From Ta-Kesh to Ta-Kush: the affordances of digital, haptic visualisation for heritage accessibility

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Highlights

- Biomedical imaging and scientific analysis of mummified remains produces new knowledge
- Haptically-enabled digital 3D workflow for facial depiction embodied in museum 'touch-object'
- Non-destructive imaging does not equal claims to 'non-invasiveness' in relation to human remains
- Creative collaboration results in innovation and positive visitor feedback despite small budget

Abstract

This paper describes the 3D facial depiction of a 2,700-year-old mummy, Ta-Kush, stewarded by Maidstone Museum, UK, informed by new scientific and visual analysis which demanded a complete re-evaluation of her biography and presentation. This paper describes the digital haptic reconstruction and visualization workflow used to reconstruct her facial morphology, in the context of the multimodal and participatory approach taken by the museum in the complete redesign of the galleries in which the mummy is displayed. Informed by contemporary approaches to working with human remains in heritage spaces, we suggest that our virtual modelling methodology finds a logical conclusion in the presentation of the depiction both as a touch-object as well as a digital animation,

and that this ‘digital unshelving’ enables the further rehumanization of Ta-Kush. Finally, we present and reflect upon visitor feedback, which suggests that audiences respond well to interpretive material in museums that utilizes cutting-edge, multimedia technologies.

Key words: Egyptian mummy; craniofacial reconstruction; haptic; affordance; 3D printing; digital heritage; digital unshelving

Declarations of interest:

None

1. Introduction

When essential building work required the Maidstone Museum (Kent, United Kingdom) to strip out its *cloisters* gallery (containing Egyptian material, European ceramics and Victorian toys and games) in 2016, an opportunity arose to develop a wholly updated, vibrant and contemporary gallery, supported by new research into significant elements of the museum’s popular Egyptian and Greek collections. These collections are key learning resources for local schools: Maidstone Museum attracts annual visitor numbers of approx. 70,000 people, of which approx. 10,000 are school learners. Nearly one-third of these attend workshops on Ancient Egyptians and Greece in support of their curriculum. The project *Ancient Civilisations: A Collectively Curated Space* was therefore devised. Its broader outcomes were focused on reflecting contemporary museological strategies to treat human remains with greater sensitivity, and offering revised empirical information and innovative interpretation strategies, with the aim of increasing intellectual access to young visitors and physical access to visually-impaired visitors.

The re-evaluation and redesign endeavour was an inter-institutional and multi-partner initiative funded largely through Heritage Lottery Funding, along with financial support from Maidstone Borough Council, the Maidstone Museums’ Foundation and other local funders. National institutions with relevant collections lent letters of support to the successful grant applications process. With no Ancient Egyptian subject-specific research staff at Maidstone Museum, its project

leaders gathered an international group of experts as collaborating consultants. This outward-looking approach extended to community groups such as the Kent Association for the Blind and the museum's youth group, Cur8, providing input to ensure that development of the revised gallery was optimised for visually impaired visitors, and relevant and engaging for younger audiences.

This interdisciplinary and participatory research process revealed significant findings about the museum's star attraction – and the focus of this paper – a 2,700-year-old mummy heretofore known as 'Ta-Kesh' (or 'the Maidstone Mummy') and now known as 'Ta-Kush', as well as an associated item believed to be a mummified hawk. Detailed medical imaging facilitated non-destructive bio-anthropological and craniofacial analysis, providing further data about her age, health, and likely appearance in life; and new interpretations of her coffin provided a more accurate name and likely origins (Sheikholeslami, personal correspondence, 2016). These are summarised in Table 1 and were key references for the anatomically accurate facial reconstruction using three-dimensional (3D) digital technologies, and variations in final appearance. By the end of this process, Ta-Kush could no longer lay claim to the singular status as 'the only human mummy in Kent', which no doubt added to her 'star attraction' reputation. As Microcomputed-Tomography and osteological analysis suggests, the mummified 'hawk' is in fact a human foetus with anencephaly (Nelson et al. 2018; University of Western Ontario 2018). Maidstone Museum in fact stewards *two* human mummies.

How would the museum choose to communicate these new findings to its future visitors? Moreover, how have visitors responded to this 're-introduction' of a well-known attraction? This paper considers the role of the multimedia 3D facial depiction of the Maidstone Mummy within the broader context of the *Ancient Lives* gallery re-design, including how collaborative dialogue engaged the ethics and aesthetics of displaying human remains; and how curatorial and design choices were directed towards active visitor engagement in the new galleries. We therefore consider the affordances (see Gibson, 1966) and potential challenges of digital and direct haptic (touch-based/enabled) solutions in heritage practices as learned through this particular project.

First, we will outline key points in the changing attitudes to displaying human remains from Ancient Egypt in museum contexts, and the application of facial reconstruction as a tool for science

communication and public engagement, with reference to current literature. We then describe the process of 'Ta-Kesh' becoming 'Ta-Kush', focusing on the haptically-enabled digital facial depiction process, and how scholarly and community-led conversations informed our final presentation, framed by three objectives: to re-humanise Ta-Kush; to ensure greater accessibility to all visitors, and to engage younger audiences. Finally, we report on the reception of our multimodal representation of Ta-Kush, and consider the contribution this project makes to re-orientating (Western) institutional responsibilities from 'collecting' (acquisition of items that enable the production and perpetuation of Western cultural authority) to 'stewardship' (responsive and responsible care and control of items acquired prior to current ethical guidelines) in respect of ancient human remains.

