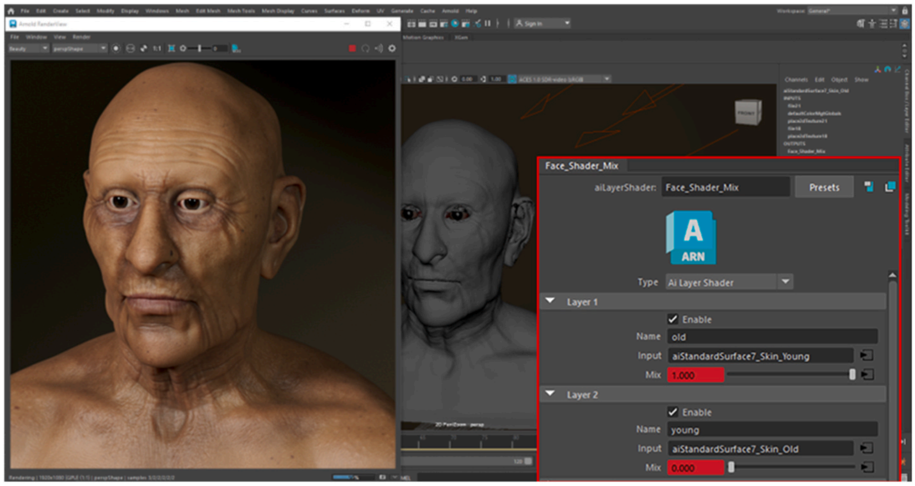

Fig. 14. Model at Blend Shape level 1 with texture and displacement maps attached for the 90 year old face.

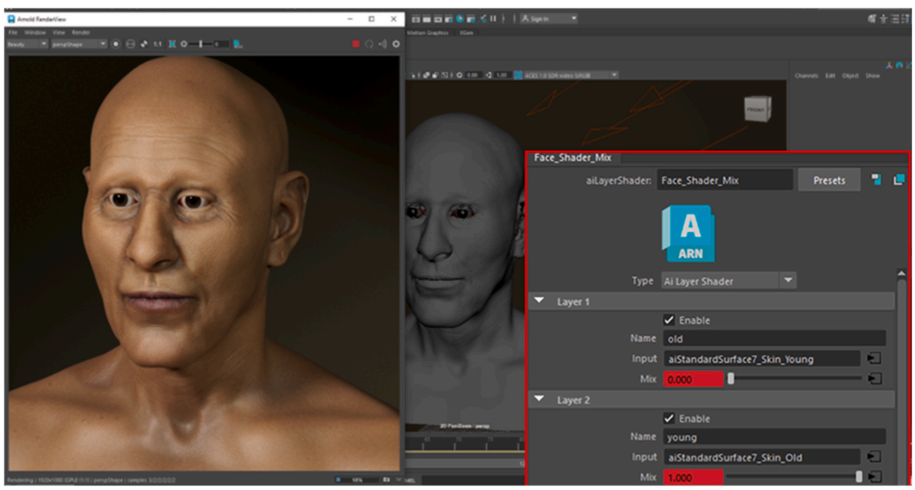

Fig. 15. Model at Blend Shape level 0 with texture and displacement maps attached for the 45 year old face.

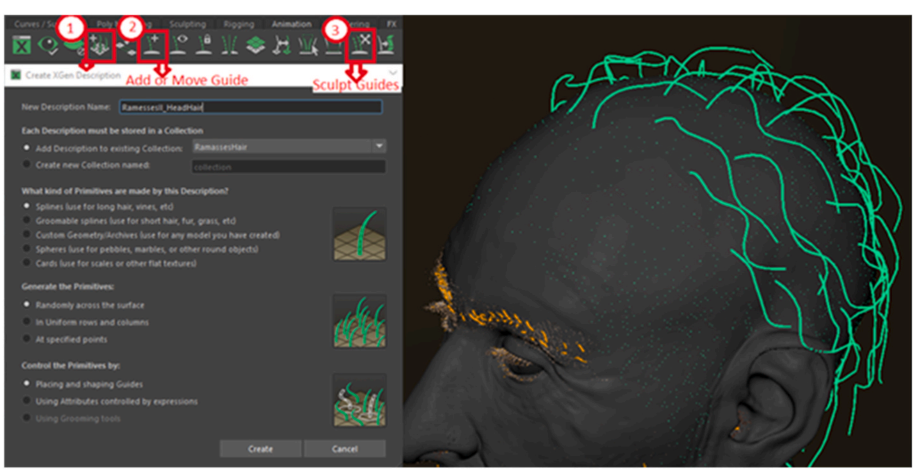

Fig. 16. Creating a hair system using descriptions and tools in X-Gen. Step 1: Create XGen Description; Step 2: Add or Move Guide; Step 3: Sculpt Guides.

