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Digital 2D, 2.5D and 3D methods for adding photo-realistic textures to 3D facial depictions of people from the past

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Abstract

Facial reconstruction is a technique that can be used to estimate individual faces from human skulls. The presentation of 3D facial reconstructions as photo-realistic depictions of people from the past to public audiences varies widely due to differing methods, the artists' CGI skillset, and access to VFX software required to generate plausible faces.

This chapter describes three digital methods for the addition of realistic textures to 3D facial reconstructions; a 2D photo-composite method, a 3D digital painting and rendering method, and a previously undescribed hybrid 2.5D method.

These methods are compared and discussed in relation to artistic proficiency, morphological accuracy and practitioner bias.

Key Words

Facial depiction; facial reconstruction; Archaeology; Facial composite; Pixologic ZBrush; Adobe Photoshop; 3D modelling

Introduction

Facial reconstruction is a technique that estimates an individual face from a human skull, using established craniofacial standards, for forensic identification or archaeological investigation.

While there are different facial reconstruction methods (Prag and Neave, 1997; Taylor, 2000; Wilkinson, 2005; Iscan and Steyn, 2013; Stephan, and Claes, 2016), most follow established and tested anatomical standards and procedural guidelines to create face shape (Wilkinson, et al. 2006; Lee, et al. 2012). Once the facial reconstruction shape is produced, a variety of primary, secondary and tertiary skin 'textures' are added, including wrinkles, creases and pores, followed by the addition of eyes, hair and additional accoutrements or clothing, plus colour information (Wilkinson, 2010; Roughley and Wilkinson, 2019; Roughley, 2020). For the purposes of this chapter, a 'facial reconstruction' describes the process of building a face from skull to skin layer. A 'facial depiction' is the outcome after textures have been added ready for presentation to public audiences.

Representing faces from the past provides the publics with an opportunity to connect with historical figures both known and unknown, as individuals rather than concepts. Some believe the depiction could create empathy and personal connection between the viewer and the historical individual (Buti, et al., 2016). As scientific methods and visualisation techniques have developed, these representations have become more nuanced, realistic and detailed.

Traditional facial reconstruction methods use skull images or casts, and, depending on the method adopted, anatomical modelling is performed in either two dimensions (2D) through drawing of muscles and facial features over an image of the skull (Taylor, 2001), or three dimensions (3D) by modelling the soft tissues using clay or wax onto a 3D replica of the skull (Prag and Neave, 1997; Iscan and Steyn, 2013). Recently, and specifically over the past decade, facial reconstructions have been performed using 3D scans of human remains, digital processes and computer software adopted from the computer gaming, movie visual effects (VFX) and engineering industries (Claes, et al. 2010; Mahoney and Wilkinson, 2010; Roughley and Wilkinson, 2019).

Existing facial reconstruction methods

2D facial reconstructions are based on frontal-facing photographic or 3D scan images of a human skull (or cast) positioned in the standard Frankfurt Horizontal Plane. Prior to the image being captured, the skull or skull cast will have soft tissue-depth markers attached at skeletal landmarks, correlating with the estimated biological profile. The facial reconstruction can be produced manually or digitally by drawing, sketching or employing composite image techniques on top of the image of the skull following established craniofacial estimation guidelines (Taylor, 2000).

A composite image technique uses a collage of sourced images of human faces, skin, eyes, hair and clothing, to build a facial depiction. Figure 1 shows a 2D digital facial depiction of a WW1 German soldier excavated from a battlefield near the French Village of Bullecourt. A 3D scan of the skull was imported into the 3D software, Geomagic Freeform, where soft-tissue markers and eyeballs were added. A 2D screenshot of the prepared skull was then exported into image graphics software

Adobe Photoshop CC, where the facial muscles, features and face shape were drawn in 2D, prior to the addition of realistic textures via image compositing.

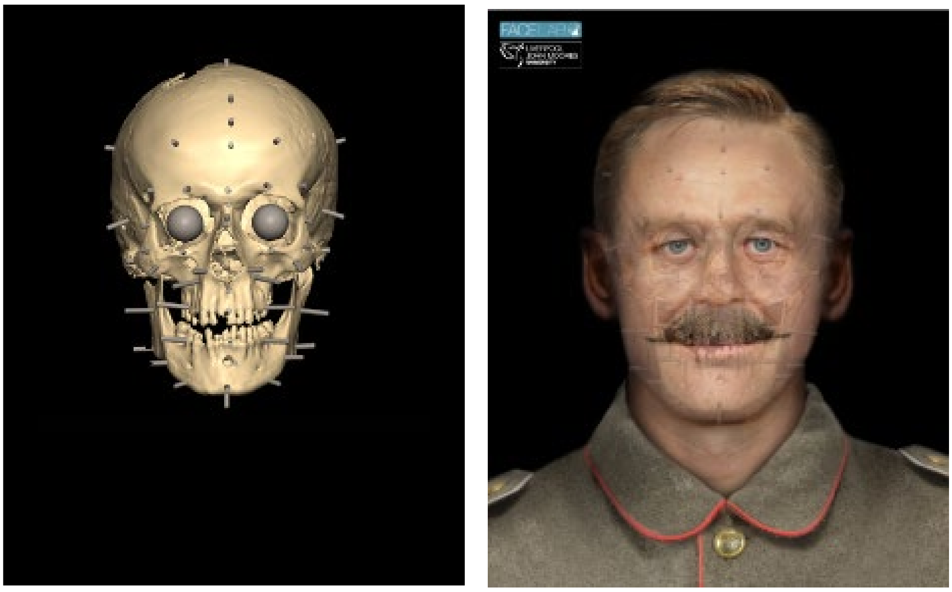

Figure 1: 2D digital facial depiction of a WW1 German soldier excavated from a battlefield near the French Village of Bullecourt. Image courtesy of Face Lab, Liverpool John Moores University.

3D facial reconstructions can be produced manually by sculpting in wax or clay on top of a replica of the skull as shown in figure 2 (Wilkinson 2010; Iscan and Steyn, 2013) or digitally using 3D scans of the skull and virtual sculpting in computer software as demonstrated in figure 3 (Mahoney and Wilkinson, 2010). Both methods follow established facial estimation guidelines. After skeletal analysis, soft-tissue depth markers, muscles and fat layers are added to the skull, followed by sculpted facial features and the final face shape. Alternative algorithmic and 3D modelling methods also exist, whereby a craniofacial model/template is morphed to fit the skull (Claes et al. 2010; Miranda, et al. 2018).

Figure 2: Manual 3D facial reconstruction using a plaster cast of a skull and modelling wax. Image courtesy of Face Lab, Liverpool John Moores University.

Figure 3: 3D digital facial reconstruction produced in Geomagic Freeform of an older Roman female found by KDK Archaeology as a single isolated burial during excavations at the Old Palace Lodge hotel, Dunstable, Bedfordshire. Image courtesy of Face Lab, Liverpool John Moores University.

Digital 3D facial reconstruction methods afford certain interactions that make them highly desirable, including a non-destructive workflow, the ability to magnify anatomical details and engage with views of the 3D models that are otherwise not visible, and the display of complex anatomical-spatial relationships more effectively than 2D images (Challoner and Erolin, 2013; Roughley and Wilkinson, 2019; Parsons and MacCallum, 2021). Although the prediction of face shape (facial reconstruction) follows anatomical standards with known accuracy (Wilkinson, et al. 2006; Lee, et al. 2012), the final presentation of these digital facial reconstructions as photo-realistic faces (facial depiction) often depends on the skillset of the facial depiction practitioner, including their CGI skills, and access to 3D software. Therefore, there is often variation in the aesthetic success of the final depiction.

What is the purpose of a facial depiction?

Craniofacial analysis and reconstruction for *forensic application* usually occurs when all usual investigative channels have been exhausted. The craniofacial identification process produces a depiction or 'likeness' of the individual to generate further investigative leads. For example, under certain circumstances, such as national media circulation of the image, the face image may trigger recognition by family and friends.

In order to produce a more realistic representation of the individual, many forensic facial depictions utilise the addition of textures such as wrinkles, hair, and/or colour (Prag and Neave; 1997 Vanezis and Vanezis, 2000; Taylor, 2000; Kahler, et al. 2003; Wilkinson, 2005; Claes, et al. 2010; Fernandes, et al. 2013). The texture is often a 'best guess' based on forensic evidence, biological profile, and circumstantial evidence. Some features, such as the hairline, are blurred in the final image, as it is not possible to ascertain this from the skull alone, and such detail could affect recognition (Frowd, et al. 2012). Depictions are often presented in black and white to reduce distractions due to the application of incorrect skin, hair and eye colour (Taylor, 2000; Vermeulen, 2012).

The main purpose of craniofacial analysis and reconstruction of *archaeological human remains* is rehumanisation and promotion of audience empathy with people from the past. A number of projects have used archaeological facial depictions to represent historical, migratory populations (Hamre, et al. 2017); re-present ancient human remains as people rather than artefacts in museum display settings (Crossland, 2009; Smith et al. 2020); re-humanise ancient Egyptian human remains to restore a sense of dignity and personhood (Smith, et al. 2019) and represent people from the past with facial differences (Smith, 2018; Wilkinson, 2018).

Depending on the information available, most archaeological depictions use historical records in conjunction with biological information to create full-colour, realistic facial depictions of the individual. This supporting information may include analysis of portraits held by public art galleries, genealogy analysis and evaluation of physical descriptions in written records (Wilkinson, et al. 2019). In recent years, it has been possible to utilise forensic DNA phenotyping or ancient DNA (aDNA) analysis to more accurately suggest skin colour, eye colour and hair colour of ancient human remains (Hamre et al. 2017). These suggestions allow the practitioner to produce a more realistic and valid depiction of the individual.

3D Digital Texture Methods

Manual 3D facial reconstructions produced using skull casts and clay or wax modelling materials can either be presented as 'clay' or solid colour models or painted in a realistic manner. With digital 3D facial reconstructions, once a face has been reconstructed virtually from the skull using 3D sculpting software, the finished reconstruction will also appear as a 'clay-like' model, lacking details and texture (figure 3). Different methods can be used to add 'textures' to these digital faces in order to achieve a photo-realistic result for publication or display. Once textured, digital 3D facial depictions can be presented either as still images, 3D animations, or 3D printed models (Roughley and Wilkinson, 2019).

Figures 4 and 5 show a digital 3D facial reconstruction of King Robert II (Robert the Bruce) of Scotland created in Geomagic Freeform. Figure 4 shows the digital 3D facial reconstruction model, and with the addition of digitally painted skin textures, including eyes, hair and clothing. A still image from a 180-degree turntable animation is also presented. Figure 5 shows the same digital 3D facial reconstruction, but it has instead been 3D printed. Two different methods of adding textures to this 3D model are demonstrated, including spray-painting with a neutral solid grey colour (left), and realistic painting using acrylic paints and additional materials including hair and glass eyeballs (right).

Figure 4: 3D digital facial depiction of King Robert II (Robert the Bruce). Image courtesy of Face Lab, Liverpool John Moores University and the University of Glasgow.

Figure 5: 3D digital facial depiction of King Robert II (Robert the Bruce), which has been 3D printed. Image courtesy of Face Lab, Liverpool John Moores University and the University of Glasgow.

The following sections describe in detail, to facilitate replication, three methods of adding realistic textures to digital 3D facial reconstructions: a 2D photo-composite method, a 3D digital painting and rendering method and a hybrid 2.5D method. The hybrid 2.5D method for application of textures to facial 3D reconstructions has not previously been described in the literature. It is a combined approach whereby the skin layer of a 3D facial reconstruction model is digitally painted in 3D software; then a front-facing still image is exported to an image graphics software where 2D photographic images are composited to add features including eyes, hair and clothing. This method allows for the production of photo-realistic faces in the absence of advanced 3D modelling and rendering skills, which are needed to add these features in high-end VFX software.

While these methods describe applications of digital textures to 3D models for forensic and archaeological facial depiction purposes, they are transferrable and can be utilised for anatomical and medical visualisation. We offer pros and cons for each method and conclude that the 2D digital photo-composite method might inadvertently increase morphological error due to the use of donor images in the final composite. We suggest that the 3D digital painting method for adding textures remains the most ideal workflow. The impact of cognitive biases on the choice and addition of realistic textures during the depiction process is highlighted.

2D Digital Composite Method

With the 2D digital composite method, a front-facing still image of a 3D virtual 'clay-like' facial reconstruction is exported from the originating 3D software into an image graphics software. For the purposes of this workflow, Adobe Photoshop CC with a default workspace is used. Skin and other complex textures such as hair and clothing are added using donor photographs from face databases, by using photo-composite techniques.

Figure 6 shows an example of the 2D digital composite method in action.. A 3D digital facial depiction of a 19th century individual unearthed on ‘Rat Island’, Portsmouth by Operation Nightingale (Osgood, 2018) was created in Geomagic Freeform. An image of the face model in the Frankfurt Horizontal Plane was exported to Adobe Photoshop CC for 2D composite texturing of eyes, hair and clothing. This method was appropriate for this project because the time taken to texture the 3D model was greatly reduced, and only one front-facing view of the facial depiction was required for publication.

Figure 6: Example of digital composite method: 3D digital facial depiction of a 19th century individual unearthed on ‘Rat Island’, Portsmouth created in Geomagic Freeform, then exported to Adobe Photoshop CC for composite texturing of eyes, hair and clothing. Image courtesy of Face Lab, Liverpool John Moores University.

Workflow

The composite process begins in Adobe Photoshop CC with a frontal still image of the 3D facial reconstruction. Donor images: high-resolution photographic images of faces or facial features, are selected based upon morphology and their similarity to the age and ancestry of the individual. These images can be sourced from a photographic database of consenting donors, but, the most common access is via online sources downloaded from image search engines and repositories. These images should either be in the public domain, be Creative Commons licensed or accessed from research databases such as the London Face Dataset (2017) by

De Bruine and Jones (https://figshare.com/articles/dataset/Face_Research_Lab_London_Set/5047666) where there is explicit consent for use in such projects.

The donor images are imported in new layers to composite the textures on top of the facial reconstruction image. It is good practice to label the new layers appropriately as there will soon be many layers to contend with. Folders and subfolders are also recommended. Depending on the donor images used, the lighting and face shape of the donor image may not match the facial reconstruction image; altering the 'opacity' of the donor image in the 'Layers' palette is important in order to make the underlying shape of the facial reconstruction visible while edits to the original donor image are taking place. An opacity level of 50% is recommended.

In figure 7, a photographic donor image of a nose has been imported as a new layer in Adobe Photoshop CC and added to a 'Nose' subfolder. In order to position the nose image in place, the 'Move' and 'Transform' tools are used. For greater control over the transformation of the donor image in order to 'fit' the underlying image of the facial reconstruction, the 'Puppet Warp' tool can be used. This tool lets the user add pins on the image to hold parts in place. Once all pins are placed, they can be grabbed and pulled to move the image into the desired position.