BIOGRAPHY	**PERCEIVED FACTS**	**NEW DATA**
Name	Her name had historically been translated, from the inside of her coffin as, 'The Lady of the House, **Ta-Kesh**, Daughter of Osiris, Pa-Muta; her mother Lady of the House, Shy'	The name from her coffin was reinterpreted from Ta-Kesh to Ta-Kush, 'Lady of the Kush', which had interesting multi-cultural implications, which would not have been identifiable through the CT scan alone
Dynasty	She was believed to have dated to c.700-650BC (25th or 26th Dynasty).	She has been dated more specifically to 25th dynasty
Ancestry	Nothing was known of her life, or where she lived or was buried.	Her Father's name is Nubian while her mother's name is Egyptian, so it is possible, along with the Kushite link with her name that she was of mixed descent.
		Her father was a Doorkeeper to a temple, suggesting they were of above working class status
Stature; age at death; signs of healed trauma	She was believed to be 14 years old when she died	Very slight build
		Skull morphology is consistent with a mature adult, supported by dental evidence.
		Her age was reassessed as between 35-49, osteoporosis and bi-parietal thinning suggesting post-menopause

		Her wisdom teeth have erupted, with heavy wearing of the teeth; abscesses in her jaw
		Her spine shows evidence of a healing wedge fracture
Death and burial	Nothing was known of her life, or where she lived or was buried.	The type of inner coffin suggests she was from Thebes.
		Her eye covers of shell or stone remain

Table 1 Summary of perceived facts and new data regarding Ta-Kush

1.1. From Historical Spectacle to Contemporary Science

Responsible and respectful stewardship of human remains held in museum collections (particularly archaeological, anatomical and 'natural history' institutions) has come under intense scrutiny in recent years (Balachandran 2009; 2016). In the UK, the Human Tissue Act (2004), as well as a number of other relevant legislation and guidelines (Antoine, 2014; DCMS, 2005; ICOM, 2018; Mitchell and Brickley, 2017), originating with the 1989 Vermillion Accord (Fforde, 2014), have had a significant effect on the way researchers and curators work with this material. Any museum in the United Kingdom with human remains of under 100 years of age in its holdings is required to be licensed by the Human Tissue Authority (https://www.hta.gov.uk/), and must abide by the strict conditions of that licence. Documented consent, a key concept in biomedical ethics, is exceedingly rare for historical material more than 100 years old, and non-existent for ancient remains held in museum collections. In the absence of consent, care, dignity and respect are the guiding concepts that ideally guide the display of such material, with the understanding that curators balance questions of spectacle against "public benefit" (Antoine, et al. 2014). For material less than 100 years old, display conditions tend to be much stricter, alert to the potential insensitivity towards living relatives.

Although the Human Tissue Act does not restrict the display, production or circulation of *images* of human remains, some curators in the UK have tended to self-restrict, withdrawing human remains from public exhibition for fear of objection (Angel, personal communication, 2018), despite research suggesting that the vast majority of museum visitors in the UK expect to see – and are

comfortable with – human remains in museum collections, and generally support the retention of such material for research purposes (Antoine, *et al.* 2014; DCMS, 2005). The same research suggests that the older the remains, the fewer objections visitors have with their presence in museum collections. Yet objections regarding remains (including material culture) of indigenous people have rightly been raised against institutions associated with the colonial project, broadly defined. Increasing demands for the 'decolonisation' of western-style institutions, both academic and cultural (see *inter* alia, Das and Lowe, 2018; Fataar, 2018; Swain, 2019; Schoenberger, 2019; Muldoon, 2019) is really an appeal to recognise the legacies of radical imbalance of knowledge production, circulation and access; and the necessary problematizing of the normative framing of the scientist (or subject specialist) as 'knower', and ancient or indigenous remains as 'object of knowledge' (Schramm, 2016). It follows therefore that repatriation and restitution procedures must now be part of any basic museum *modus operandi*, which impacts on both institutional and individual curatorial praxis, shifting the focus from collecting to stewardship.

But what of human remains for which there is little or no demand for repatriation, and which lend themselves to highly aesthetic treatment, as in the case with Ancient Egyptian culture? Conventions of trading, collecting and displaying both biological remains undoubtedly contribute to their respective conceptual transformation from (artefact of) 'human subject' to 'museum object', crafting a critical distance between the body as individual, and cultural commodity (Swaney and Balachandran, 2018; Houlton and Wilkinson 2016).

Exhibitions featuring ancient Egyptian mummies continue to capture contemporary audiences, as the investment in the recently opened *Ancient Egypt* exhibition (2017) at Liverpool's World Museum, and the blockbuster *Ancient Lives, New Discoveries* exhibition (2014) at the British Museum suggest. The former foregrounds human remains as a form of 'material culture' as theorised by Sofaer (2006), with mummies and associated funerary objects occupying a large display case placed in the centre of a dedicated room, clearly signposted as 'containing human remains' yet still staged as spectacle. The latter subjected a select group of mummies to sophisticated imaging technologies, the results of which were used to produce virtual 3D representations and interactive

displays, which visitors could manipulate (rotate and digitally 'unwrap') on touch-screens, all while navigating a palimpsest of interpretive annotations (Taylor, Antoine and Vandenbeusch, 2014).

Developments in scientific and biomedical imaging have no doubt advanced both specialist knowledge and popular understanding. There is no doubt that digital imaging technologies offer numerous affordances related to scholarship, conservation and visitor experience. A chief advantage is generally agreed to be the non-destructive and /or non-invasive access to otherwise invisible features of these bodies and other items. But what are the objectives of translating these technologies into digital and haptic (touch-based) interfaces in museum contexts? In the case of *Ancient Lives, New Discoveries*, they were clearly aimed at an 'immersive' or otherwise 'interactive' visitor experience. As a visitor to this exhibition, one of the authors (Smith) suggests that a possible effect of this technological integration framed the body of the visitor in a simultaneously virtual-physical enfolding as the subjects of the museum display (the mummies), thereby fostering inter-subjective relatability, if not empathy. However, as Zoe Pilger reminds us in her review of *Ancient Lives, New Discoveries* for *The Independent* newspaper (2014), "These bodies were not designed to be seen." Interactive biomedical imaging technologies permit us intimate access into the body's internal cavities, consent for which cannot possibly be granted or assumed from ancient people. That they afford new knowledge about the interior realities of mummies without material destruction is an insufficient benefit in Pilger's assessment. The assumption, therefore that digital imaging technologies are 'non-invasive' cannot go unchallenged.