stubbles, ear and nose hairs, were added with simple density guides and noise (Fig. 21). Since we do not know the head hair pattern of Ramesses II at age 40s, a generic hair pattern was depicted, but the hair style and hair length are still reflective of the mummified remains (Wilkinson et al., 2023). The same hair groom was used for the two ages, with the only difference being in the density mask and colour.

A gentle gradient of a rich orange/red hair colour was depicted based on what henna dye would look like on white hair (see Fig. 22 for the

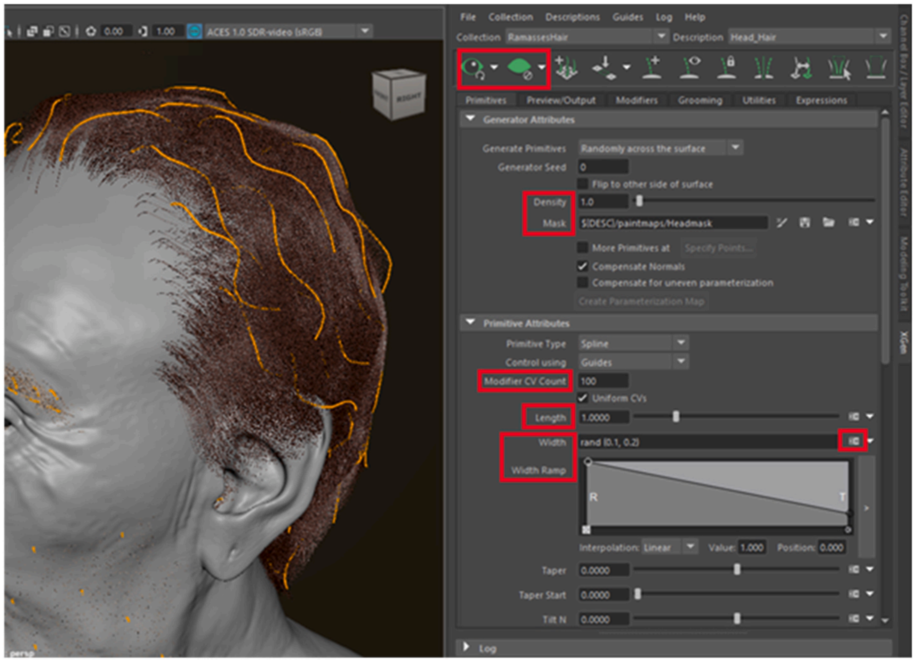

Fig. 17. XGen controls showing hair preview, and modification for density, length and width of the hair visualisation following the placement of the guides.

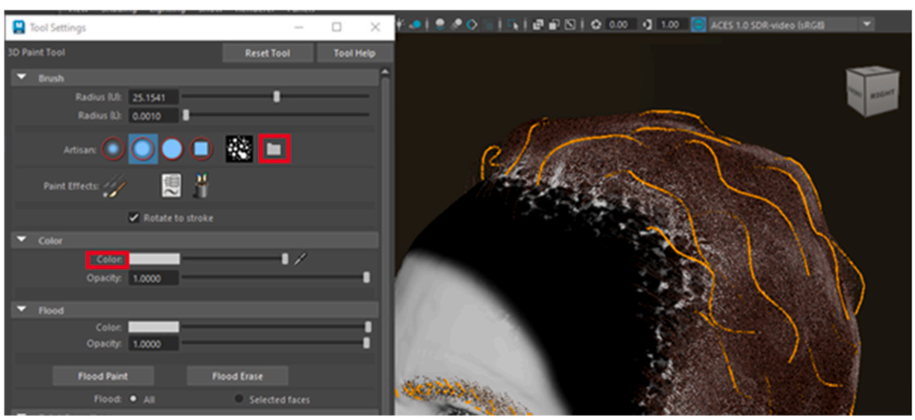

Fig. 18. The use of mask to adjust density of the hair, area painted black to reduce density.

shader settings and Fig. 23 for the outcome). For the younger depiction of the king, a reddish dark brown colour was chosen, reflective of the Egyptian population (Wilkinson et al., 2023) (Fig. 24).