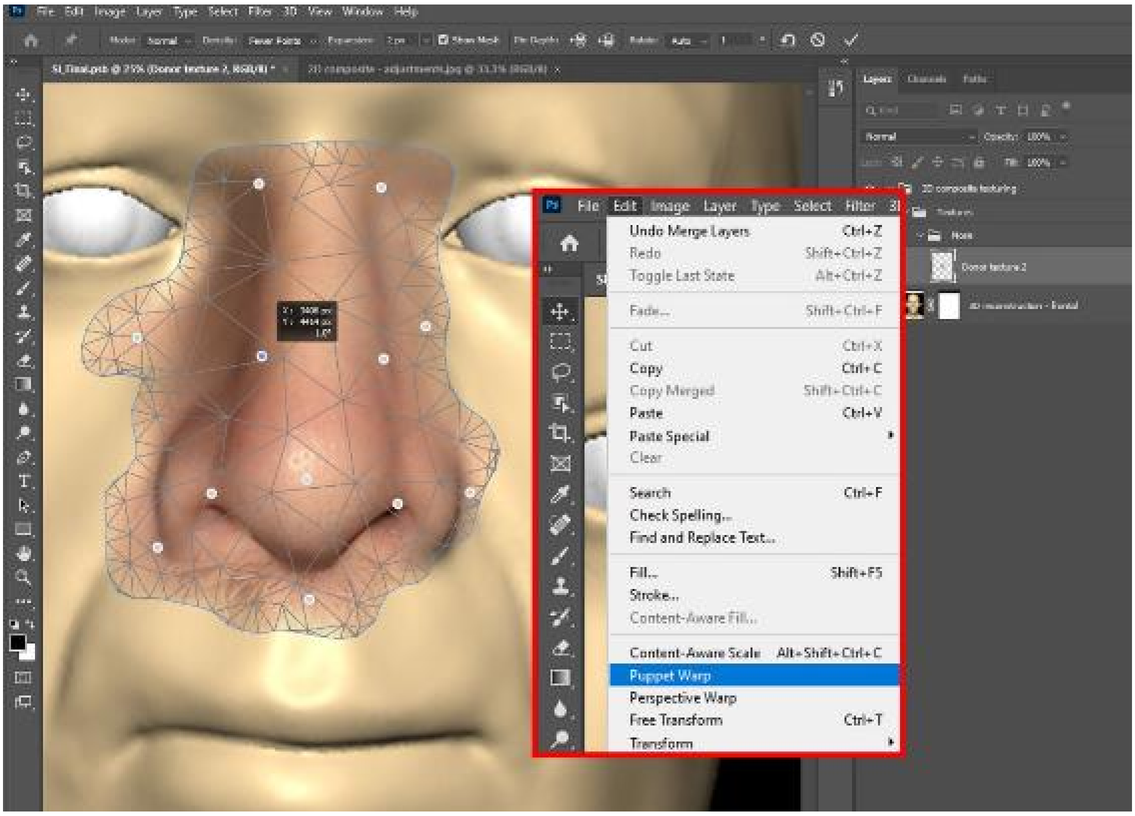

Figure 7: The 'Puppet Warp' transform tool in action in Adobe Photoshop CC.

For more advanced control of the image transformation, the ‘Liquify’ tool can be used. With the donor image selected in the ‘Layers’ palette, choose ‘Filter’ from the menu at the top of the Adobe Photoshop CC interface, then ‘Liquify’. Only the layer selected will appear in the window. To show the underlying layers including the imported image of the facial reconstruction, tick the ‘Show Backdrop’ box in the lower right of ‘Properties’ panel. Both images will be shown, one on top of each other. The tools to the left of the ‘Liquify’ window, including the ‘Foward Warp’ tool can be used to push the donor image to fit the shape of the facial reconstruction (figure 8).

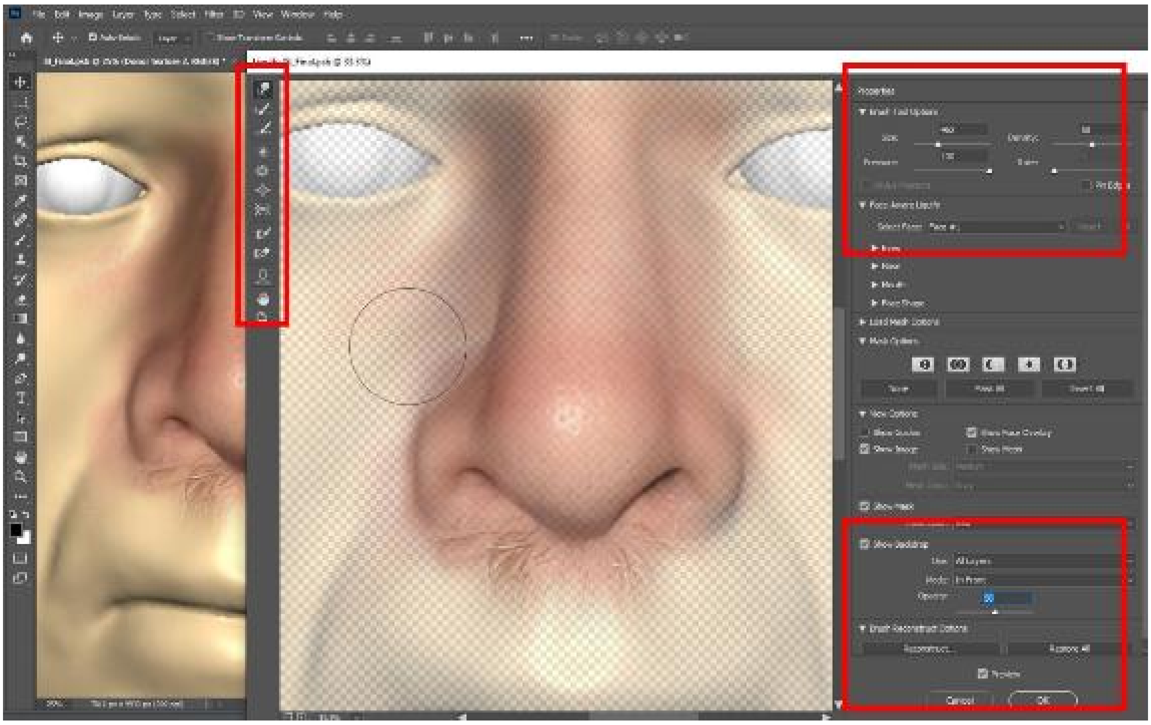

Figure 8: The ‘Liquify’ filter tool in action in Adobe Photoshop CC.

As more donor images are added on additional layers, the ‘Eraser’ tool or ‘Layer Masks’ can be used to soften the edges of the images and blend them to create a smooth transition between images. ‘Layer Masks’ are less destructive than simply erasing parts of the donor image. A ‘Layer Mask’ to a can be added to a selected layer by choosing 'Layer' from the menu at the top of the Adobe Photoshop interface, then ‘Layer Mask’ and ‘From Transparency’. The mask layer will appear alongside the image in the ‘Layers’ palette (figure 9). With the mask selected, the ‘Paintbrush’ tool can be used to hide parts of the donor image. Painting on the ‘Layer Mask’ with a key colour (black) will make the source image appear as though it is being erased. If a white colour is painted the source image will reappear. This non-destructive method allows the user to make subtle or radical adjustments and blend between donor images.

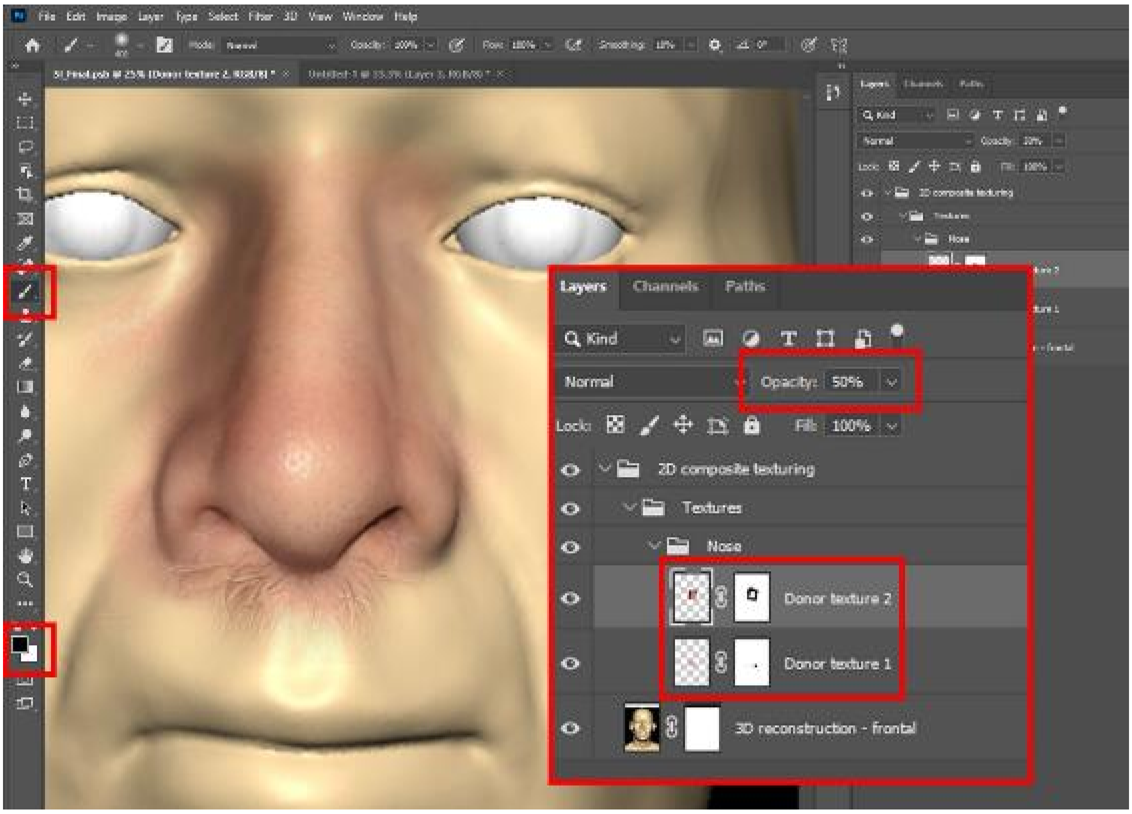

Figure 9: Using 'Layer Masks' and altering 'Opacity' in Adobe Photoshop CC.

It is recommended that multiple photographic donor images are used to create a textural composite, as this reduces the chance of unintentional recognition of the donor's facial features or textures (Shrimpton, 2018). As more donor images are composited, colour-correction adjustments will need to be applied to the images to increase visual appeal and tonally blend the different images together (see Brinkmann, 2008). The 'Adjustments' tools shown in figure 10 have been used on the two donor 'nose' images in the 'Nose' subfolder to tonally blend the two different images together to reach a convincing result.

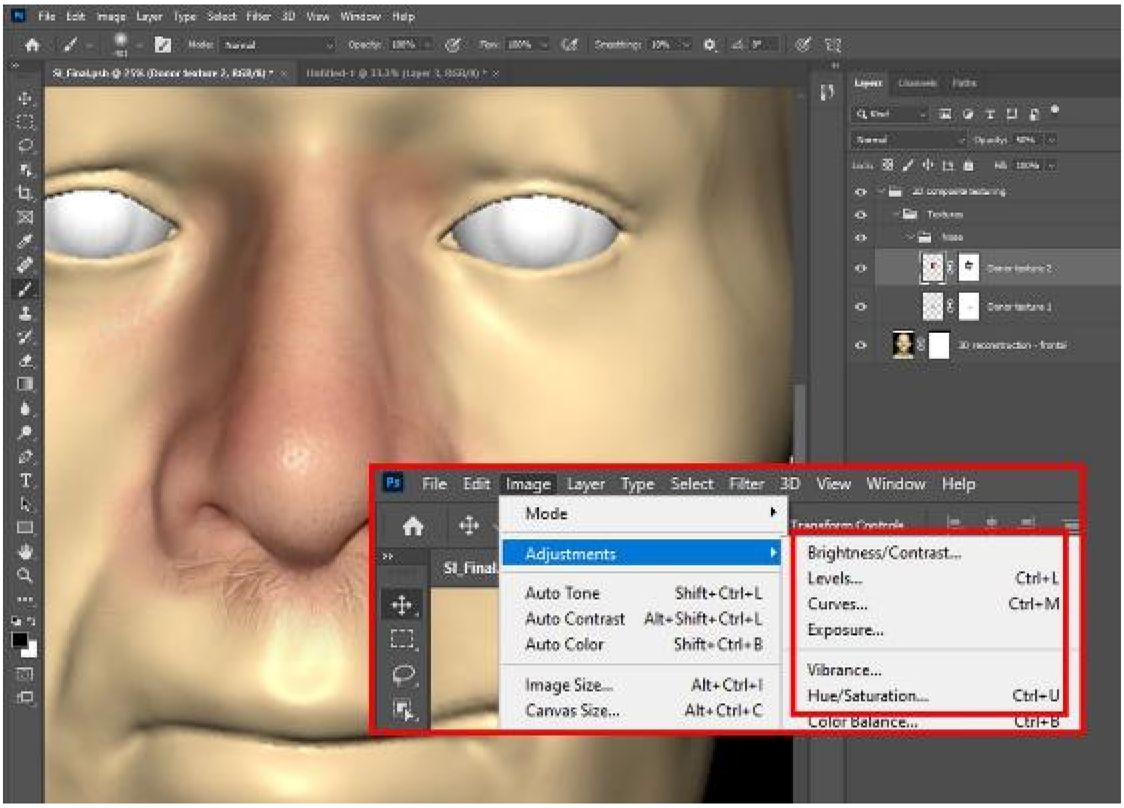

Figure 10: Making colour corrections to layers in Adobe Photoshop CC.

In addition to compositing of photographic images, Adobe Photoshop CC facilitates digital painting of textures in layers atop the image of the 3D facial depiction. Colours can be selected from the colour palette or sampled from donor images using the 'Eyedropper' tool from the toolbar to the left of the interface. The selected colours can be painted on a new layer using one or more of the brushes in the 'Brushes' palette. These brushes can be customised to alter softness of the edge of the brush and opacity of the painted stroke for example. Additionally, custom brushes can be created to perform techniques such as scattering of colour, which may be helpful in adding details such as pores. Painting using digital brushes in two-dimensions is useful in blending between composited images, for anonymisation of donor images, addition of textures such as sunspots, and adding details that are not necessarily available from donor images such as scars.

Once the compositing process and any digital painting is complete, it is good practice to flatten the image under the 'Layers' menu, ready for export. This reduces the file size, however, it cannot be undone once saved so it is recommended to 'Save As' a new file. To save a high resolution image for print, a .TIFF image file type is recommended in CMYK colour mode. A .JPEG or .PNG image file type in RBG colour mode is recommended for screen or web display. The colour mode can be changed in the 'Image' menu under ‘Mode’. The facial depiction image can now be published via screen display, in print and circulated online or in the media.

3D Digital Painting and Rendering Method

For the 3D digital painting method, ‘clay-like’ 3D models produced from the 3D facial reconstruction process can be digitally textured by painting directly onto the 3D skin surface in software such as Pixologic ZBrush or Autodesk Mudbox. Once painted, the 3D model can be exported to VFX software such as Autodesk Maya where eyes, hair and clothing can be modelled. Final images can then be rendered using a rendering engine such as Arnold or VRay.

Figure 11 shows a 3D digital facial depiction of the Medieval Abbot, John of Wheathampstead, textured using the 3D digital painting and rendering method. The facial reconstruction was created in Geomagic Freeform; exported to Pixologic ZBrush for digital texturing, and then exported to Autodesk Maya for modelling of eyes, hair and clothing, and final rendering in Arnold. St. Alban’s Cathedral, where John was twice abbot, and where his remains were discovered (Clark, 2020), requested that the public be able to ‘see’ the facial depiction from multiple angles. The 3D digital painting and rendering method was required for the 3D facial depiction to be animated and the face viewed from differing viewpoints.

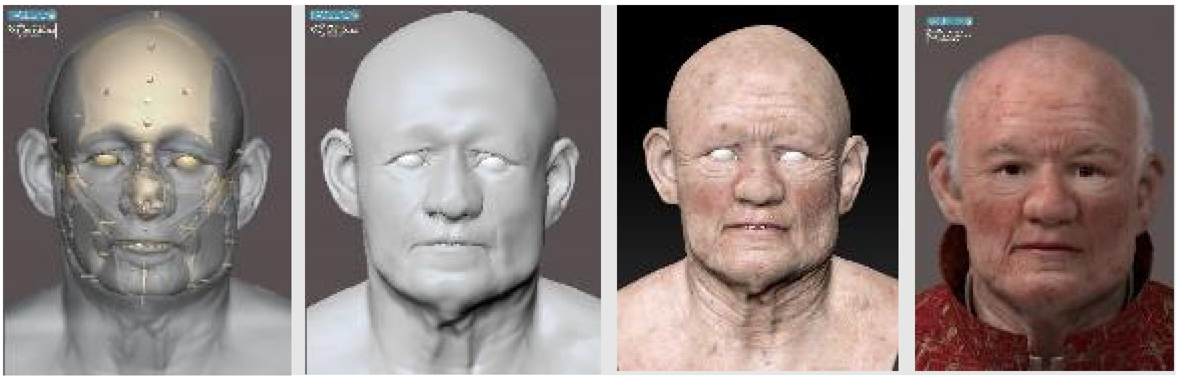

Figure 11: Example of 3D texturing method. 3D digital facial depiction of Abbot John of Wheathampstead. Image courtesy of Face Lab, Liverpool John Moores University

Workflow

A completed 3D facial reconstruction's skin layer is exported as a .OBJ file from the software that it is generated in and imported into a digital sculpting and painting software. For the purposes of this workflow we used Pixologic ZBrush with a default workspace. Certain 3D modelling software allow for organic sculpting, whereby ‘virtual clay’ can be sculpted akin to sculpting with clay or wax in real life. This is often problematic as the topology or ‘mesh of polygons’ generated might be messy and unusable, especially for digital painting and animation of the 3D model. Re-topology can be undertaken to prepare the model for the next steps of the texturing process.