1.2. Representing Past People

In the United Kingdom, the Human Tissue Act (2004) has had a significant impact on curatorial practice in respect of the conservation and display of human biological material. Museum professionals and scholars generally agree that the most sensitive (potent) items are those that preserve a recognisable aspect of the face, or which represent foetuses or neonates, which are both relevant here, given the new findings about Maidstone's mummy holdings. Yet, as with any item presented for exhibition, no act of exhibition is ever a neutral practice. With the exception of some

notable contributions to anatomical museums and thanatology scholarship respectively (Alberti et al, 2009; Krmpotich et al, 2010; Harries et al, 2018), curators in the UK have reached uneven agreement on if and how human remains in museum collections should be accessed, and by whom. Very few sources, with the exception of Angel's visual and material anthropology (see Angel 2013, 2015, 2016), discuss the potentially productive aspects of encountering human remains in museums. However, a general 'consensus through practice' suggests that special consideration should always be given to what *motivates* the decision to display human remains, particularly those acquired from indigenous cultures, and/or where provenance is unclear; and that such decisions should be sensitively and informatively framed through interpretive material.

Depicting the faces of the dead is an established practice in human history, motivated by three broad interests, namely ritual practices, historical interest and forensic identification. Reconstruction of the face from the skull affords the re-humanization of remains through the crafting of a relatable appearance. This individualising process, we argue, re-introduces the notion of personhood to otherwise generic 'artefacts', enacting a translation from collected 'object' back to 'individual subject.' It also permits a critical consideration of cognitive bias; how our perception of others is shaped by appearance and presentation (Wilkinson and Smith, 2018).

Previous facial depictions of ancient Egyptians that have utilised similar presentation methods to this project, including Elisabeth Daynes' silicone facial depiction of Tutankhamun (2005) and Philippe Froesch's CGI facial depiction of Nebiri the Chief of the Stables (2016), all aim to humanise these individuals through presentation of a relatable and realistic facial depiction. However, DNA evidence to support choices for skin, hair and eye colour for ancient individuals, plus references for clothing or hair styles are not often available. Here we sought an alternative which would allow us to foreground the part of the facial reconstruction process that is the most scientifically justifiable, namely the shape (Wilkinson, et al. 2006), and leave textural interpretations open for discussion.

In the context of a museum display, presenting an anatomically accurate and convincing facial depiction of a person from the past is often assumed to do the immediate work of humanisation, allowing us as contemporary visitors to connect with historical individuals across time through the

affordances of specialist techniques and technologies (Buti, Gruppioni and Benazzi, 2015). Traditionally, facial reconstructions of historical people tend to be presented either as a two-dimensional (2D) images, a traditional sculptural portrait (modelled in clay or wax and cast in a permanent material) or a 'realistically' painted model. Associated objects and texts inevitably enrich such depictions. Mummies, Kenneth Nystrom (2015) suggests, offer particularly potent opportunities for a human connection, as preserved soft tissues, particularly of the face, ease the process of re-identification and embodied empathetic connection, and from a practical point of view, can provide reasonable justifications for featural accuracy in depictions of their in-life appearance. 3D facial reconstruction from the skull can also offer an important historical corrective, particularly where existing representations of a known individual may be coloured by certain perceptions and biases, for example, a 3D facial depiction of English King Richard III by Wilkinson and Aitkin (2014) presented this historical figure as a relatable, rather ordinary-looking person rather than the 'monster' described in Tudor propaganda.

The duty of care that publically-funded institutions like Maidstone Museum have to their collections translates to how their visitors experience those collections, by presenting those collections in accessible, informed and sensitive ways. Maidstone Museum's curatorial task was ultimately about balancing the twinned demands of 'access' and 'engagement' with appropriate sensitivity to the potential affective potency of Ta-Kush's remains, which is amplified when this potency is also largely responsible for the popularity of the display in question. Removing Ta-Kush from display would mean that a small, regional museum that must remain viable in the eyes of its funders, would effectively forfeit an iconic part of the collection, as well as a critical learning resource. Finding a visual solution to embody this new data, whilst also pointing to what is not or only partially known, with the objective of fostering meaningful connections between this ancient Egyptian woman in their care, and contemporary visitors of all ages and abilities became the challenge.

2. Materials and Methods

Maidstone Museum is one of the earliest local authority museums in the UK. It opened in 1858 and now occupies a listed building. Its adult mummy entered the founding collection between the late 1830s to early 1850s as a gift from local doctor Hugh Welch Diamond to his cousin Dr. Charles of Maidstone. Some contemporaneous but very cursory documentation suggests that the mummy was brought to England in the 1820s, but only the inner wooden coffin reached the museum in the nineteenth century. Upon entering the country, she was confiscated by Customs officers who cut open her wrappings in a search for alleged contraband believed to be stored within her body cavity.

The 'Maidstone Mummy', as she became known, has been on display since the museum first opened, laid out for at least thirty years in a staircase lobby, and then in the cloister galleries, in what used to be the chapel of the original building (see figure 1). In addition to the aforementioned documentation, the museum archive also holds an autopsy report, an 'unwrapping' report dated 1843, and a student paper from the 1980s on the decoration of the inner coffin (Ellis, 1986). In 2016, essential building work catalysed the redesign of the museum cloister galleries, requiring the wholesale relocation of collections housed there.

Figure 1: Photograph of Ta-Kush on display at Maidstone Museum in 2016 in the chapel of the original building. Image courtesy of Maidstone Museum

With the decision made to retain Ta-Kush as a key feature in the new *Ancient Lives* gallery, non-destructive research into her history was necessary to construct a revised biography and visual representation sensitive to contemporary curatorial ethics. Given the educational and community-facing mandate of Maidstone Museum, decisions on how to make these findings interesting and accessible to the public were paramount. With no Egyptian specialists on the staff, the museum was required to establish national and international research partnerships to discover more about Ta-Kush and explore options for re-presentation of her remains. The Egyptology Department at the British Museum, Brighton Museum, the Petrie Museum at University College London, Garstang at the University of Liverpool, and the Egypt Exploration Society all joined as 'supporter museums', and international expertise was sought in the fields of craniofacial analysis and reconstruction, medical imaging, bio-anthropological analysis, and analysis of the coffin, related artefacts and a foetus mummy. The participatory focus and community-facing ethos of this project distinguishes this initiative from others which have used facial reconstruction as an interpretive tool.

2.1. Cur8 and Kent Association for the Blind

The museum's youth group 'Cur8', and the Kent Association for the Blind (KAB) were integral in developing perspectives on, and solutions for, increased museum accessibility for this display, as part of the parallel *Ancient Civilisations: A Collectively Curated Space* initiative. Cur8 consists of young people aged between 12 and 17, who meet monthly at Maidstone Museum. Eleven members participated in *Ancient Civilisations* between August 2016 and March 2017. Their contribution was written into the Heritage Lottery Fund application, which funded travel to a number of supporter museums. Their initial brief , based on received data, was to research the life of a teenager in Ancient Egypt.