2.4. *Rendering the 3D facial depictions using Autodesk Maya*

With all preparations made, three animations were exported: 1) a frontal facing morph from old to younger appearance; 2) a 180-degree rotation of the older head model; 3) a 180° rotation of the younger head model. For 1, the camera was positioned in front of the face model with a focal length of 200 mm. For 2 and 3, a second Camera and Aim was added to the scene and attached to a curve, with Aim located at the centre of the head model to allow the camera to move around the head model as a desired distance. Using Arnold, the animations were rendered as a sequence (Render View > Render Sequence) and exported as a series of 1080HD TIFF image frames, then assembled as video outputs using video editing software, Adobe Premiere (https://www.adobe.com/products/premiere.html).

3. Results: morphing facial depiction of Ramesses II

Figs. 25 and 26 show the resulting textured facial depictions of Ramesses II at 90 and 45 Years Old. Video 1 shows a 180-degree rotation of the 90 year old depiction and Video 2 shows a 180° rotation of the 45 year old depiction. Video 3 shows the morph-based animation from 45 to 90 years old.

The animated facial depictions of Ramesses II were showcased in a French television documentary titled "*Des Racines et Des Ailes: L'Egypte, une passion française*", which aired on the France 3 television channel in December 2022 (https://www.france.tv/france-3/des-racines-et-des-ailes/4087963-l-egypte-une-passion-francaise.html).

Supplementary to the video animations, the individual 3D facial depictions can be viewed separately in 3D on Sketchfab: 90 years old https://skfb.ly/oWIU8 and 45 years old https://skfb.ly/oWIJZ. Note that hair is not shown on the models presented on Sketchfab due to limitations displaying XGen hair guides on that platform. Due to the methodology adopted to create the morph-targets and blendshapes in ZBrush, the layer shader mixing in Maya, and the overall file size of the models, it is also not possible to visualise the morphing of the two depictions in one 3D scene on Sketchfab currently.

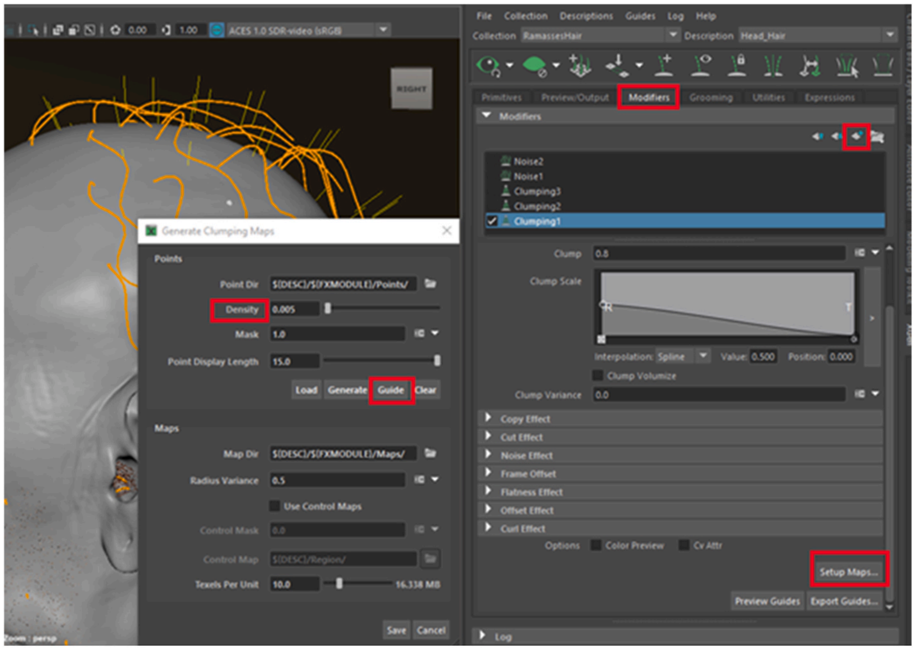

Fig. 19. The use of modifiers (three clumps) to add variation to individual hair strands.