Pixologic ZBrush has a number of built-in tools that allow for quick re-topology. These include the 'ZRemesher' and 'Dynamesh' tools. Both tools will automatically re-arrange the polygons that comprise the model and organise them for use (Roughley, 2020). Figure 12 shows the topology of a 3D model before and after 'ZRemeshing'. 'Dynamesh' is especially useful as when it is active, the mesh continues to be re-topologised as you sculpt. For facial animation projects, a more complex and rigorous re-topology will be required to create useful edge loops and topology suitable for moving facial features. While this is not discussed in detail in this chapter, Autodesk Maya has comprehensive online guides for their 'Quad Draw' tool, which can be used for advanced re-topology (https://knowledge.autodesk.com/support/maya/learn-explore/caas/CloudHelp/cloudhelp/2020/ENU/Maya-Modeling/files/GUID-74867E07-5CCD-4D55-B60B-C90C3AD65DF4-htm.html).

Figure 12: Topology of the skin layer of a 3D facial depiction before and after 'ZRemeshing' in Pixologic ZBrush

The next step in the 3D digital painting workflow is to generate a UV map. A UV map is the 2D representation of the surface of a 3D model, which is used to add textures. Creating a UV map is generally know as 'UV unwrapping'. "The U and V refer to the horizontal and vertical axes of the 2D space, as X, Y and Z are already being used in the 3D space" (Denham, n.d). There are numerous ways to generate UV maps quickly in Pixologic ZBrush, however, the most effective method is to us the 'UV Master' plugin. With this plugin the automated UV mapping tool can be told to 'Attract' UV seams to specific areas of the model and 'Protect' other areas from seams appearing. For a 3D model of a face, the preferred location for UV seams is from the top of the head and down the back of the head towards the shoulders. This avoids the placement of UV seams across important landmarks and facilitates the production of a clean and usable UV map (figure 13).

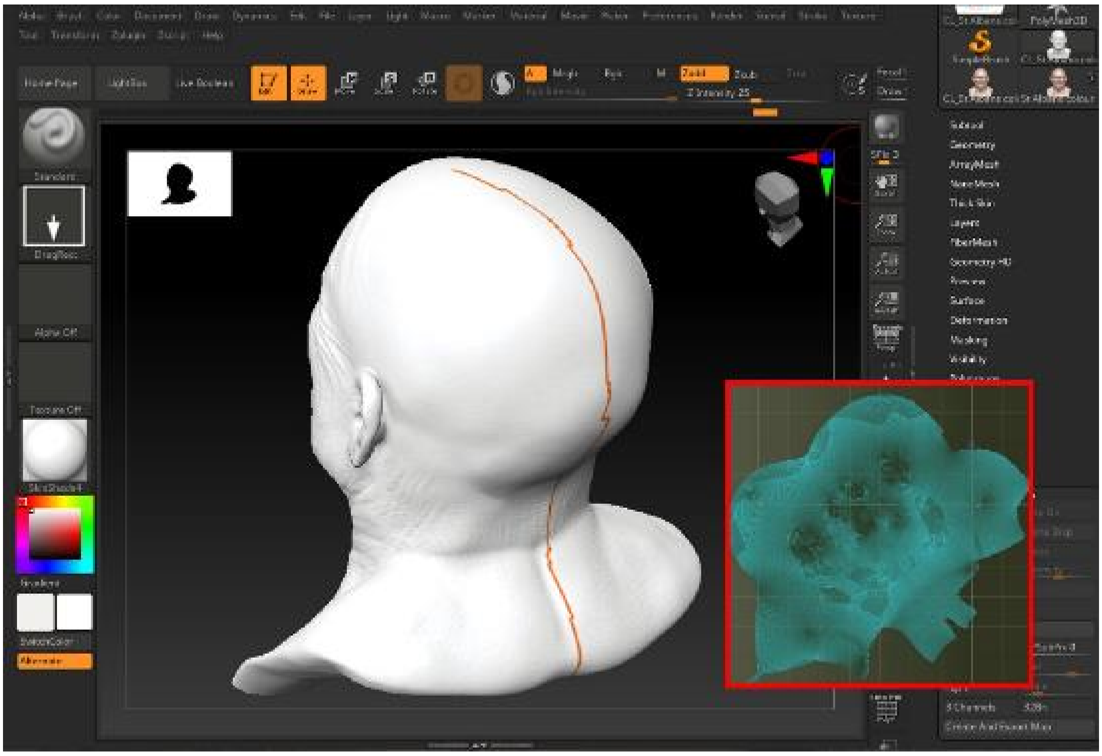

Figure 13: Results from UV mapping using the 'UV Master' plugin in Pixologic ZBriush. - location of UV seams in orange, and the subsequent UV map displayed

As described in detail in "*Pores, Pimples and Pathologies: 3D Capture and Detailing of the Human Skin for 3D Medical Visualisation and Fabricatio*n" by Roughley (2020), the generated 3D skin layer can be sculpted with primary, secondary and tertiary forms. Each of these forms should be sculpted on a new layer in the 'Layers' palette in Pixologic ZBrush for optimal customisability. Using 'Layers' allows the user to use a slider to increase or reduce the intensity of one or more of the sculpted forms until a desired appearance is reached.

In 'Zadd' or 'Zsub' sculpting mode, primary forms such as skin folds are added first using brushes from the 'Brushes' toolbox, including the 'Dam Standard' brush. Commonly, primary forms are sculpted at the lowest subdivision in the first instance. Then, at the highest subdivision, tertiary forms including micro-skin details are added to the entire surface of 3D model using a brush with a ‘DragRect’ or ‘Spray’ stroke and a greyscale image alpha. Secondary forms such as wrinkles and other distinguishing features such as scars follow the tertiary forms by using a combination of sculpting brushes and alphas. An image alpha would be something like a series of pores or crows feet as shown in figure 14. Skin alphas can be downloaded from repositories including Pixologic ZBrush’s resource centre (https://pixologic.com/zbrush/downloadcenter/alpha/). This layering approach will produce good skin textures ahead of digital painting.

Figure 14: Layering of skin ’textures’ through a combined use of sculpting brushes and alphas in Pixologic ZBrush

Following the sculpting of these skin textures, the skin layer can be virtually painted with colour using imported digital photographs or virtual paintbrushes. The most effective approach to adding skin colour is to use a combination of these two methods. ‘Zadd’ or ‘Zsub; sculpting mode will be deselected and ‘Rgb’ colour mode will be selected in the upper toolbar to enable ‘Polypainting’. The 3D model is now ready for painting. To add a photographic donor image to the 3D surface, it first needs to be added to the ‘Spotlight’. In the ‘Texture’ menu at the top of the Pixologic ZBrush interface, click on ‘Import’, navigate to an image file on your computer and then select it. This image will appear in the ‘Texture’ menu. With the image selected in the ‘Texture’ menu, click on the ‘Add to Spotlight’ button below it. As shown in figure 15, the circular ‘Spotlight’ interface appears.

It is recommended to place the 3D model into a position that allows for effective transfer of the donor image to the model, without distortion. In the ‘Spotlight’ wheel, reduce the opacity of the image to approximately 50%, and resize and reposition it until it is placed correctly atop the model. When ready to paint the image onto the skin surface, choose a ‘Standard’ brush, ‘Freehand’ stroke, and a soft alpha. With these options selected, press ‘Z’ on the keyboard to hide the ‘Spotlight’ wheel and begin painting the donor image onto the model. Holding ‘Shift’ and ‘Z’ on the keyboard hides and shows the ‘Spotlight’ tool. This allows for alternation between the donor image and the painting results.

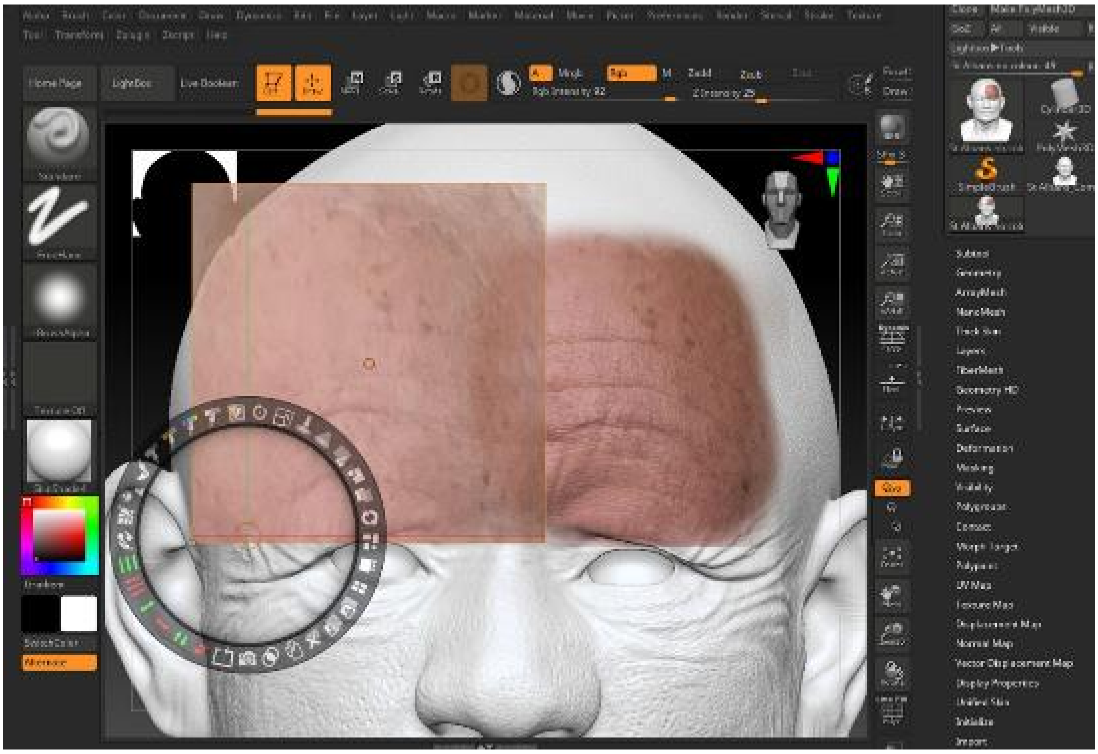

Figure 15:Adding photographic skin textures to a 3D skin model using donor images and the ‘Spotlight’ tool in Pixologic ZBrush

Photographic donor images are helpful in applying realistic textures to a facial reconstruction, however, it is important to choose the right textures to suit the morphology of the face, as with the 2D Digital Composite method. To blend multiple donor images that have been added using the ‘Spotlight’ tool, colour and additional textures can be painted using custom brushes and alphas.

With a chosen colour selected in the colour palette, a brush from the ‘Brushes’ palette can be chosen. Depending on the desired effect, it is recommended to either use the ‘Freehand’, ‘Spray’ or ‘DragRect’ strokes, and a variety of alphas. It is useful to begin with a ‘Standard’ brush with a ‘Freehand’ stroke and no alpha. Alphas can be then be interchanged, for example, a ‘sprinkling’ of pores can be added by using the ‘Standard’ brush, a ‘Spray’ stroke and an alpha with a dotted pattern. For more controlled placement of alpha images, it is recommended to use the ‘Standard’ brush with a ‘DragRect’ stroke. Custom brushes and alphas can also be imported. Figure 16 shows a custom ‘pore-controlled placement’ brush and alpha with a ‘DragDot’ stroke from Pablo Munoz Gomez (www.zbrushguides.com), used to carefully place additional skin details to a painted skin layer.

If preferred, it is possible to skip the ‘Spotlight’ step and proceed directly to painting in this manner. Choose a colour in the colour palette and a brush from the ‘Brushes’ palette to paint with. We recommend choosing the ‘Standard’ brush, change the stroke to ‘Freehand’ and for now, do not add an alpha. With these tools selected, paint a base colour across the entire surface of the skin layer. Colour changes, discolouration, and fine details such as wrinkles, freckles and sun damage can be added following the steps in the previous paragraph.

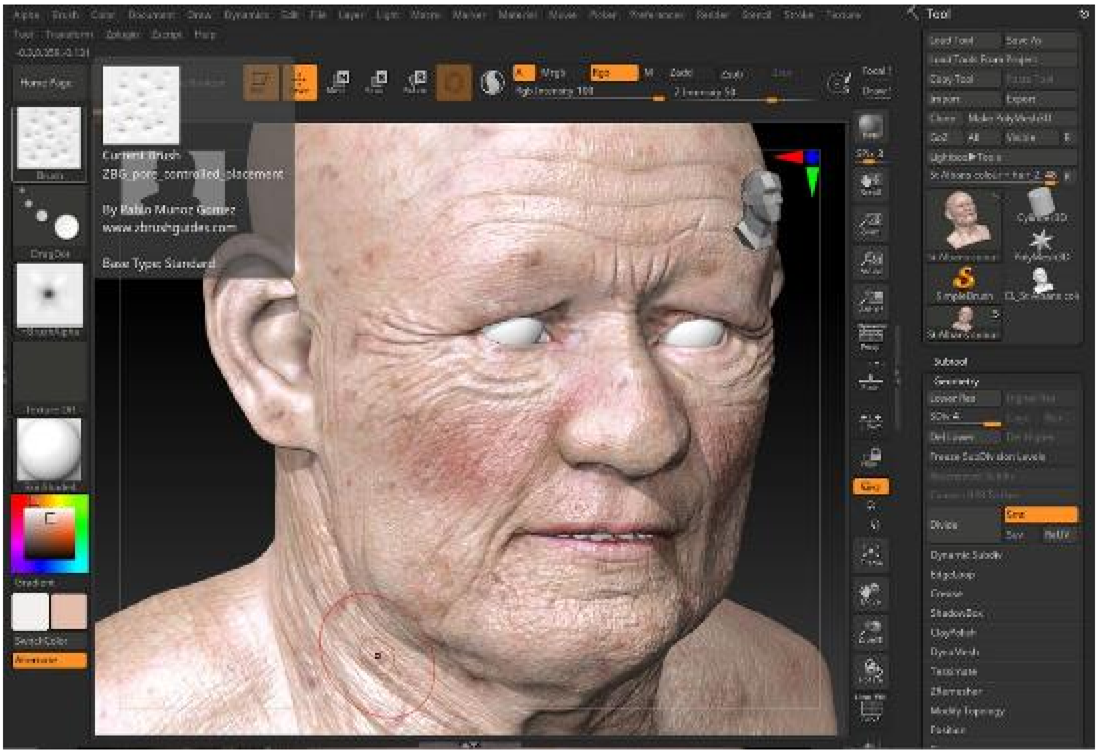

Figure 16: Adding skin details and additional colour using a variety of skin brushes and alphas in Pixologic ZBrush

Once digital painting of the skin layer is complete, two additional ‘mapping’ steps are required prior to exporting the model for rendering in software such as Autodesk Maya. To create a ‘Diffuse’ texture map (this is the map the retains the colour that has been painted), navigate to the ‘Texture Map’ palette in the Pixologic ZBrush interface to the right of the screen. To complete this step, a UV map would need to be created first. Then click 'Create' and 'From Polypaint' I the 'Texture Map' palette. A 'Diffuse' texture map is generated (see figure 17).