In conversations with the museum's collections teams, both Cur8 and KAB created a list of questions they wanted answered about the people of Ancient Egypt, and Ta-Kush specifically, and visited three different supporter museums, including the British Museum, Brighton Museum and the Petrie Museum to find answers. The Cur8 group gathered information that would be used to inform

the facial depiction of Ta-Kush in the new gallery, including decisions about make-up, hairstyling and jewellery. The groups also considered the ethics of displaying human remains in museums and how such issues would inform the display of Ta-Kush's remains, finding that,

"…it's important to remember that Ta-Kesh was actually a person and that she should be referred to as 'she' instead of 'it' [...] She is a person and you want the visitors to feel that and understand that […] We learnt that in some museums they covered their faces to be more respectful but we are not entirely sure about doing with Ta-Kesh at the moment […] We want to give people a choice of whether they want to see her or not because that's more ethical" (Boyd, 2017).

Focus groups held periodically during these seven months allowed for dissemination of the groups' research findings to the museum and exhibition design teams.

2.2. 3D Imaging and Scientific Analysis

The Kent Institute of Medicine and Surgery (KIMS) conducted Microcomputed-Tomography (CT scanning) of Ta-Kush, along with partial human remains (hands, feet) and various animal mummies (crocodiles, cats, snakes, and birds) stewarded by the museum. With the majority of these still in their original wrappings, there is no way of knowing what the packages actually contain, other than previous estimates based on their size and shape, and any data recorded in often questionable documents of provenance. The aim of the CT scanning was therefore to identify the contents of the wrappings, their possible date, place of origin and mummification methods. The use of CT technologies affords fine discrimination between materials with different densities, providing an enormous amount of information not only about the mummy and its skeleton, but also about associated artefacts (Attardi, 2000).

The resulting images were passed to the IMPACT radiology project at Western University (Ontario, Canada) for osteological analysis, and Face Lab at Liverpool John Moores University for craniofacial analysis and 3D digital facial reconstruction. The imaging process also afforded new knowledge about a particular animal mummy known as item 'EA 493', with an associated label;

‘Mummified Hawk, Ptolemaic Period’. Viewed supine, the undisturbed cartonnage, depicting a falcon, also features tiny painted sandals on its ‘foot’ end, a rather human clue within an otherwise avian theme. As such, the item had been misidentified when it arrived at the museum possibly over a century ago; the medical imaging confirmed the truth behind this historic secret. According to Nelson (2018), this is only the second identified anencephalic foetus mummy.

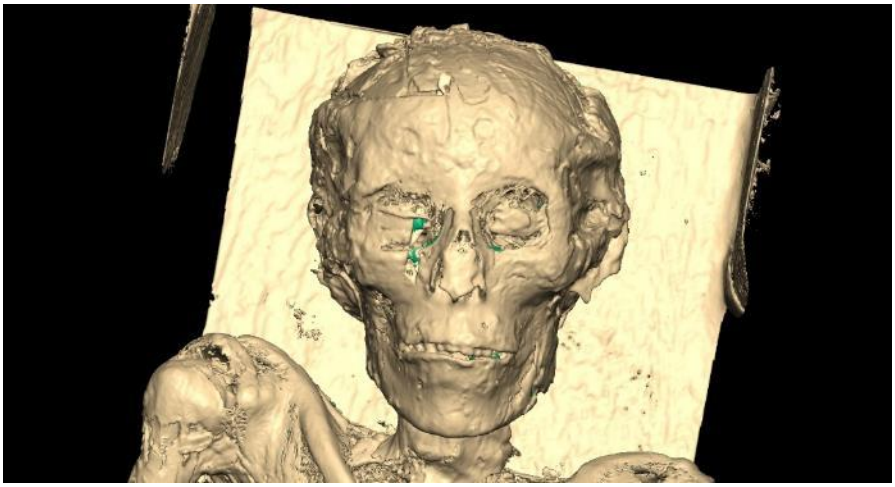

Figure 2: Visualisation of the CT scan of Ta-Kush in Geomagic Freeform©

Descriptive material previously made available to visitors relied on 'perceived facts’ that were a legacy of Ta-Kush’s incomplete object-biography. New data presents corrections to these perceived ‘facts’, and which were germane to the facial depiction, for example, the revised age estimation (from teen girl to post-menopausal woman), Nubian-Egyptian heritage, and our ability to call her by her real name. With the primary aim of the 3D facial depiction being to re-humanise Ta-Kush, and thereby mitigate the spectacle of fascination so often associated with (particularly unwrapped) Ancient Egyptian mummies, this new biographical information provided essential information towards a more accurate representation of this ancient individual. Reimagining the purportedly adolescent Ta-Kesh as a post-menopausal Ta-Kush presented both challenges and opportunities for the museum team and the various partners involved, particularly the Cur8 team who were no longer researching a fellow (albeit ancient) teenager, but a middle-aged woman.

2.3. Craniofacial Analysis and 3D Facial Reconstruction

2.3.1 Extracting and Processing the 3D Skull Model

To begin the process of producing a 3D facial reconstruction of Ta-Kush, 3D .OBJ files of the cranium, mandible and soft tissues were generated from the DICOM data supplied by KIMS using the open-source medical imaging viewing software InVesalius© (https://www.cti.gov.br/invesalius). These files were exported and imported into 3D modelling software Geomagic Freeform© (https://uk.3dsystems.com/software/geomagic-freeform), operated by a 3DSystems Touch X© haptic interface device (https://www.3dsystems.com/haptics-devices/touch-x). The Touch X© haptic interface is a common force-feedback device adopted worldwide in engineering of mechanical parts, and force-feedback devices are known to engage proprioception, which is the sense of force and position enabled by tactile and visual cues (Schneider, 2017). Gaver (1991) notes that "novel 3D digital interfaces, may offer observable affordances because they can offer information about objects that may be acted upon." Devices such as the Touch X interface afford new interactions when sculpting virtual clay by making the interaction of touching appear visually similar to that in life, therefore mimicking the haptic sensations of traditional sculpting with clay and wooden tools (Roughley and Wilkinson, 2019).