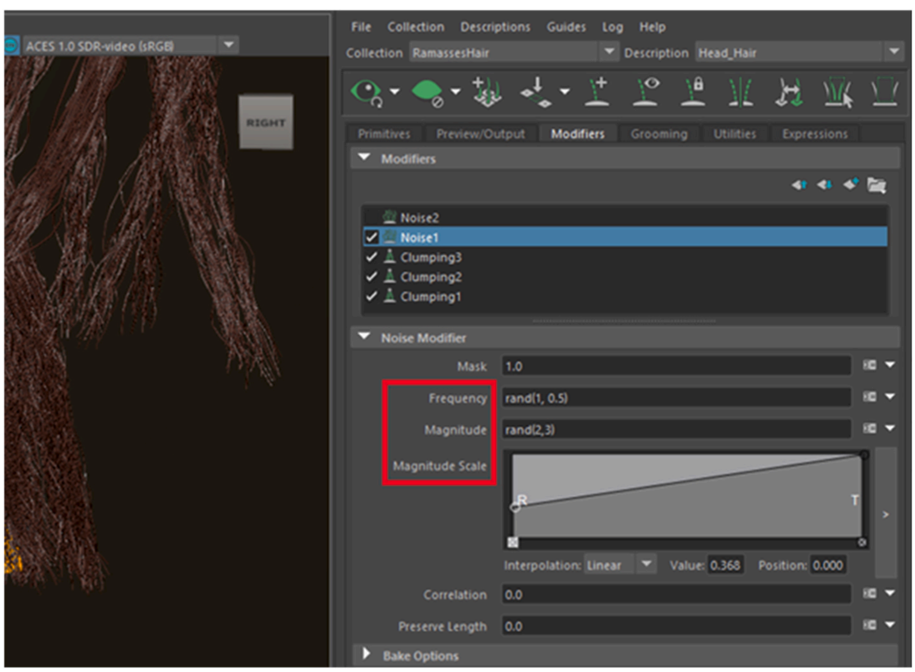

Fig. 20. The use of modifiers (two noises) to add variation to individual hair strands.

Supplementary video related to this article can be found at https://doi.org/10.1016/j.daach.2024.e00377

4. Discussion

Public fascination with Ancient Egyptians has led to the production of numerous digital facial depictions of famous Pharaohs including Ramesses II. These include Akhenaten (Davis-Marks, 2021) and Tutankhamun; with the latter having received more than one facial depiction (Hawass, 2005; Cascone, 2014; Moraes et al., 2023b), and also less-well known individuals including Nebiri, Chief of Stables (Loynes et al., 2017) and Ta-Kush (Smith et al., 2020). These 3D digital facial reconstructions facilitate opportunities for interactions with ancient people, offering a tangible connection to the past for the public and providing researchers with opportunities to gain insights into the physical appearance and characteristics of individuals who lived long ago (Anđelković et al., 2011; Butti et al., 2017; Campbell et al., 2021; Martínez-Labarga et al., 2021; Milani et al., 2022; Aidonis et al., 2023; Redfern and Booth, 2023).

Encounters with these reconstructions in museums, educational settings, and in the media give the public a chance to connect with history on a more personal level; seeing a reconstructed face in a museum exhibition or in a historical television documentary helps bridge the gap between the past and present, making historical figures