Figure 17: A 3D model and its generated texture map, visible in Pixologic ZBrush

The next step is to create a 'Displacement' map. A 'Displacement map' contains all of the height and depth information from the sculpted skin textures in your layers. It allows for the export of a base model at its lowest subdivision for maximum usability in the subsequent VFX software, and then reapplies the highly detailed sculpted skin textures using a map. First, with the model at its highest subdivision, go to the 'Layers' palette and choose to 'Bake All' layers. This combines them into one, therefore, sculpting should be complete and chosen layer intensities settled upon. Next, with the model at its lowest subdivision, go to the 'Displacement Map' palette in the Pixologic ZBrush interface to the right of the screen, and select 'Create DispMap'. A displacement map will be generated (see figure 18). To export the map for use in other software, choose 'Create And Export Map'.

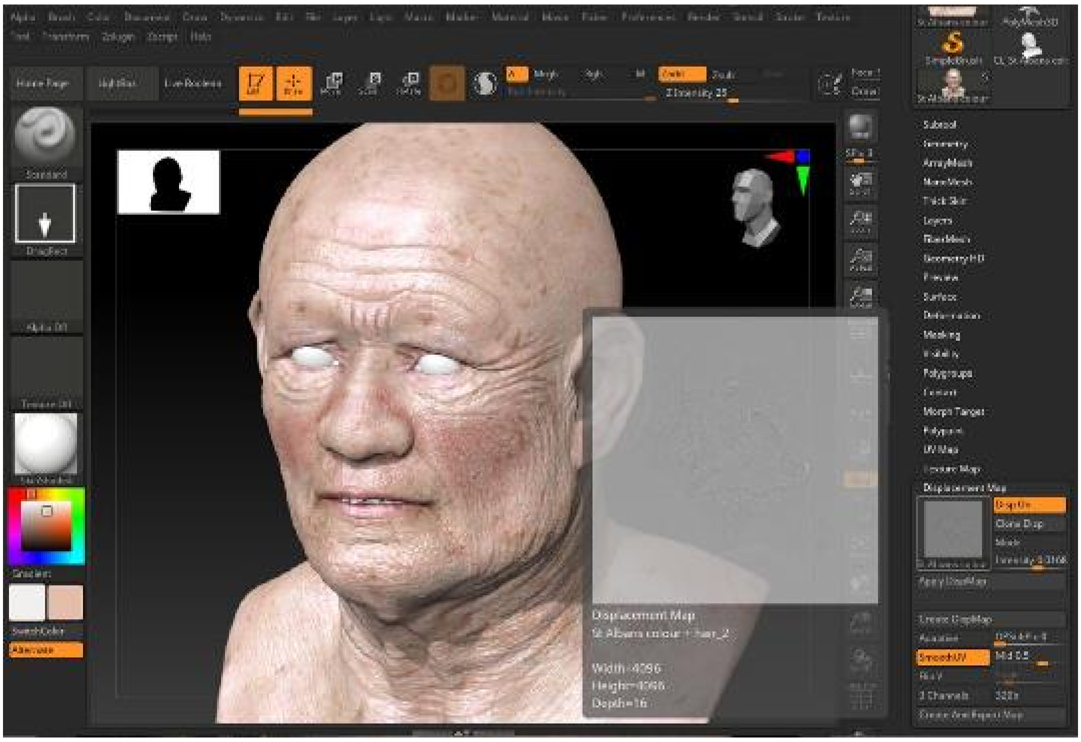

Figure 18: A 3D model and its generated displacement map, visible in Pixologic ZBrush

The 3D head model and its associated maps are now ready for export. In the ‘Geometry’ palette, the model should be moved to its lowest subdivision. The next step is to navigate to ‘Export’ in the menu at the top-right of the Pixologic ZBrush interface. Choose .OBJ as the file type and select a save location on your computer. When ‘Export’ is clicked, multiple files will be saved: the 3D mesh as an .OBJ file, a material as a .MTL file, and the diffuse maps as an image file.

Open a VFX software and import the .OBJ of your 3D model, which will be at its lowest subdivision. For the purposes of this workflow we used Autodesk Maya 2020 with a default workspace. Any imported 3D models plus other 3D objects generated in Autodesk Maya can been seen listed in the ‘Outliner’ as shown in figure 19. To create a default workspace and file system on your PC (to hold assets, scenes and rendered images amongst other things), go to ‘File’ > ‘Project Window’ > ‘New’, rename the project and choose the desired save location on your computer. Then click ‘Select’.

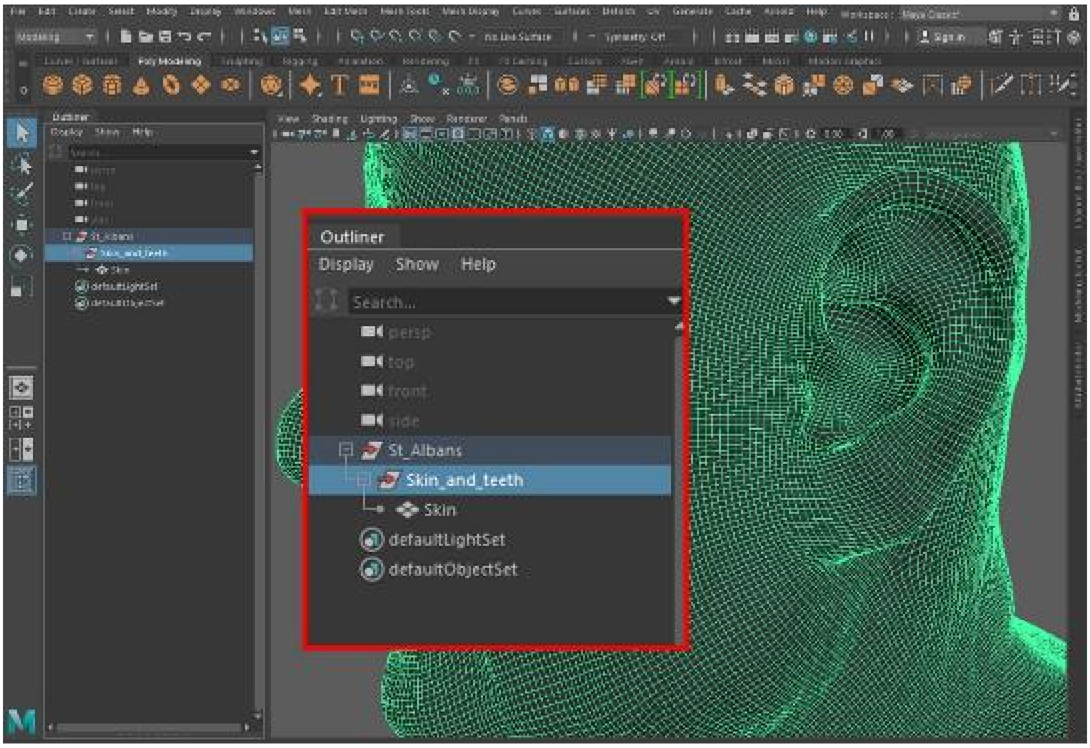

Figure 19: 3D model imported into Autodesk Maya, and the 'Outliner' window

Once the model is imported into an Autodesk Maya 3D scene, a studio setup similar to a photography studio with a lighting rig will need to be created (see figure 20). At a minimum, a 'floor' and 'walls' should be added so the lights can be contained within the area where your 3D model is placed. From the menu at the top of the Maya interface choose 'Create', 'Polygon Primitives' and 'Plane'. Once the plane is inserted into the 3D scene, use the 'Transform', 'Move' and 'Rotate' tools from the left-hand toolbar to position it into the desired location. Do this as many times as required to create a 'photography studio'. Reposition and resize the 3D head model to fit the studio space. Default 'Perspective' and 'Orthographic' virtual cameras are added when a new scene is created, and the user can move between them by selecting them from the 'Panels' tab at the top of the viewport.

Without lights in the scene, it will not be possible to visualise the 3D models when images are rendered. A standard 3-point light set up will illuminate the 3D models evenly and replicate real-world environments. To add lights, navigate to 'Create' in the menu at the top of the Autodesk Maya interface and choose 'Lights' then 'Directional Light'. Once a light is inserted into the 3D scene, use the 'Transform', 'Move' and 'Rotate' tools from the left-hand toolbar to position it into the desired location. Do this as many times as required to create a 3-Point light setup. The exposure, diffusion and temperature of the virtual lights can be adjusted accordingly in the 'Attribute Editor' panel, found to the right of the Autodesk Maya interface. A warm soft pink light and a cooler soft blue light are recommended to be placed at either side of the 3D head, with a brighter white light pointing towards the face for optimum illumination. Experimentation with positioning of the lights and their associated settings is recommended until a desirable setup is reached.

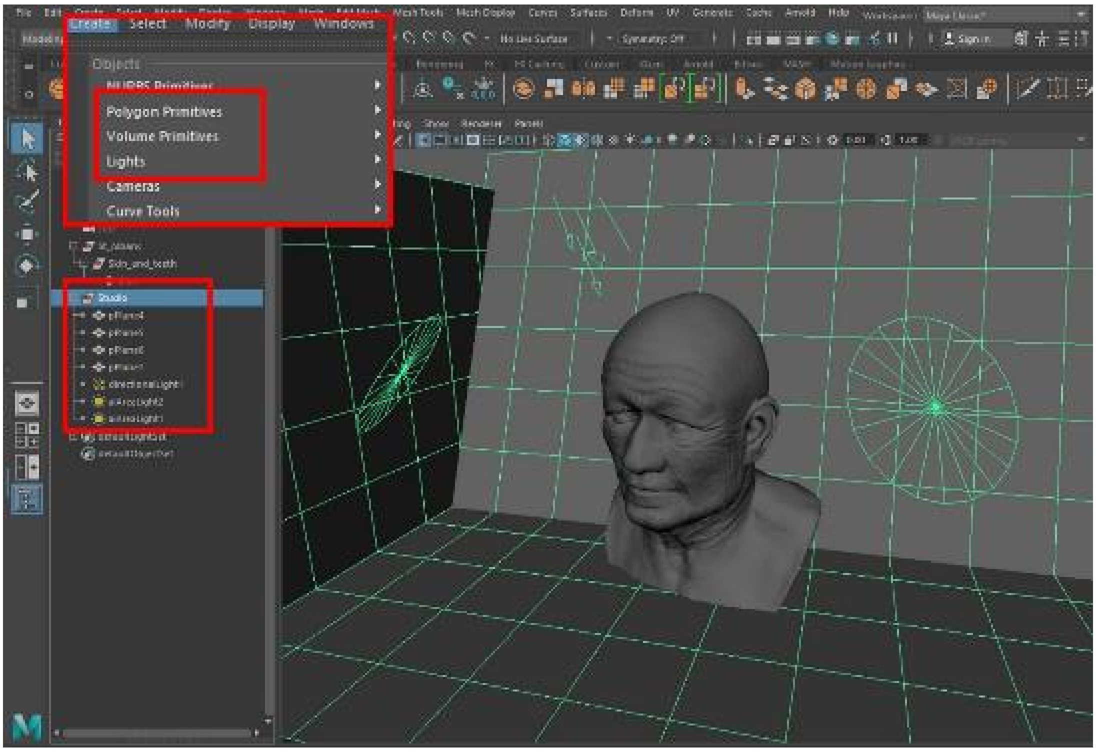

Figure 20: A studio setup and 3-point lighting system in Autodesk Maya

The default material assigned to a 3D model when imported into Autodesk Maya is ‘Lambert’, which is “a material (shader) that represents matte surfaces, such as chalk, matte paint, and unpolished surfaces with no specular highlights” (Autodesk, 2016). A different shader would need to be assigned for the surface of the 3D model to resemble human skin. In this example, with the 3D model eventually being rendered using the Arnold rendering engine, an ‘aiStandardSurface’ shader is used. This shader is capable of producing many types of materials (Autodesk Arnold,a) and a surface that resembles skin can be generated.

With the 3D model selected, press and hold the right mouse button for the menu in figure 21 (left) to appear. Navigate to ‘Assign New Material’ and choose ‘aiStandardSurface’ shader. In the ‘Attribute Editor’, accessed to the right of the Autodesk Maya interface, the material shader options will appear. Click the ‘Presets*’ button and choose ‘Skin’ and ‘Replace’. This shader is now applied to the 3D model and can be further customised by altering material settings and adding texture and displacement maps, either within the ‘Attribute Editor’ or via the ‘Hypershade’ window (Autodesk, 2014a).

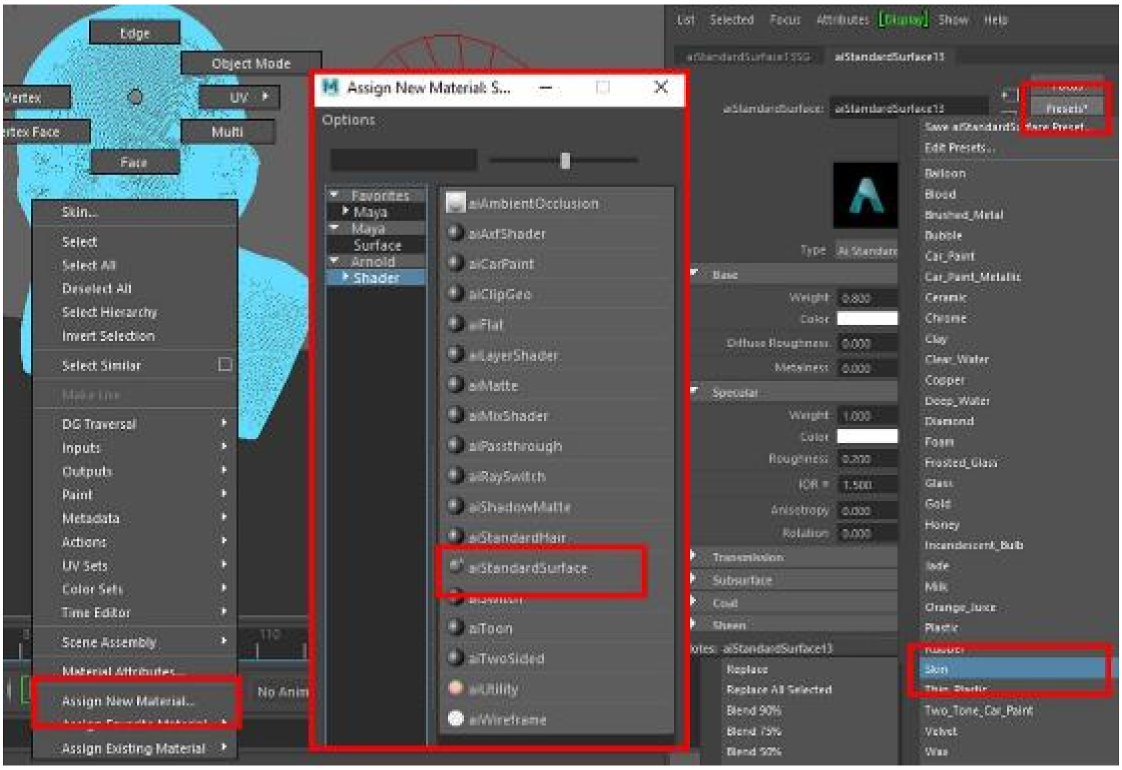

Figure 21: Applying an 'aiStandardSurface' shader to a 3D model in Autodesk Maya

With the 3D model selected, in the 'Attribute Editor', add the 'diffuse' colour texture map that was exported from Pixologic ZBrush to the 'Subsurface Colour' node. Click on the checkerboard icon, then choose 'File' in the '2D Textures' menu. Click the folder icon next to 'Image Name' then navigate to the colour texture map on your computer and click 'Open'. The colour texture map is now applied to the 3D model, as demonstrated in figure 22. If the texture map does not align correctly when applied and viewed in the Autodesk Maya viewport, the map may need to be transformed. Depending on the version of Pixologic ZBrush used to digitally paint the 3D model, the exported colour texture map might first need to be flipped horizontally to be in the correct orientation for use in Autodesk Maya.