Once imported into Geomagic Freeform©, it was necessary to make some adjustments to the skull model prior to commencing the facial reconstruction process. The eye-covers (or artificial eyes) were clearly visible in the eye sockets, suggesting they are of a similar density to bone (such as shell or stone). This feature is consistent with the imaging produced of 'Tamut', one of the mummies features in Ancient Lives, New Discoveries (see Taylor, Antoine and Vandenbeusch 2014. 80, fig. 66) A duplicate of the skull model was created to avoid making any destructive changes to the original digital model. Eye-covers were then digitally removed from the duplicate skull model, along with residual mummified soft tissue and other material artefacts, to provide a 'clean' skull on which to work. Past practical experience has demonstrated that segmenting CT scans of mummified human remains can be challenging, due to the difficulty in density discrimination between hard tissue (bone)

and mummified soft tissue. Geomagic Freeform© allows the user to work in 'object layers', with the ability to make objects ('pieces') visible or not. Accuracy of the modified skull model was verified by toggling visibility between the original (visible in green in figure 3) and the duplicate piece (visible in beige in figure 3).

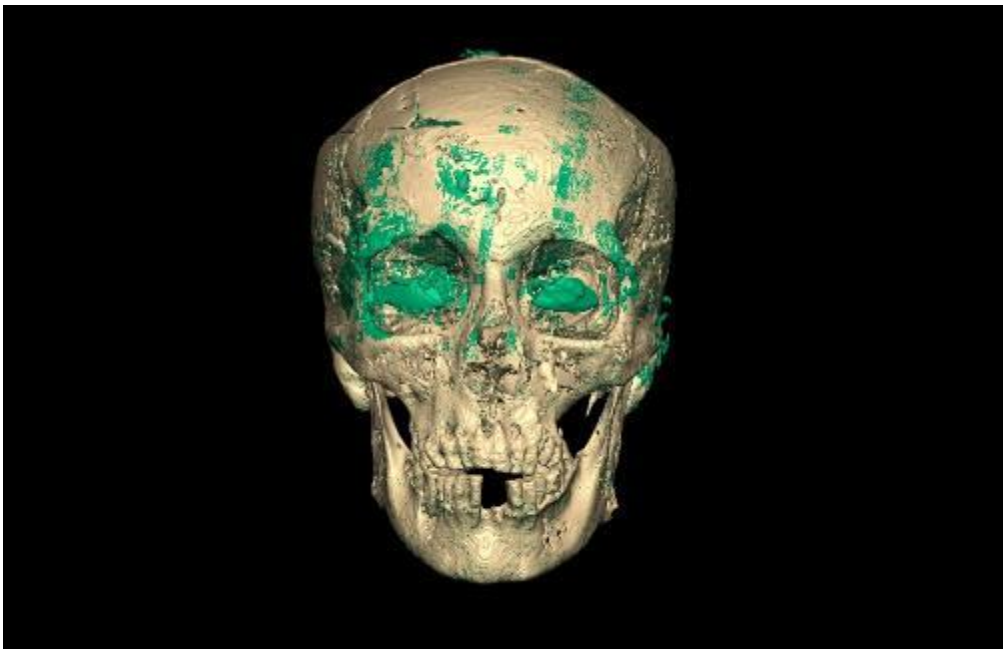

Figure 3: Original and edited 3D models of Ta-Kush's skull in Geomagic Freeform©

2.3.2. Assessing Ante-mortem Appearance

Craniofacial analysis suggested facial asymmetry and individual features that would present a highly individualistic appearance. Her facial appearance suggests a relatively wide and very slightly upturned nose that marginally deviates to the right, with inferiorly placed nostrils (Rynn, et al. 2009). There is no visible brow-ridge. Straight eyebrows with a subtle arch frame eyes that are neither protruding nor overly deep-set, with horizontal eye fissures (Fedosyutkin and Nainys, 1993; Wilkinson and Mautner, 2003). The mandible suggests a long chin and narrow jawline in relation to the cranial vault, and slight prognathism combined with her dental patterning and a receding chin gives her a convex facial profile. She has a wide mouth with a fuller lower lip that protrudes slightly more on the left side. Her mastoid processes suggest adherent ears (attached lobes) (Rynn, Balueva and Veselovskaya, 2012; Fedosyutkin and Nainys, 1993).

The skull also shows a relatively rare condition known as biparietal thinning, where the parietal bones have an unusually depressed appearance, which would be visible in life (assuming the scalp was visible, or the hair was worn very short). This condition is noted in Nelson's report, and further research confirms this is associated with post-menopausal osteoporosis, which in turn further supports the revised age estimation of a mature female >40 years (see Table 1). This unusual feature, her revised age and very slight stature (not evident from the skull alone, but supported by post-cranial remains and biological assessment) would certainly influence our depiction of Ta-Kush's in-life appearance.

2.3.3. Craniofacial Reconstruction Methodology

The craniofacial reconstruction system utilises a database of pre-modelled muscles and anatomical structures created for use in forensic depiction (Mahoney and Wilkinson, 2012) which can be modified to meet the specifications of individual skulls. This system has been tested using the skulls of living subjects (Lee, et al. 2012; Wilkinson, et al. 2006). These accuracy studies suggest that it is possible to create a face that is recognisable, with at least 67% of the surface of the face showing less than 2 mm of error.

Using the sex and age criteria, the appropriate set of tissue depth measurements were chosen from an *in vivo* set published for contemporary adult Egyptians (El-Mehallawi, et al. 2001). The minimum depths for adult females were selected as being more likely to reflect the body mass of an individual of very slight stature from an ancient population. This data provided the measurement for virtual tissue depth markers attached to the 3D skull model at ninety degrees to the bone surface, at the appropriate anatomical points. Eyeball models of 24 mm diameter were set into the eye sockets, at normal protrusion (Wilkinson and Mautner, 2003). The facial muscles were imported from a database and modified for size and shape (Mahoney and Wilkinson, 2012), after which the subcutaneous fat and skin layer was then added in virtual clay over the muscle structure, guided by the tissue depth markers, to create the finished face model.