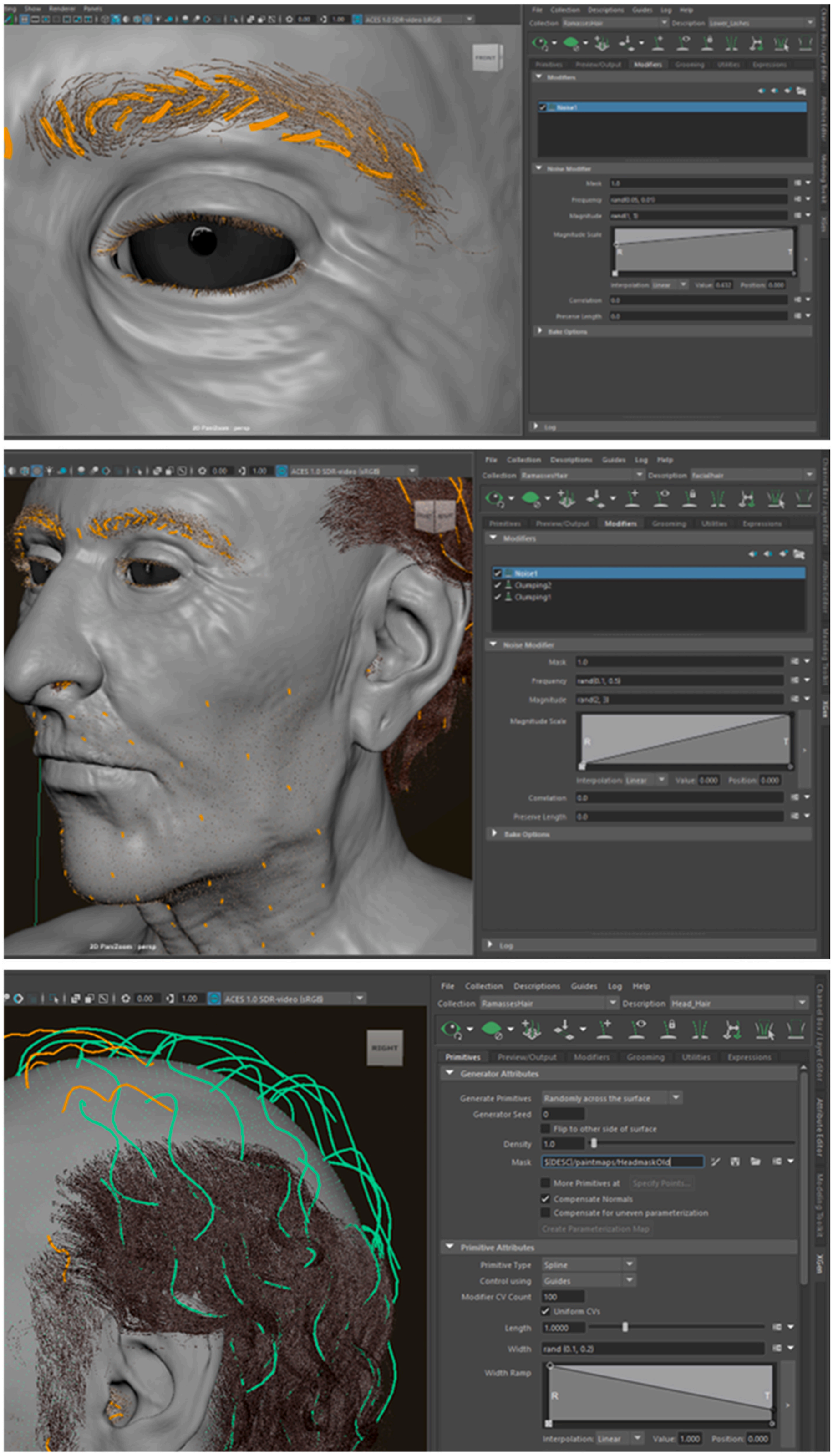

Fig. 21. XGen hair system: (Left) Eyebrows and eyelashes, (Centre) Short facial hair/stubbles, (Right) Hair patter of Ramesses II at age 90 years, matching the hair style and pattern of the mummified remains.

more relatable, credible, and emotionally impactful to the general public. The depictions also invite the public into conversations surrounding the depiction of ancient people; changing public perception about ancient individuals and contribute to cultural enrichment (Lindsay et al., 2015; Hayes, 2016; Wilkinson, 2018; Wilkinson et al. 2019; Roughley and Wilkinson, 2019; Wilkinson et al., 2019; Smith et al., 2020; Campbell et al., 2021; Roughley and Liu, 2022; Moraes et al., 2023a; Sertalp et al., 2023; Redfern and Booth, 2023). While the

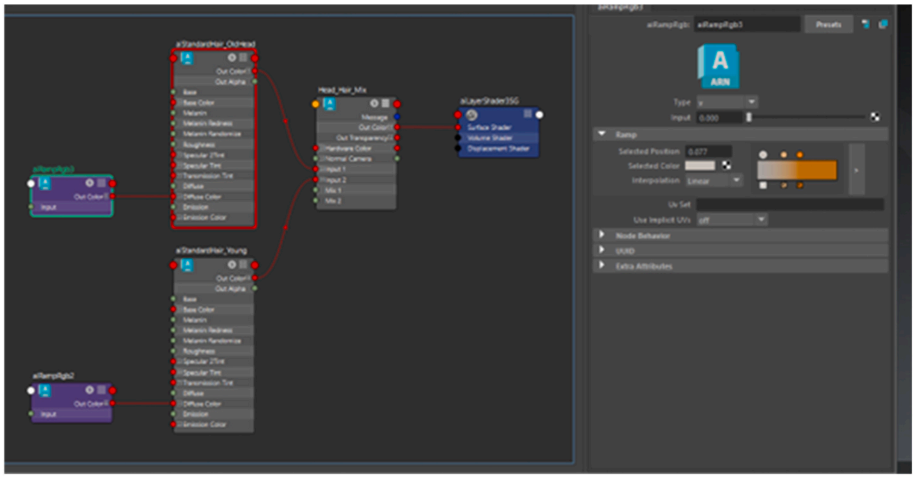

Fig. 22. X-Gen Hair ramp showing a gradient from white/grey to orange/red hair, for the depiction of Ramesses II at age 90 years. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