For additional customisation of the skin's material properties, the 'Subsurface', 'Specular' and 'Sheen' properties can be adjusted, however, the settings added earlier by the 'Skin' preset should suffice. If the 3D model was resized, the 'Radius' in the 'Subsurface' properties may need to be reduced to avoid the skin layer appearing too washed out. A grayscale specular map can be added to the 'Specular' > 'Colour' node for more advanced control of where highlights appear on the skin surface.

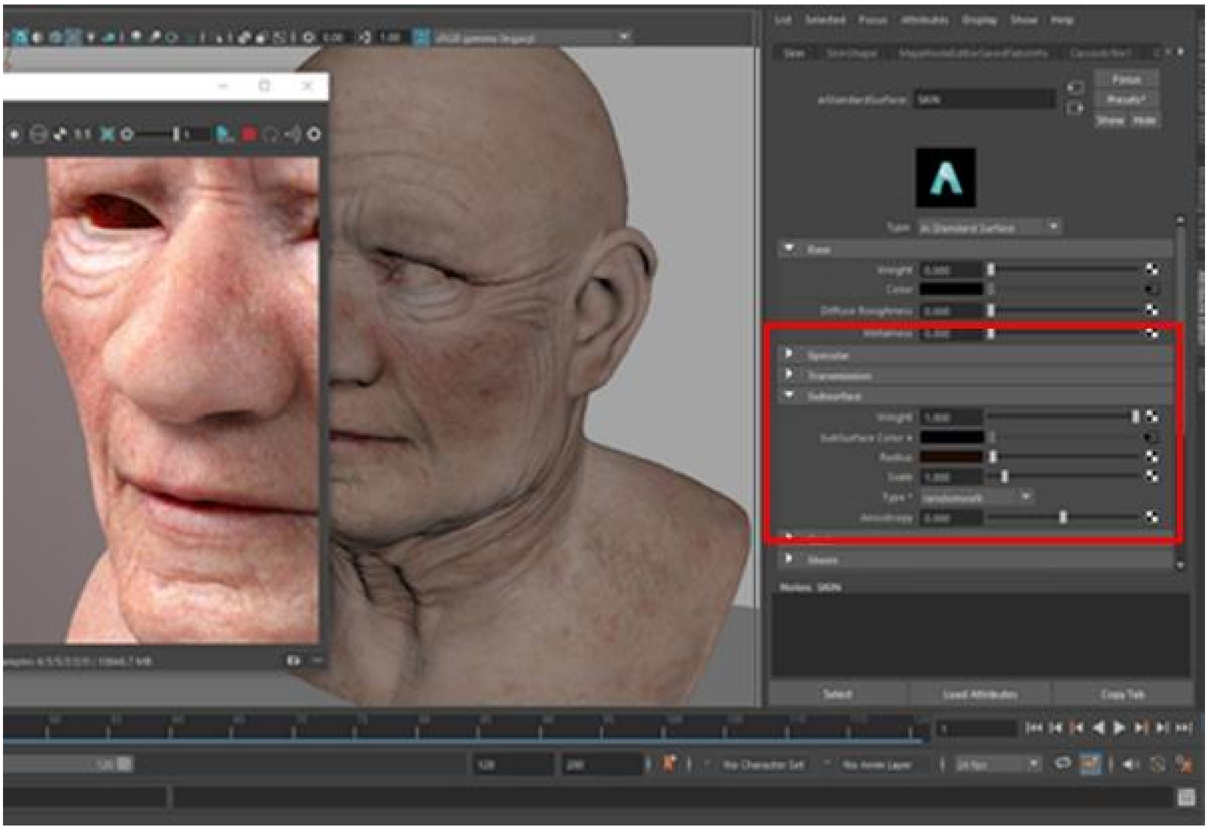

Figure 22: Applying texture maps and adjusting shader settings in Autodesk Maya

The connections between the material nodes and shaders can be visualised in the 'Hypershade' window. The 'Hypershade' window is accessed from the 'Windows' > 'Rendering Editors' menu from the top of the Autodesk Maya interface. With the shader selected in the 'Hypershade', under 'Shading Group Options' click on the icon to the right of 'Displacement mat.' and the additional nodes will be added to the node tree in the viewport (visible at the bottom of figure 23). Click on the 'image' node and add the displacement map in the same way that the colour texture map was added to the 'Subsurface Colour' node. In this node, select 'Alpha is Luminance' under 'Colour Balance'.

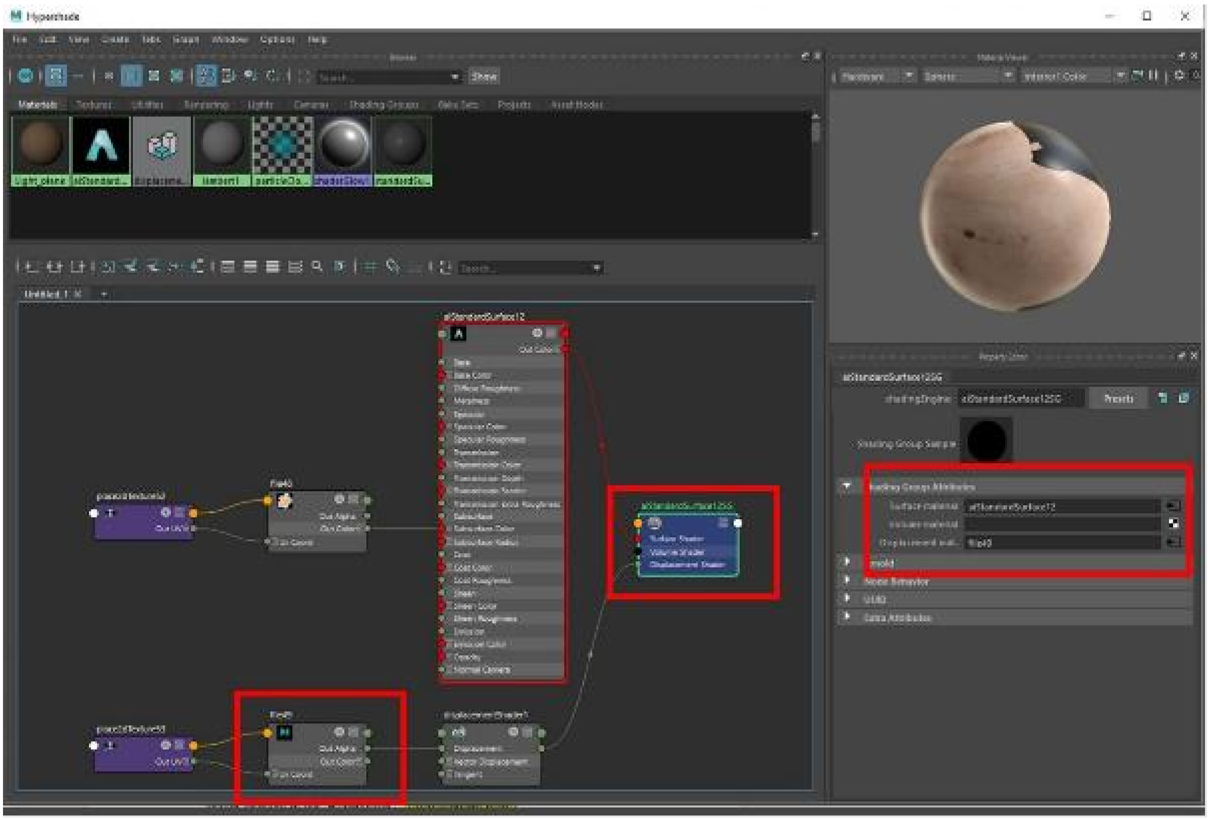

Figure 23: A node tree for a skin shader, highlighting the workflow for adding a displacement map to the 3D model in Autodesk Maya

To adjust the displacement settings select the 3D model in the ‘Outliner’ and under the ‘Shape’ tab in the ‘Attribute Editor’. Scroll down to ‘Subdivision’, select ‘catclark’ under the ‘Type’ with a recommended 4 iterations. This figure controls the subdivision of a surface and a higher number increases the displacement quality. However, a high value will also increase render time (Autodesk Arnold, b). Under ‘Displacement Attributes’ the ‘Height’ of the displacement map can be altered until the desired final appearance of skin layer is reached. Multiple test renders might be required. Adjustments to the virtual lights in the scene may be required if the model is too exposed or the scene is too dark.

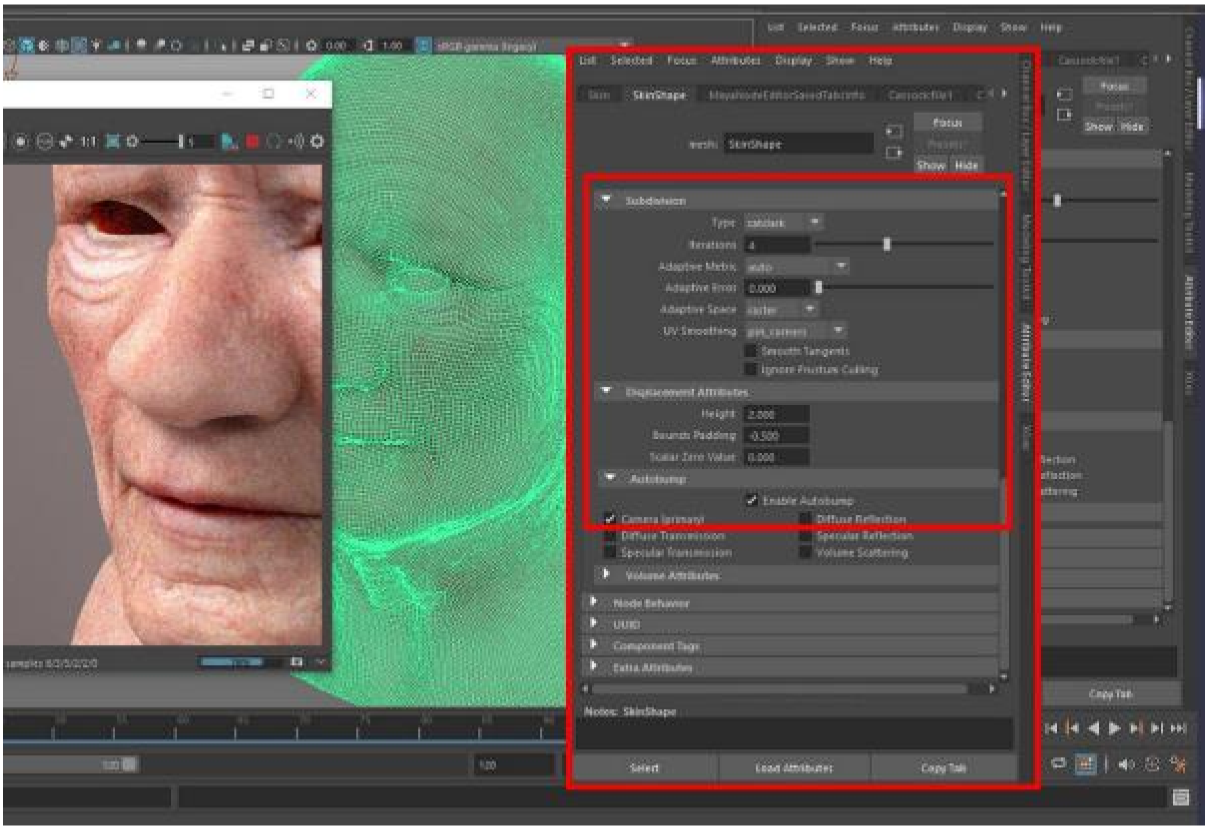

Figure 24: Altering displacement map settings in the 'Attribute Editor' in Autodesk Maya

To add realistic human eyes to the scene, eyes can be 3D modelled in Autodesk Maya or downloaded and modified under Creative Commons licenses to suit your project needs. These are available from online repositories such as TurboSquid and Sketchfab. For this workflow, 3D eye models freely available from the Autodesk website have been used (https://www.autodesk.in/campaigns/arnold/asset-3d-eye). Figure 25 shows the setup of these eye models in the 'Hypershade' window after importing the models, resizing them to fit the 3D head, and connecting texture and displacement maps. The 3D eye models exist in two parts; the 'eyeball' and the 'cornea', with preloaded material settings for each. The colour texture map for the eyeball can be altered in Adobe Photoshop CC if the pre-existing iris colour is incorrect for the facial depiction.

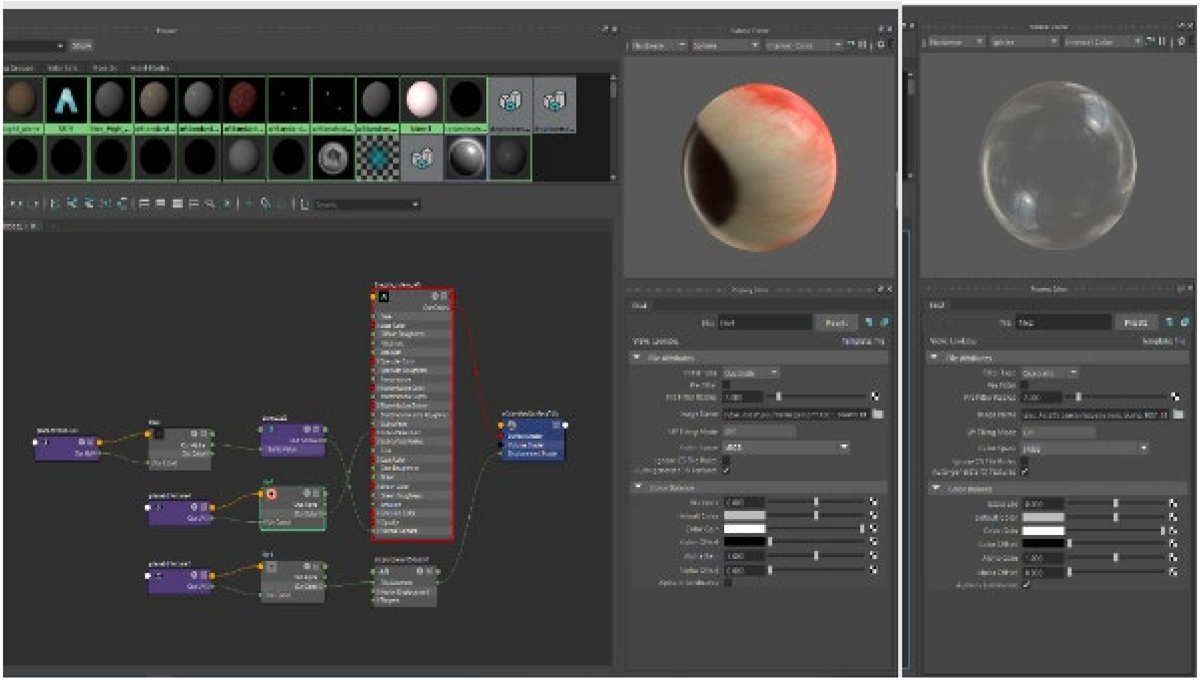

Figure 25: The node tree and shader settings for 3D eye models available from the Autodesk website. Viewed in the 'Hypershade' window in Autodesk Maya

At this stage, additional objects such as garments and jewellery can be imported or 3D modelled, and digital textures added to them following the aforementioned workflow. To create hairs, the XGen tool within Autodesk Maya should be used. XGen is a geometry instancer, able to create and style hair, fur, feathers, grass and forests (Autodesk, 2014b). Select the 3D skin model in the 'Outliner' that hairs should populate from. To create hair in specific areas on the 3D model select the faces of the 3D model in the desired locations. Once a specific area of the 3D model is selected, click on 'Create a new XGen description' under the 'XGen' menu at the top of the Autodesk Maya interface. In the popup window, name the new description and click 'Create a Collection'. To generate hair, select 'Splines' as a primitive, and to be generate 'Randomly across the surface'. The controls should be 'Placing and shaping guides' (see Figure 26).