Facial features were modelled following standards suggested by Rynn et al. (2009) and Gerasimov (1955) for the nose, Gerasimov (1955) for the mouth and Fedosyutkin and Nainys (1993) for the ears, eyes and eyebrows, with general reference to Rynn et al. (2012). Lobed, prominent ears were modelled using the external auditory meatus, mastoid process and estimated gonial angle to determine position. Features were then blended with the skin layer and the surface of the face was smoothed. A neck model was imported from a database and modified accordingly. Feature refinement and detailing completed the face model.

2.4. Digital Texturing

The primary aim of a facial reconstruction from skeletal remains is to produce an accurate depiction of facial shape. However, additional texturing is often necessary to depict life-like appearances with which audiences may relate (Claes, et al. 2010). We refer to details extrinsic to face and feature shape as 'texture'. This includes information such as skin tone and texture, such as creases, wrinkles and distinguishing marks, plus hairstyle and colour and eye colour, of which none can be predicted from the skull shape alone. With no DNA testing possible due to financial limitations, the Face Lab team relied on the wider research team, including the Cur8 group at Maidstone Museum, to guide choices about the textures utilised for Ta-Kush's facial appearance.

Following a facial depiction texturing method as described by Roughley and Wilkinson (2019), the skin layer of the 3D facial depiction of Ta-Kush produced in Geomagic Freeform© was exported into Pixologic ZBrush 4R8© (https://pixologic.com/get-zbrush-4r8/); a software used in mainstream modelling and animation and capable of handling complicated 3D models (Vernon, 2011), that can produce outputs consistent with photographs or film sequences (Wilkinson, 2005). Here, the 3D model was retopologized (the process of creating a cleaner polygon mesh for subsequent digital sculpting of details) and a UV map created for the addition of colour. Skin textures, such as pores, wrinkles and skin colour, were sculpted and painted using a variety of digital brushes.

Alterations to the 3D skin layer in texture and colour, based on age, sex and population, enhance the individuality of the generated facial form (Evenhouse, et al. 1992). For the approximately 40 year old Ta-Kush, age-related face texture changes to the skin, including crow's feet, eye bags, neck and forehead creases, sagging tissues and overall roughness, were added cautiously to the facial depiction following guidance from Neave, (1998); Wilkinson, (2004); Naini, (2011); and Mullins, (2012). The resulting facial reconstruction is shown in figure 4.

Figure 4: Facial reconstruction with visible skull and muscle structure (left) and skin shape (right)

Museum visitors should be able to engage with Ta-Kush as a relatable individual; her visual depiction should therefore be highly plausible, and reflect the archaeological record relating to her status in the 25th dynasty. Maidstone Museum, the Cur8 group and its international research partners sought evidence and examples to support choices on her final 'look', including wig styles of the period, make up, and jewellery. Being of Nubian ancestry, it is thought that Ta-Kush's natural hair would probably have been naturally curly and worn short. Yet observation of contemporary statuettes suggested that Ta-Kush may have occasionally worn a 'Nubian wig' of the 25th dynasty type, with gold hoop earrings and broad painted collar. To support this theory, a statuette of another Ta-Kush (Princess-Priestess Ta-Kushit at the National Archaeological Museum, Athens, Greece) from the 25th dynasty was found that depicts a wig in the 'Nubian' style, which is notably shorter than most Egyptian wigs but slightly longer at the front than the back; a classic 'bob' in today's terms (Serpico,

personal correspondence, 2017). Contemporary sculptures also evidenced the possible makeup of the 25th dynasty, which specifically shows broad, shaped eyebrows with an extended line of the kohl.

Ta-Kush was to look very different than the museum originally anticipated. It was decided that digital animation would be produced that would build up her look, evolving from her natural appearance, which visitors may relate to as familiar with contemporary people, and to gradually add her historically-specific accoutrements. In ZBrush 4R8©, two different layers of skin were painted. One, showing her without makeup and one with make-up as defined by the research team and detailed above. A faience blue collar appropriate to the 25th Dynasty, gold hooped earrings of the same period and a Nubian wig in a dark colour were also created and textured following the aforementioned processes.

Looking at Ta-Kush's cartonnage, Cynthia Sheikholeslami (2017) noted that "Ta-Kush's name means 'the Nubian', and her mother may have been Egyptian, as her name seems to be Egyptian". This lead the research team to believe that Ta-Kush would have had slightly darker skin tone and eye colour than people whose origins were further north in Egypt. Skin colour was painted directly on to the surface of the 3D skin layer using the 'PolyPaint' function in ZBrush 4R8 and skin blemishes and spots of a brownish hue, similar to freckles, become more obvious with age and in later life (Neave, 1998) were added sparingly.

Once these texturing processes were complete, all of these 3D models or 'assets' were exported as an .OBJ files with accompanying UV and texture maps using the relevant ZBrush 4R8© plugins, ready for use the third-party rendering and animation software Autodesk Maya 2018©. Here, the assets were re-poisitioned in a 3D scene and appropriate 3D eyeballs from the Face Lab database placed in the anatomical position. Short, curly, grey/dark brown hair was created and styled using Maya's XGen interactive grooming hair system. Three virtual lights and an orthographic camera were placed in the scene facing the assets head-on. The assets, including the hair and eyeballs, were then grouped together and a keyframed animation set to rotate the assets 45 degrees either side of the Y axis. Four animations were then rendered and exported as image sequences; one shows Ta-Kush make-up free with short curly hair; the second shows Ta-Kush with make-up, short curly hair and

earings; the third shows Ta-Kush with make-up, short curly hair, earings and the faience collar; the fourth shows Ta-Kush with make-up, earings, faience collar and nubain wig. The image sequences were then composited in Adobe Premiere CC© and exported as an MP4. Stills from this sequence are shown in figure 5.

The decision made to develop a digital animation that shows Ta Kush initially without embellishment - no wig and with her natural short hair, no make-up and no jewellery – was for the museum visitor to see Ta-Kush as 'one of us', an essentially rehumanising strategy, before seeing her with the inevitably transformative effect of her particular accessories. This technique leverages 'visual cues' (Keehner and Lowe, 2010) that offer multi-sensory perceptual and potentially interactive advantages that may not have been otherwise available with more traditional representations of people from the past.