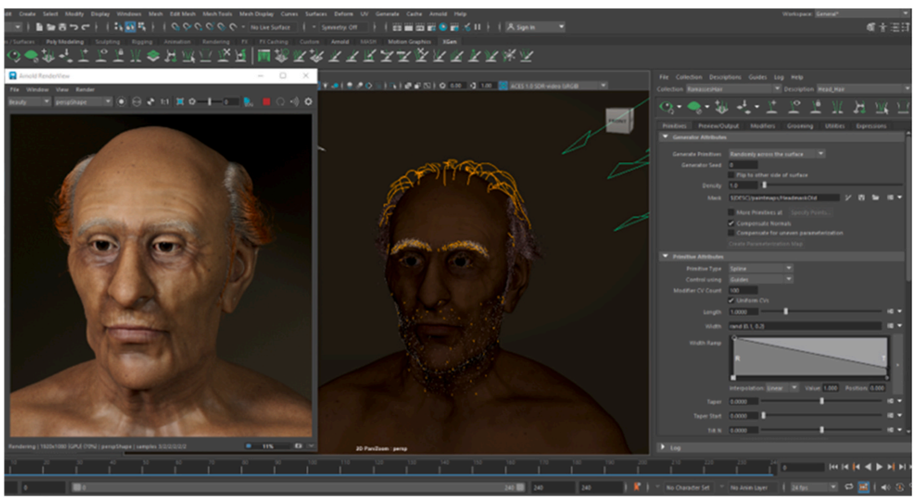

Fig. 23. XGen hair guides with render (left) showing Ramesses II at age 90 years.

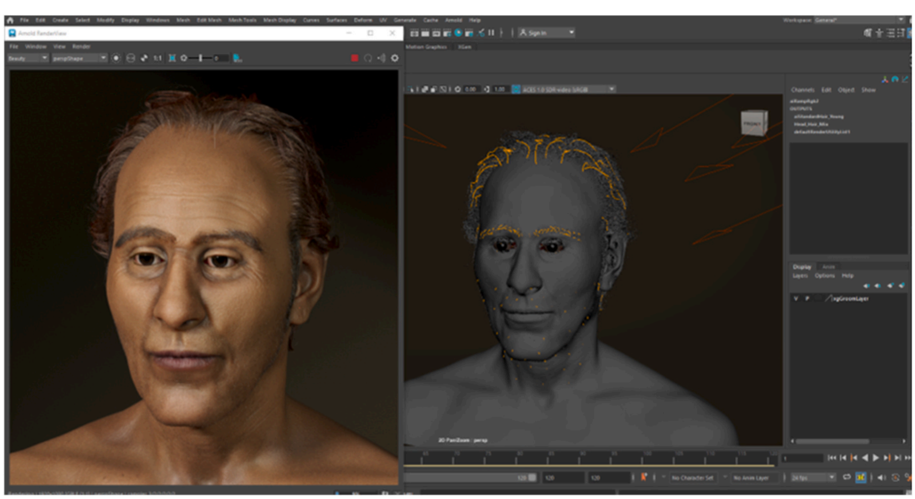

Fig. 24. Hair colour and style change to Ramesses II at age 45 years. Same hair system when compared to age 90 years, with a different density mask and colour. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 25. Facial depiction of Ramesses II at approximately 90 years of age.

Fig. 26. Facial depiction of Ramesses II at approximately 45 years old.

depiction of ancient faces can often spark public debate, controversies surrounding the depiction of race and suggestion of identity in facial depictions can mean that viewers often overlook the informed choices made by scientific analysis and interpretation of historical records (Redfern and Booth, 2023).