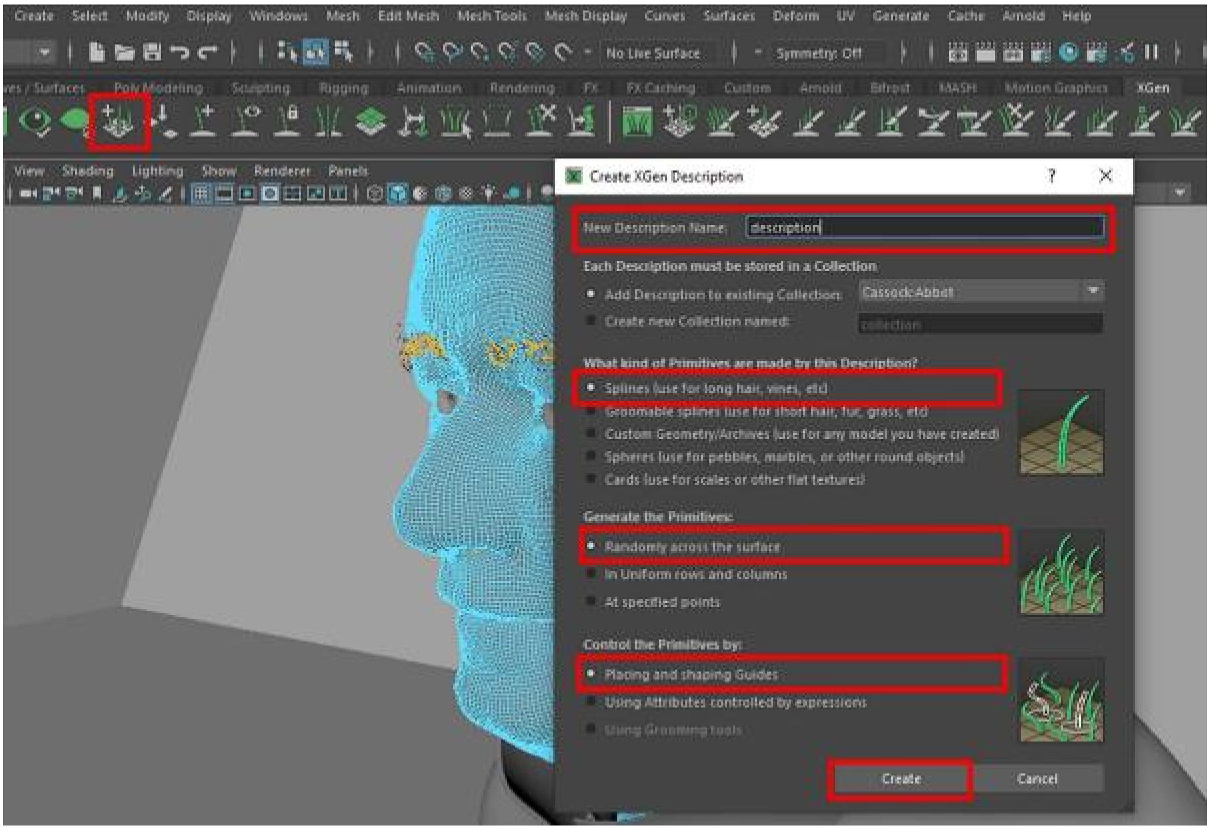

Figure 26: Creating XGen Descriptions for hair modelling in Autodesk Maya

Once ‘Create’ is selected, the new collection will appear in the ‘Outliner’ as a folder in green. Hair is generated by placing guides on the surface of the selected area. Hair will ‘grow’ according to the direction of the guides. Under the XGen tab, select the ‘Add or Move guides’ (the icon with a ‘+’), click on the surface of the model and adjust the guide using the ‘Transform’ and ‘Rotate’ tools from the left-hand toolbar. The guide can be moved by holding ‘Ctrl’ on the keyboard when ‘Add or Move guides’ is selected. The ‘Move’ tool from the left-hand toolbar is ineffective to adjust the position of the guide. The shape of the guide can be manipulated using ‘Sculpt guides’. Create a new description for different types of hair e.g. one for eyebrows, one for a beard, one for head hair etc. (see figure 27).

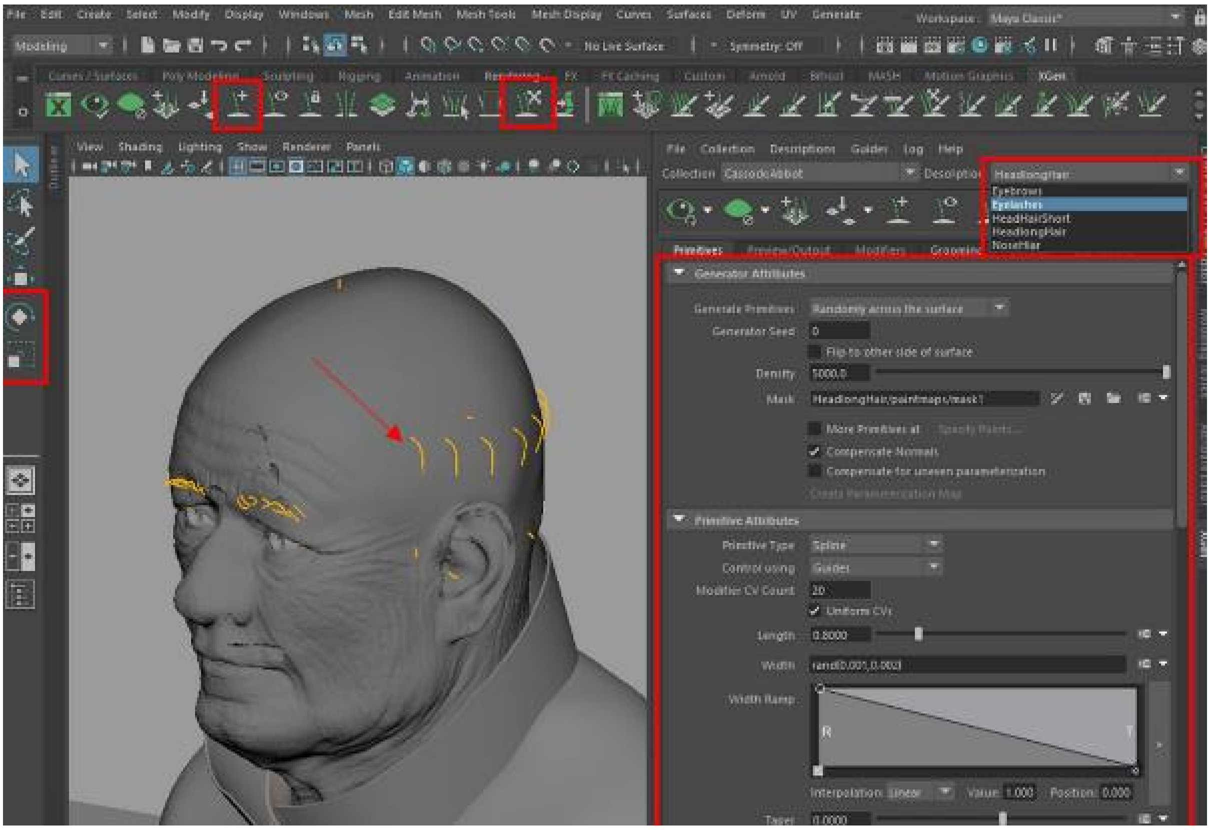

Figure 27: Adding and editing XGen hair guides in Autodesk Maya, using different hair description for different hair types.

The hairs can be visualised in the viewport by using the 'Update the Preview' (icon with an eye highlighted in figure 28). The 'Generator Attributes' tab in the XGen window (figure 27) can adjust the density and randomness of the hairs across the surface of the 3D model. The shape, length and width of the generated hairs can be adjusted under 'Primitive Attributes' (figure 27). To create realistic hair, 'Modifiers' such as 'Noise' and 'Clumping' can be added and adjusted, as shown in figure 28. Expressions can also be used to create more randomness in the structure, as explained in detail by JesusFC (https://jesusfc.net/tutorials/introduction-to-xgen).

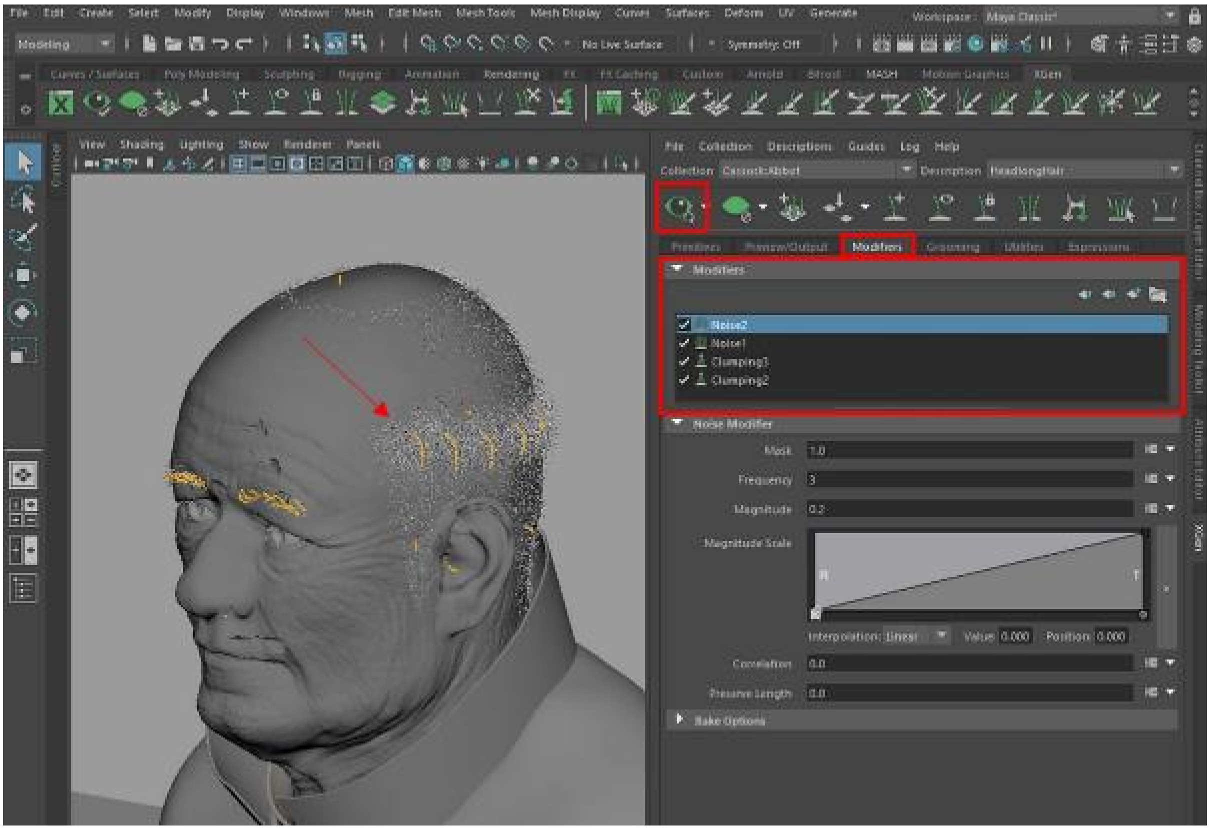

Figure 28: Visualising the XGen hair in the viewport with 'Update the XGen preview'. The addition of modifiers to generate realistic hair using Arnold in Autodesk Maya.

A new hair shader can be assigned to the hair systems in the 'Hypershade'. The Arnold 'aiStandardHair' shader allows users to adjust the level of melanin, redness and randomness of the hair colours (figure 29). This is an intuitive system in adjusting the colour of the hair.

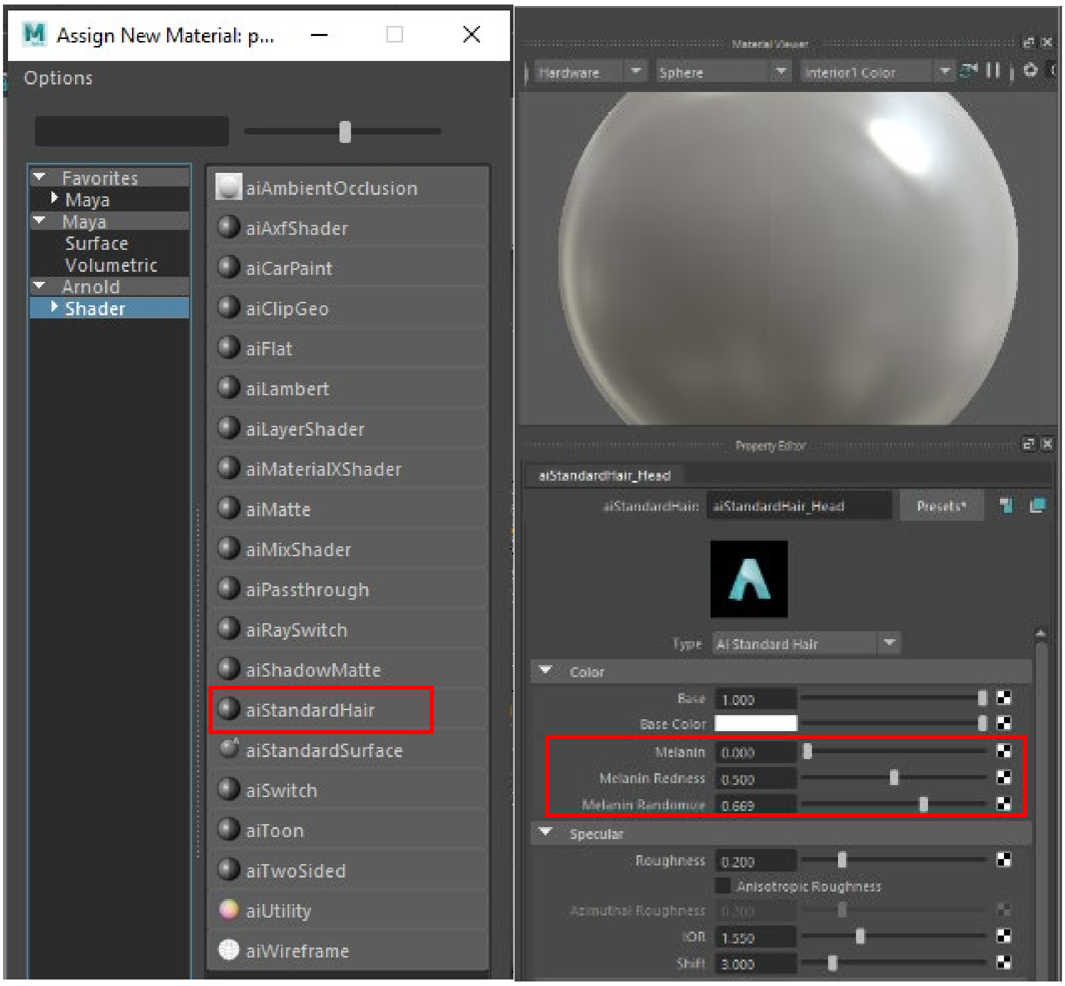

Figure 29: Arnold 'aiStandardHair' shader with options to adjust the level of melanin, redness and randomness, to generate realistic hair using Arnold in Autodesk Maya.

Throughout this process, test renders of the 3D scene can be performed at lower resolutions, which reduces render time. Select 'Render' from the top menu bar in the Autodesk Maya interface, then 'Test Resolution' and choose one of the reduced percentage settings. Then navigate back up to 'Arnold' in the menu bar and click 'Render' to render the scene in a new 'Arnold RenderView' window (figure 30). If the render doesn't automatically start, click the 'Play' button.