Figure 5: Facial depictions of Ta-Kush unadorned and then with make-up, jewellery and wig

2.5. 3D-Printed Model

3D models created using Geomagic Freeform© are unicolor. While simple colour shades can be added to a model using Freeform's native paint tools, additional software such as Pixologic ZBrush©, which has more advanced painting tools, are often used to add true-to-life colours and textures (Mahoney and Wilkinson, 2010). As previously stated in section 2.3, Pixologic ZBrush© was used to add textures to the 3D facial reconstruction of Ta-Kush. These textures were chosen carefully by the project team but the process of exporting a texture-free 3D model of Ta-Kush from Geomagic

Freeform© to Pixologic ZBrush© provided an opportunity for the team to think about how our uncertainties about Ta-Kush's skin and eye colour could be left open to interpretation by visitors.

In Pixologic ZBrush©, the 3D skin layer of the Ta-Kush model (without colour enabled) was hollowed using the 'Boolean' function to a thickness of 3mm and exported as a .STL file suitable for 3D printing. Prior to this, some additional 3D modelled hair was sculpted atop of Ta-Kush's head that was 3D printing 'friendly,' as the digital hair produced in Autodesk Maya© was not suitable. The .STL file was then printed by PDR-SPD (Cardiff) using a large format SLA printer in a clear, clinical-grade resin. The internal surface of the 3D printed model was subsequently bead-blasted and the external surface lacquered to prevent discolouration of the material through sunlight exposure and persistent touch, and can be wiped clean. Figure 6 shows the clear 3D printed model alongside the digital animation of Ta-Kush viewed on a monitor.

Figure 6: Clear 3D printed replica alongside the digital animation of Ta-Kush viewed on a monitor

3. Results: Meet Ta-Kush

Ta-Kush and her reclaimed biography are presented in the new *Ancient Lives* galleries, dramatically reconfigured from their original iteration. Her in-life appearance is presented in the main gallery as an interactive display entitled 'Discovering Ta-Kush' (figure 7), with her remains in a private alcove,

referred to by the museum as a ‘tomb’, immediately behind this (figure 8). Visitor choice to view the actual mummy is informed by current legislation and guidance about stewarding and exhibiting human remains. The structure of the new gallery is such to allow visitors to make a decision whether to see Ta-Kush’s remains or not, with two distinct spaces intended to increase dwell-time and to adapt the visitor flow.

Figure 7: Photograph of Ta-Kush on display at Maidstone Museum in 2016 in the chapel of the original building, alongside a photograph of the new gallery taken in 2017 from the same vantage point. Doorways into the tomb can be seen either side of the new ‘Discovering Ta-Kush’ display in the 2017 photograph. Images courtesy of Maidstone Museum

Figure 8: Ta-Kush’s mummified remains on display in the ‘tomb’ directly behind the main *Ancient Lives* display at Maidstone Museum. Images courtesy of Maidstone Museum

Visitors are initially presented with two iterations of her in-life appearance (figure 9). In 'Discovering Ta-Kush' a translucent, clinical-grade 3D print is displayed and functions as a touch-object (video 1), alongside a monitor playing a full-colour CGI animation (video 2) depicting Ta-Kush unadorned, and then wearing earrings, a wig and elaborate neckpiece consistent with her status in the 25th dynasty. This affords visitors the opportunity of encountering her as an individual prior to *choosing* to see her mummified remains, in other words actively making a choice to enter the alcove to see her remains, and ideally *after* encountering a vibrant and multimedia interpretation of her living appearance.

Figure 9: Ta-Kush's facial depictions on display at Maidstone Museum. Images courtesy of Maidstone Museum

Video 1: An animation demonstrating the 3D model of Ta-Kush with sculpted hair textured in Pixologic ZBrush 4R8© that was 3D printed for display at Maidstone Museum

Video 2: A full-colour CGI animation depicting Ta-Kush unadorned, and then wearing earrings, a wig and elaborate neckpiece consistent with her status

Clear wayfinding and contextual signage directs visitors to this alcove. The tomb features subdued lighting, which has both conservational and emotive affordances. Seating is provided for contemplation and viewing. Her remains and coffin are exhibited in a custom-designed vitrine (figure 8). Her mummified body is shown bearing the full evidence of its undignified treatment by traders, customs officials and collectors. Positioned midway in the vitrine, she is nestled within her opened wrappings, and a series of mirrors permits study of the inscriptions on the coffin lid and base. Her coffin lid had been in storage since she entered the museum in the 19th century, meaning that the reinterpretation and display have enabled them to be reunited for the first time in at least 150 years. It is hoped that this holistic approach to representing Ta-Kush's presumed ante-mortem appearance (digital, virtual, synthetic), contrasted with her insistently material (biological, organic) post-mortem body will allow visitors to transcend their reading of her as an 'artefact' and enable them to imagine her as a once-living individual.

3.1. Visitor Feedback

Visitor exit surveys, using a 'smiley face' evaluation card (figure 10), were undertaken by the museum for two months following the opening of the *Ancient Lives* gallery in October 2017. They received 236 responses, which are published in a Heritage Lottery Evaluation Report (Boyd, 2017).

Figure 10: Maidstone Museum's 'smiley face' evaluation card

The visitor feedback on the whole appears positive, with over 95% 'Excellent' and 'Good' responses to the museums re-design. Free text comments relating specifically to Ta-Kush and her 3D facial depictions include:

- "Loved seeing Ta-Kush, lovely to see she has her own section now"
- "I really liked finding out how Ta-Kush looked"
- "Treats the human remains very respectfully"
- "The mummy looked awesome"
- "A great improvement on what was here before"
- "We liked the things we could touch"
- "I liked it lots and lots, my favourite was the mummy"

Summative evaluation focus groups with Cur8 and KAB, led by the museum team, took place before gallery opening. Specifically, KAB commented on the availability of touch objects in the gallery with some members saying, "We don't see through our eyes; we see through our fingers" and "It's even better having something tactile in front of you…to judge the scale."