The addition of digital textures to sculpted 3D reconstruction face models enhances the acceptance of the 3D face by the public as valid and recognisable, more so than if only flat colour was added (Anderson, 2012; Bruce et al., 1991; Lewis, 1997; Johnson, 2016). It is important to acknowledge though that in general the production of facial depictions can be influenced by the personal biases and artistic choices of the researchers involved, which could potentially lead to the creation of portrayals that do not accurately reflect historical realities. Therefore, textural choices need to be approach with caution and justification as not to unintentionally mis-represent individuals (Wilkinson, 2020). To minimise the bias involved in the depiction of the faces of Rameses II, all stylistic and colour choices were informed by review of historical depictions of Egyptians from the period of Ramesses II (Eaverly, 2013; Wilkinson et al., 2023), existing anthropological and phenotypic research into the appearance of ancient Egyptians (Batrawi, 1946; Brace et al., 1993; Cady et al., 2021; Weisberger, 2021) and prior scientific observations of the well-preserved mummified remains of Ramesses II (Ceccaldi and Roubet, 1987). Although Egyptian co-author Saleem was able to undertake first hand visual observations of the remains and also peer-reviewed all textural choices, it is acknowledged that a level of assumption and interpretation remains.

It is important to note that the role of a facial depiction is not to produce a photograph of an individual, but instead, a likeness. Enhanced realism of a reconstructed face afforded by the use of ZBrush and Maya might potentially be problematic as there could be suggestion that the depiction is a photograph of an individual representing their exact appearance. Therefore, a level of un-realism is sometimes preferred to establish the facial reconstruction as a depiction that has a level of interpretation in its presentation. This is notable in the final renders of Ramesses II, where a level of the uncanny still persists and high-fidelity realism is not present.

A further complication to this project was the decision to animate the facial depictions of Ramesses II. Ethical issues can arise in the animation of facial depictions of ancient humans, where animation of facial features to create expressions or allow the reconstruction to 'speak' could be viewed as disrespectful to the deceased. While animations of ancient humans exist, and have been met with positive media coverage, including the Shíshálh family facial reconstruction where four, 4000 year old indigenous people found in an ancient burial site near Sechelt, Canada, appear to blink and tilt their heads (Clark et al., 2019), there exists the possibility that a moving facial depiction could inadvertently perpetuate stereotypes about ancient civilizations, leading to potentially misleading or oversimplified representations.

For this project, it was decided that the two facial depictions would be presented with neutral resting facial expressions with no other face movement apart from morph of the two face meshes between each other, which give the suggestion that the face and skin were aging. While blend-shapes are used commonly for facial animation of 3D digital avatars, this is the first time that a morph-based animation between two 3D facial depictions of one ancient individual at different ages has been produced. A video transition between two still images of the depictions could have achieved a similar effect as a morph-based animation, however, the morphing of the meshes provides viewers an opportunity to see creases and wrinkles deepen, facial features sag, and skin colour alter with age, directly on the 3D face model, not through an illusionary fading between two videos or still images. This facilitates a more relatable experience to viewing Ramesses II age, albeit through a digital avatar. The depiction of ageing should be approached with reserve however, as this is simply a suggestion based on understanding of how skin ages and visual review of his mummified remains, and it is not an exact reenactment of the aging Ramesses II's skin, which would be impossible to know.

Embracing digital 3D technologies and tools for facial depiction demonstrates a commitment to using cutting-edge tools for public engagement with depictions of people from the past; attracting audiences to develop an interest in ancient figures from history. It is hoped that this project may encourage other researchers to use the methods described in this paper to present faces of ancient people at different life stages.

5. Conclusion

Digital 3D facial reconstructions bring ancient figures to life in a visually compelling manner, making the individuals more accessible and relatable to the general public. A morph-based animation of realistically painted 3D facial reconstructions of Ramesses II show representations of how he might have looked during his lifetime. The methodology described in this paper enhances storytelling and educational efforts by animating facial depictions of Ramesses II between two different ages, to imply a journey from middle age to old age. Digital 3D technologies can significantly enhance the presentation of facial reconstructions to public audiences, offering a more interactive and informative experience that fosters a deeper appreciation for ancient history and the people who lived in the past.

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CRediT authorship contribution statement

Mark Roughley: Writing – original draft, Visualization, Methodology, Investigation, Conceptualization. **Ching Yiu Jessica Liu:** Writing – original draft, Visualization, Methodology, Conceptualization. **Caroline M. Wilkinson:** Writing – review & editing, Visualization, Supervision, Investigation, Funding acquisition, Conceptualization. **Sahar N. Saleem:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors report no conflict of interest.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.daach.2024.e00377.

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