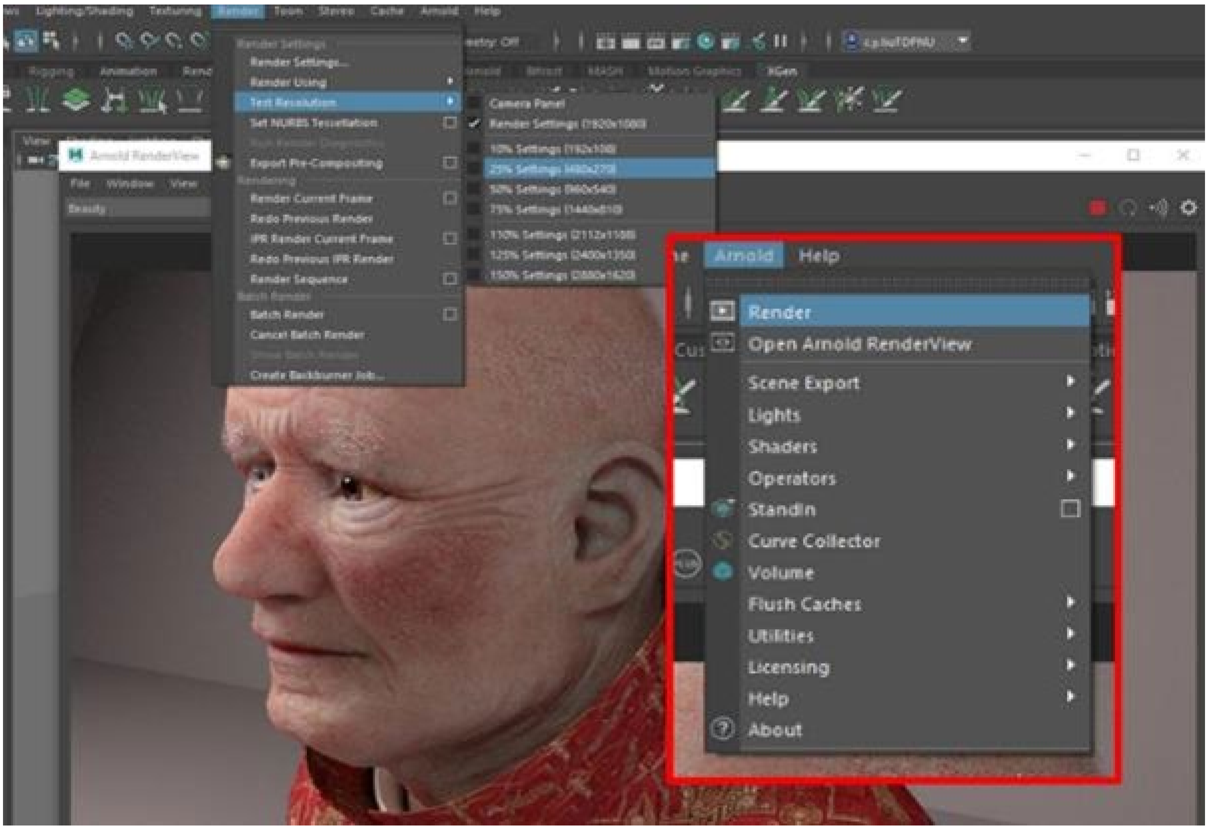

Figure 30: 'Arnold RenderView' in Autodesk Maya under 'Arnold'. Test resolution can be adjusted from the 'Render' menu.

When satisfied with the appearance of the 3D model, hairs and shader settings, a final image of the facial depiction can be rendered at 100% resolution. To choose an image format, change the render settings in 'Render' > 'Render Settings' from the top menu bar in the Autodesk Maya interface. Specific cameras, image formats, images sizes and image resolutions can be chosen here. For more advanced image rendering, the CPU and GPU settings can be changed in the advanced options. Please refer to this guide provided by Arnold for more information (https://docs.arnoldrenderer.com/display/A5ARP/Getting+Started+With+Arnold+GPU).

Select 'Render' from the top menu bar in the Autodesk Maya interface and select 'Render Current Frame'. Any images rendered will be saved to the 'Images' folder within your Autodesk Maya project on your computer. The 3D model is often positioned to face the camera in the Frankfurt Horizontal Plane prior to rendering.

If you were animating the 3D model, for example, getting it to move on a turntable, the models can be translated and rotated then keyframed in the scene by using the tools in the 'Animation' menu and the timeline at the bottom of the Autodesk Maya interface. Alternatively, the camera can be animated to move around the 3D model. In 'Render Settings' choose start and end frame numbers for the sequence length, then choose 'Render Image

Sequence' in the 'Render' menu to render all layers. For detailed animation and sequence rendering steps consult guides on the Autodesk Knowledge Network (https://knowledge.autodesk.com/support/maya/learn-explore.html)

2.5D Digital Composite Method

3D modelling of eyes, hair and clothing, plus skin material and virtual lighting choices that require advanced CGI skills can be time consuming to generate in VFX software. Like the 3D digital painting method, the hybrid 2.5D method adds skin textures directly on the skin layer of the 3D facial reconstruction model. However, more complex textures such as hair and eyes, are composited on a 2D image of the painted 3D model.

Figure 31 visually demonstrates the 2.5D workflow. The image shows a digital facial depiction of a 1200-year-old bog body from Bernuthsfeld, East Frisia (Wilkinson and Roughley, 2019) for which a front-facing 2D image of the face was requested. The 3D facial reconstruction was created in Geomagic Freeform and the skin layer of the 3D model painted in Pixologic ZBrush using the aforementioned 3D digital painting techniques. Eyes, hair and clothing were added to a 2D, front-facing image of the facial depiction in Adobe Photoshop CC using the techniques described in the 2D digital composite method.

When first approached by the archaeological team, the choice of eye colour, hair colour and style, and clothing materials were yet to be confirmed as scientific analyses of the human remains, which included preserved hair and fabrics were incomplete. The facial reconstruction and skin painting was undertaken and the depiction process was then paused until information regarding eyes, hair and clothing were made available from the scientific researchers. In addition to this flexible approach to working and an increased speed in texturing the face model, compositing these features in 2D provided opportunities to produce multiple iterations of the depiction for consideration. For example, generating different combinations of clothing material and hairstyle, until a scientific and artistic consensus was reached.

Figure 31: Example of 2.5 texturing method: 3D digital facial depiction of a 1200-year-old bog body known as "Bernie" created in Geomagic Freeform; exported to Pixologic ZBrush for digital painting; exported to Adobe Photoshop for composite texturing of eyes, hair and clothing. Image courtesy of Face Lab, Liverpool John Moores University.

Workflow

Like the digital 3D painting method, the skin layer of the 3D facial reconstruction is exported from the software that it was created in and imported into Pixologic ZBrush. The model will usually require a simple retopology, and the 'ZRemesher' tool can be used to create a mesh with organised topology ready for painting. If the mesh appears to have too few polygons, more can be added by using the 'Divide' button in the 'Geometry' palette. This increases the number of subdivisions that the 3D model has. It is recommended to also generate a UV map at this stage in case the model is to be used in VFX software in the future. The previously described method for UV mapping can be implemented, however, it may be unnecessary for this type of project, therefore simply pressing the 'UV Unwrap' button in 'UV Master' will be sufficient. The 3D model will need to be at the lowest subdivision in the 'Geometry' palette for UV unwrapping to take place. This can be increased to the highest subdivision level again prior to start the next stage.

If desired, skin textures such as creases and wrinkles can be sculpted as demonstrated in figure 14, however, the 2.5D method can continue without the need for sculpted skin textures. Digital painting of the skin layer commences by using brushes and alphas or by using photographic donor images and the 'Spotlight tool'. The workflow for digital painting (shown in figures 15 and 16) can be followed until the model is ready for export.

Pixologic ZBrush also possesses a number of other tools that can be used prior to exporting the front-facing image, to enhance the photo-realism of the generated face image. These include adjustable material settings, built in virtual lights, and an integrated rendering engine. We have recommended the use of the 'SkinShade4' material when painting in Pixologic ZBrush due to its specularity adjustment options, and this material's properties (and any other material's properties) can be altered in the 'Material' drop-down menu at the top of the Pixologic ZBrush interface. The diffuse colour, transparency or specularity settings could be changed to increase realism of the painted skin surface.

The built-in lighting system allows the user to add, move and adjust the intensity and colour of the virtual lights in the 3D scene. The settings of these lights can be altered in the 'Light' drop-down menu at the top of the Pixologic ZBrush interface until a desired appearance is reached. The scene can be rendered using the inbuilt BPR renderer. This is found under the 'Render' drop-down menu at the top of the Pixologic ZBrush interface and it has options to adjust appearance features like shadow intensity. While the BPR renderer may not appear as effective as the Arnold render in Autodesk Maya, it is very quick and may enhance the photo-realism of the painted skin.

When the model is sufficiently painted, instead of exporting the 3D model as an .OBJ file with its associated maps, go to ‘Document’ in the menu bar at the top of the Pixologic ZBrush interface and choose ‘Export’ (figure 32). This will allow for the export of the current view as an image file to be opened in Adobe Photoshop CC. It is recommended that the 3D model be placed in the Frankfurt Horizontal Plane and exported a frontal facing image.

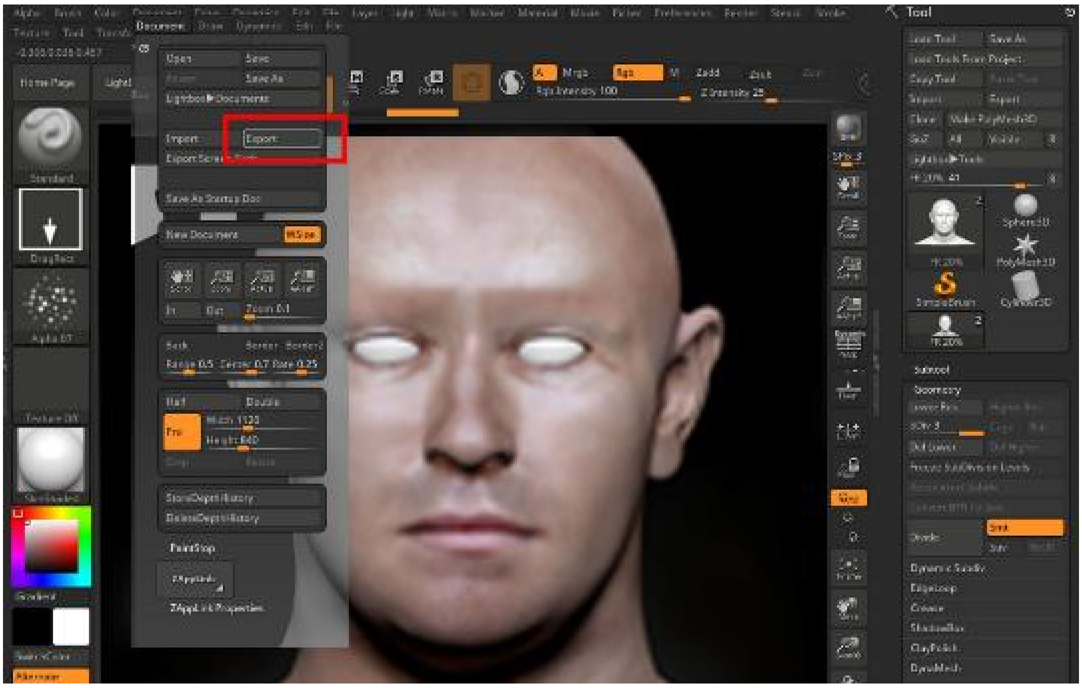

Figure 32: Exporting an image of the current scene from ZBrush as an image document.

When the image is opened in Adobe Photoshop CC, digital compositing methods can be used to add realistic eyes, hair, clothing and accoutrements to the 2D image of the 3D painted facial depiction (figure 33). Once complete, the layer can be flattened and a final image can be exported for publication.

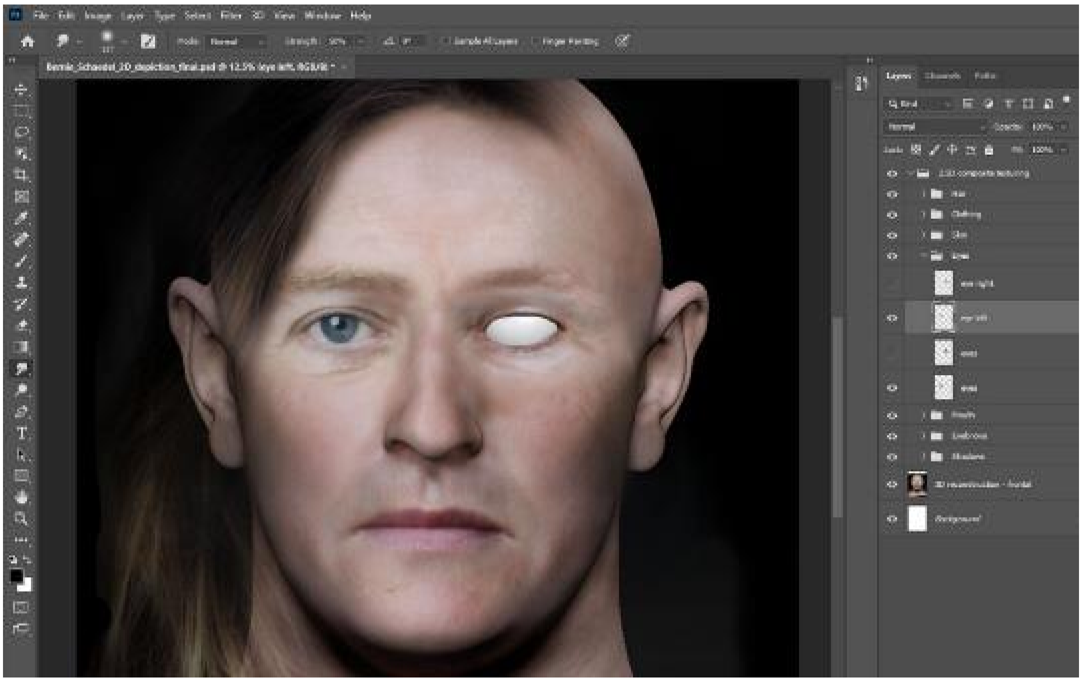

Figure 33: Compositing of eyes, hair and clothing in Adobe Photoshop CC on top of an image exported from Pixologic ZBrush as an image document.

Discussion

Facial reconstruction and depiction visualizes a facial appearance of an individual from their skeletal remains. While the prediction of face shape follows anatomical standards and the accuracy of methods available have been established (Wilkinson, et al. 2006; Lee, et al. 2012), the texturing process is driven by the preference and skillset of the facial depiction practitioner, alongside access to required technologies and availability of supporting information relating to textural appearance. Technologies are also changing rapidly, and this requires a significant investment from the practitioner to learn or keep up to date with advancements. The three methods described in this chapter for adding textures to digital 3D facial reconstructions each have their own affordances, and although these methods are described in the context of adding digital textures to 3D models for facial depiction purposes, they are transferrable and can be utilised for anatomical and medical visualisation.

Comparing Methods for Adding Digital Textures to 3D Facial Reconstructions

Facial depiction practitioners can use various off-the-shelf image graphics software with image transformation and digital painting capabilities to add digital textures to facial depictions (Taylor, 2000; Roughley and Wilkinson, 2019). Adobe Photoshop CC contains suitable tools for adding digital textures to 2D images of 3D facial reconstructions. It facilitates compositing of numerous photographic images and digital painting to create realistic 2D digital facial depictions for display on screen, online or in print. In comparison to the other two techniques described in this chapter, the 2D digital composite method is the fastest – taking approximately 8-10 hours to complete.

It is also relatively low cost and does not require advanced 3D painting and VFX skills to add textures to 2D images of 3D facial reconstructions.

Care should be taken when applying donor textures to the facial depiction image during the composite texturing process. Application of identifiable textures might inadvertently affect recognition or be recognised as the donor. Good practice is to use less than 10% of one donor image for anonymization. For individual features, Shrimpton (2018) suggests the compositing of more than two donor images per feature, and if one face donor image is being used to composite multiple parts of the facial depiction, no more than half of the donor face image should be used. With facial features that include identifiable biometrics (iris patterns and lip prints) it is possible to anonymise them. If the shape of these features has been chosen because they best match the morphology of the 3D facial reconstruction, but further anonymisation is required, parts of the features can be blurred, additional details digitally painted on new layers, and parts of the image can be swopped for parts of other images. For example, using a lip shape from one image and a lip print from another, or blurring the iris pattern.

In addition to an awareness of the impact of applying identifiable donor textures to a depiction, caution when choosing and applying photographic donor textures should be taken to ensure that any 'shape' information transferred does not infer incorrect morphology. Errors can occur when attempting to texture an image of a 3D facial reconstruction with 2D images. In the 2D digital composite method, the contour, lighting and shape from the donor photographs can be difficult to match to the 3D shape of the facial reconstruction. This potentially creates opportunities for the suggestion of different morphology through the application of unsuitable textures.

Figure 34 shows different photographic donor images of a nose applied to two iterations of the same 3D face model via the 2D composite method in Adobe Photoshop CC. Transformation of the donor images was limited to rotate, scale and opacity. It is demonstrated that the nose shape added by the image compositing process appears to be different to that of the 3D facial reconstruction and more advanced transformations are required if this donor texture is to be used. If caution is not taken to transform and edit the donor images sufficiently, the shape of the face can be affected.

Shadows present on the image of the 3D facial reconstruction in the 2D digital composite method are important in helping to define morphology. These shadows are created by virtual lights in the 3D software where the facial reconstruction was created and they can be harnessed by duplicating the layer that contains the imported 3D facial reconstruction image and moving it to the top of the layer stack. Then, in the 'Blend Mode' drop-down menu in the 'Layers' palette, change 'Normal' to 'Multiply'. The image may appear oversaturated and require some minor image adjustments or a reduction in opacity to reach a desired finish but importantly, the morphology-defining shadows will remain.

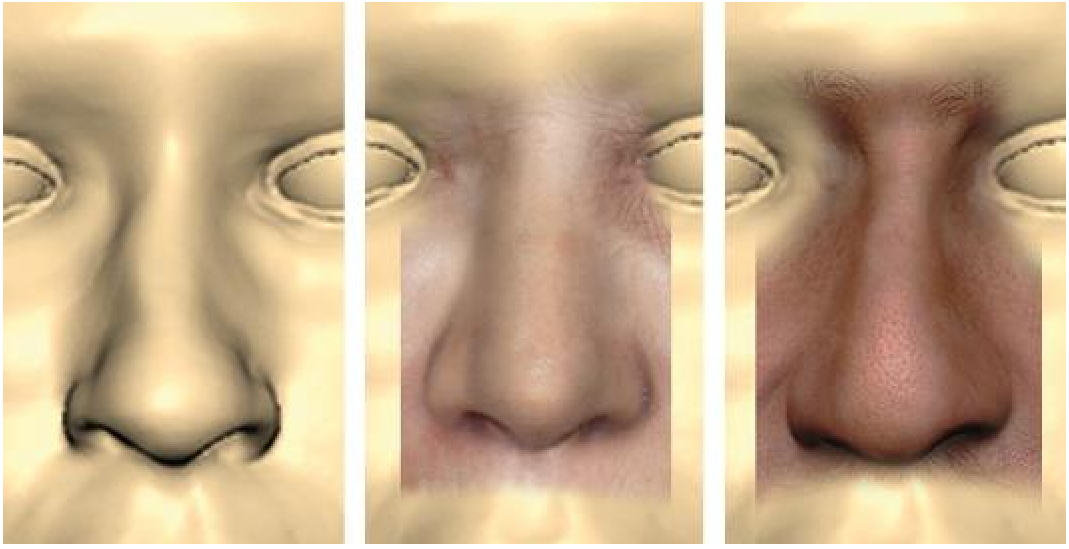

Figure 34: Potential impact on feature shape from different photographic donor images via the 2D digital composite method in Adobe Photoshop CC.

ZBrush is a digital sculpture software that combines 3D modelling, texturing and painting, and its resemblance to traditional sculpture makes ZBrush easier to learn and adapt to than other available 3D modelling software. Its application in anatomical and medical visualisation has been effectively demonstrated (see Erolin, et al. 2017; Webster, 2017; Christ, et al. 2018; Erolin, 2019; Jędrzejewski, et al. 2020; Knight, et al. 2020; Maniam, et al. 2020; Šulek, et al. 2020; Adams, et al. 2021), however, there is limited documentation of its use for texturing 3D facial depictions with only a small number of examples currently available (see Charlier, et al. 2019; Roughley and Wilinson, 2019; Wilkinson, et al. 2019; Smith, et al. 2020; Martínez-Labarga, et al. 2021).

The software facilitates digital painting and sculpting in three-dimensions and has real use in applying textures to 3D facial reconstructions. Unlike the 2D digital composite method, painting textures directly onto the surface of the 3D model, and compositing with the 'Spotlight' tool in Pixologic ZBrush, could reduce the likelihood of morphological errors occurring between the 'clay-like' model and the final textured face. This is because the paintbrushes and projected images follow the contours of the 3D skin layer.

Figure 35 shows a photographic donor image applied to two iterations of the same 3D face model. On the left, the digital 2D composite method was follow using a screenshot of the 3D model in Adobe Photoshop CC. The transformations applied to the donor image were rotate, scale and opacity. A 'Multiply' blend mode was also applied to use shadows from the facial reconstruction image. On the right is the application of the same donor image via the digital 3D painting method using the 'Spotlight' tool in Pixologic ZBrush. The donor image was rotated and scaled, and the opacity reduced before being painted directly onto the surface of the 3D model. It is possible that 'shape' information from donor images can be transferred to the 3D model in both methods, however, the risk of extreme morphological error is reduced in the 3D digital painting method.

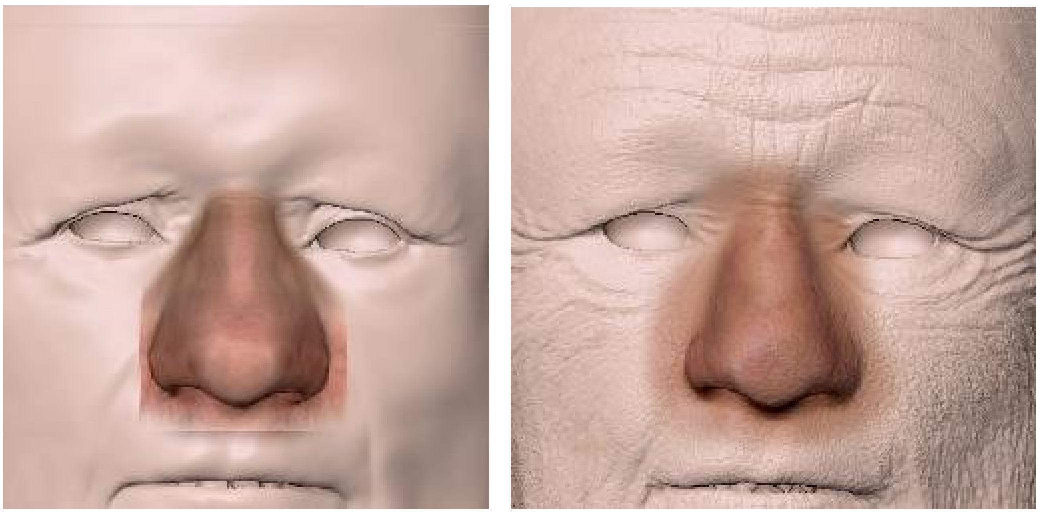

Figure 35: The same photographic donor image applied to two iterations of one 3D face model. On the left, the digital 2D composite method was used with little transformation of the donor image. On the right, the digital 3D painting method and 'Spotlight' tool was used with little transformation of the donor image

Working entirely in 3D enables the head model to be moved, viewed and textured from different angles (figure 36), unlike the 2D methods of facial depiction where only the frontal view is available. However, difficulties can arise when trying to apply 2D frontal-facing photographic donor images using the 'Spotlight' tool to the oblique surfaces of the 3D model. Unless there is access to donor facial images from multiple viewpoints – frontal, medial or lateral, it can be difficult to project 2D textures onto 3D surfaces that are not directly visible in a frontal view, and some image distortion may occur. Painting skin textures using virtual and brushes directly onto the surface of the 3D model instead of using the 'Spotlight' tool avoids these difficulties and potential morphological errors adopted from donor images.

Figure 36: 3D digital painting of skin textures directly onto the surface of the 3D model most likely reduces shape error compared to the 2D digital composite and 3D 'Spotlight' methods. 3D facial depiction of a 17th Century Scottish Solider unearthed at Durgam Cathedral. Image courtesy of Face Lab, Liverpool John Moores University.

If the addition of textures using the 'Spotlight' tool is preferred, another option for texturing 3D models with photographic images is to create a library of anonymised 'textures' in Adobe Photoshop CC and apply these to the 3D model. These textures do not include and 'shape' from the donor image but are simply square images with softened edges, as shown being used in the 3D digital painting method in figure 15. They can easily be composited using the 'Spotlight' tool, with additional blending and edits undertaken using virtual brushes and image alphas. Using these textures ensures that any shape information in the final facial depiction is driven by the shape of the 3D facial reconstruction.

The realism and appearance of the 3D painted skin in the 3D digital painting and rendering method depends on the CGI skills of the artist, and additional access to software and hardware needed for rendering. Human skin has several properties that include "variation in colour, surface roughness, and translucency over different parts of the body, between different individuals" (Nagano, et al. 2015), which make it difficult to replicate. The material properties of skin shaders applied to a 3D model in Autodesk Maya, such as sub-surface scattering, can be altered to produce more realistic outcomes with good success. However, an understanding of skin structure and reflectance (Angelopoulou, 1999), and the shader's ability to "simulate the scattering of light beneath the surface of the skin" (Jensen, et al. 2001) is required for the skin to "appear fleshy and organic" (Nagano, et al. 2015).

Virtual lighting of a 3D facial reconstruction model in a 3D scene can be controlled to generate a desired aesthetic. Shadows are cast on the 3D model from the virtual lights in the 3D scene, and these shadows help to define morphology. Using the 3D painting and rendering method, the 3D depiction is unaffected by erroneous shadows that might be present from donor photographs applied during a composite texturing method.

Tweaking the material shader and light settings in a 3D scene until a desired appearance is reached, will be a process of trial and error for individual practitioners. The skin material shader, sub-surface and specular settings are easily affected by small changes to light intensity and colour. If a light is moved within the 3D scene or its intensity is changed, you may need to spend time re-adjusting the skin shader settings and performing multiple test renders until the desired appearance is reached. This adds additional time and complexity to the 3D digital texturing and rendering process. Rendering time will also increase with the addition of 3D hair and clothing. In comparison to the other methods described in this chapter the 3D digital painting and rendering method is the most time-consuming and has the most complex workflow. A facial depiction textured using this method will take approximately 80+ hours.

The 2.5D method requires some 3D modelling and painting skills, but no advanced VFX or rendering skills, or access to expensive rendering software and hardware. Similar to the 3D digital painting method, lighting can be controlled within Pixologic ZBrush, and painting directly onto the surface of the 3D model reduces the inference of incorrect morphology. This method reduces time compared to the digital 3D painting and rendering method, taking approximately 10-20 hours to complete a facial depiction. It could also increase accuracy when compared to the 2D composite method.

Where possible, it is recommended that the digital 3D painting and rendering method is used to add realistic textures to 3D facial reconstructions, and that virtual lights are used to cast shadows. In the absence of advanced rendering and VFX skills, the 2.5D method presents a suitable compromise and a potentially more accurate methods of adding digital textures to 3D models than the digital 2D composite method alone.

Artistic Proficiency and Cognitive Biases

The digital workflows described in this chapter use Adobe Photoshop CC, Pixologic Zbrush and Autodesk Maya with default workspaces, but it should be noted that "no two artists work identically or have identical training" (Erickson et al., 2016). Even if the base 3D reconstruction model is the same, artistic variability will result in different aesthetics on the textural layer, especially in relation to information such as hair, colour and surface details. There are no known studies that note if an artists' proficiency with digital texturing software can affect the morphological accuracy of digital facial depictions. Further studies are required to establish this with certainty.

Some studies highlight that artistic proficiency can affect recognition of an individual from a facial depiction in forensic settings. Erickson et al. (2016) suggest that the professional and artistic experience of the practitioner could be a contributing factor to the performance of a facial depiction for identification purposes. However, Lampinen et al. (2015) found no correlation between resemblance to the target and the experience or artistic training of the artist. Even archaeological facial depictions, where there is access to historic written descriptions of the individuals, portraits and DNA analysis to suggest textural appearance, may rely on stereotypes in order to create super-realism (Wilkinson, 2020).

The aforementioned 3D digital facial depiction of King Robert II (figure 5) is an example of a multi-year project that involved an interdisciplinary research team to make decisions about the applied textures and overall presentation of the facial reconstruction based on available historical evidence. The application of brown hair and eye colour was informed by analysis of portraits of confirmed descendants held in art galleries by a geneticist at the University of Glasgow (Scotland), challenging the pre-existing stereotype of a blue-eyed and red-haired Scotsman. The bascinet and crown were produced through a collaboration between a curator of European Arms and Armour at Kelvingrove Art Gallery & Museum (Scotland), and a 3D artist, who used historic depictions of King Robert II (statues, coinage) and armour held in European museums as references (Wilkinson, et al. 2019). Care was taken to ensure that the choices made were appropriate, down to the leather and twine materials used to attach the aventail to the bascinet, and the type of mail (steel rings with a domed fastening). However, not every project will have access to similar data, records or collaborators.

Forensic DNA phenotyping provides more comprehensive details relating to individual appearance; the phenotyping process is useful for characteristics that involve pigmentation such as eye, hair and skin colour (Kayser, 2015), and the addition of this information to facial depictions can update or change portraits of people from the past. Figure 37 shows depictions of two Mesolithic individuals from Norway; cases where aDNA phenotyping suggested dark skin and blue eyes, contrary to popular theory for this ancient population.

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Figure 37: 2.5D facial depictions of two Mesolithic individuals from Norway on display at Bergen City Museum. Image courtesy of Face Lab, Liverpool John Moores University

However, caution must be taken when relying on forensic DNA phenotyping as it presents a spectrum of possibilities. In contemporary art, Heather Dewey-Hagborg’s artwork ‘*Stranger Visions*’ (2012-13) received criticism due to its ancestry bias in relation to textures chosen and applied to 3D printed face models produced from DNA profiling. The follow up work ‘*Radical Love: Chelsea Manning*’ (Dewey-Hagborg, 2017) drew attention to this problematic use of forensic DNA phenotyping through the generation of multiple (approx. 30) faces with different textural appearances from one DNA sample.

Although the facial reconstruction process is rooted in scientific knowledge, subjective material is often added during the depiction process, especially when the facts prove insufficient for a realistic appearance. This subjectivity is conditioned by confirmation bias and any accepted knowledge/beliefs. The facial depiction practitioner should be aware of their own cognitive biases when applying textures to facial depictions, especially for forensic purposes whereby application of incorrect colour textures can affect recognition.

One solution is to present facial depictions as solid colour models (see grayscale 3D printed replica of King Robert II in figure 5 as an example) to lessen subjective addition of textures that may be incorrect or shaped by cognitive biases. However, research has shown that the degree of realism in facial depictions influences their reception by the publics as valid faces (Lewis, 1997; Johnson, 2016), and that faces are generally more difficult to recognise without textural information (Bruce, et al. 1991). Textural information is therefore an important component of a facial depiction, however, the desire for hyper-realistic depictions of human remains, particularly for museum display, sometimes outweighs available evidence for justification of texture choices; potentially ignoring the fact that the chosen textures are some of many possible options (Wilkinson, 2020).

Conclusion

The presentation of a facial depiction can be critical to public perception, academic dialogue and scientific progress. This chapter describes three methods of adding realistic textures to digital facial depictions produced using 3D software: a 2D photo-composite method, a 3D digital painting and rendering method, and a previously undescribed hybrid 2.5D method. Each method has its advantages, including reduction in time taken to digitally texture a 3D facial reconstruction model, or increased opportunities to present facial depictions in different formats. The affordances of each method are highlighted, and it is suggested that the digital 3D texturing and rendering process for adding textures to 3D facial reconstructions can reduce the inference of incorrect morphology compared to the 2D digital composite method. It is recognised that practitioner biases may impact the choice of textures and final display of the facial depiction for public audiences.

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