A recent study conducted observations in a number of British museums, including Maidstone Museum to observe the role of the 'digital' in museums (see Waterfield, 2019). This study yielded a number of comments and observations about visitors' engagement with the digital content in the *Ancient Lives* galleries, including the 3D print. Over two days in August 2019, 22 museum visitors responded to a questionnaire and under 100 visitors were observed in the *Ancient Lives* galleries for periods of under five hours on both days. The results note that most visitors first watch the videos on the monitors and then touch 3D print before they go through the doorway to the tomb. Here, the opportunity to gain contextual and humanising information regarding Ta-Kush *before* choosing to view her remains is clearly enacted. The 3D print and videos create a base of knowledge for people to then approach Ta-Kush's body with. Children under 10 years tend to gravitate first to an interactive digital game adjacent to the 3D print (displayed on a separate monitor to the videos of Ta-Kush and visible in figure 9); older children and teens move first to the 3D print and then to the monitor with the digital animations of Ta-Kush; while adults watch the animations and then touch the 3D print. If children go straight into the tomb, it is usually because they have already been to the museum with their school, and they bypass the monitors pulling family in to see Ta-Kush. Most people revisit the monitors and 3D print after going into the tomb.

Based on these findings it appears that the goal of showing the mummy as a once-living human instead of a museum object, has indeed succeeded, and that the clear 3D printed replica of Ta-Kush offers a provocative and engaging way of presenting a facial depiction of an ancient individual for all visitors. In the absence of DNA evidence that might suggest her eye and hair colour, the translucent sculpture also rejects declarative statements about her appearance that could not have been avoided had we presented a painted and dressed bust. The CGI animations suggest these textures, while still maintaining a level of ambiguity and fluidity by virtue of the medium itself. Her image is not 'fixed' in time.

4. Discussion

In the *Ancient Lives* galleries, Maidstone Museum is affording the public an opportunity for both physical and emotional experiences with Ta-Kush that are augmented by simultaneous visual and haptic explorations (Lacey and Sathian, 2014). Through visual and haptic interactions with Ta-Kush and her remains, via human-computer interface during the facial reconstruction process and physical touching of the 3D printed model, we are permitted access to additional information about her facial appearance through visual and touch-based experiences with her 3D shape (Keehner and Lowe, 2010).

The haptic is a modality of perception that is about touch. It usually attends to surfaces, but within art theory (Richards, 2005), it also refers to a mode of optical perception that is capable of penetrating a surface to see within a given form, which is a particular affordance of medical imaging. These two modes come together in the concept of haptic-optic dynamics, which has found various inflections in relation to creative visual media, including art and film. Bio-archaeologist Joanna Soafer (2012) has extended the conceptual framework of haptic-optic dynamics in relation to empirical observation, stressing the importance of touch in knowledge acquisition in biological anthropology, a process which represents the multi-sensory 'embodied knowledge' that is innately understood by visual artists (Reid, Shapiro and Louw, 2019) but which is largely overlooked in the sciences, in which sight dominates.

In recent years, digital fabrication or 3D printing technologies have been used more frequently in the cultural heritage sector to provide new possibilities for study and exploration, and to allow better interaction through visual and haptic interfaces (Butler and Neave, 2008). Early digital fabrication technologies were not capable of producing material or textural characteristics of real-world objects, however, current advanced 3D fabrication technologies (including the SLA 3D printer used in this project) are capable of printing models with high-resolution surfaces that improve tactile perception (Scopigno, et al. 2017). Ballarin, et al. (2018) recently noted that the "museum visit as we understand it is shifting towards multi-layered and multi-sensorial experiences" that allow new ways

of interaction, particularly through haptic interaction with touchable exhibitions, and in turn can present easier ways for people to learn and experience reality.

Tools often afford interactions with both physical and digital 3D models that allow the user to take in significant information about the object (Lederman and Klatzky, 1987). With a physical 3D model, haptic interactions (with our hands as the tools) complement visual sources of information to assist in the formation of a more detailed and comprehensive 3D understanding (Reid, et al. 2018). A life-sized 3D printed model of Ta-Kush's head and shoulders not only allows visually able museum visitors the opportunity to touch and feel Ta-Kush but it also allows visitors who are visually impaired to 'see' her through haptic contact; in turn, fulfilling the accessibility brief set by Maidstone Museum; KAB were involved in the gallery re-design, and making it more interactive with objects to touch was key. The decision to produce a 3D printed replica of Ta-Kush stemmed from the Museum's greater awareness of the needs of visitors with visual impairment and more specialist needs generally, as reported in the *Ancient Civilisations: A Collectively Curated New Space* Heritage Lottery Evaluation Report (Boyd, 2017).

Existing research into face recognition through hand contact acknowledges that "sighted humans recognise faces almost exclusively through vision but also demonstrated that they can be distinguished haptically with levels of accuracy over 70%, whether they are seen solely through touch or using both vision and touch" (Kilgour and Lederman, 2002). Keehner and Lowe (2010) also notes that additional haptic interface with an object to "obtain and make decisions about shape related information allocates more weight to that sense, enabling perception to be more accurate", meaning that touch-based interactions may provide opportunities for all visitors to 'see' the face of Ta-Kush.

Ta-Kush can be noted as an example of digital 'unshelving', where 3D digital technologies afford the production of facsimiles of otherwise delicate or significant objects, for museum and gallery visitors to interact with directly. For example, 3D printing technologies afford the production of likenesses of otherwise fragile human remains (Roughley and Wilkinson, 2019), Alternatively, virtual, mixed or augmented reality applications may provide additional ways in which collections and their interpretations might be communicated in an immersive or interactive manner. Within a

museum setting, haptic barriers often exist between visitor and artefact, as most artefacts must be displayed behind glass. The 3D printed facial reconstruction of Ta-Kush encourages the opposite: its primary objective is haptic interaction. Further we suggest that digital technologies, as in the they have been approached and deployed here, afford an alternative and accessible way of considering 'posthumous personhood' via the digital animation, which allows the viewer to consider her various guises as windows into her possible identity.

5. Conclusions

Digital and interactive interpretive material encourages active investigation in the museum setting, fronting what is both known *and* unknown, and a touch-object, in the form of the 3D printed facial reconstruction, extends an otherwise visual experience to the visually-impaired, and encourages 'embodied knowledge-making' among all visitors (Sofaer, 2012). We suggest that the haptically-enabled 3D digital modelling software used to reconstruct the Maidstone mummy's facial morphology finds a logical conclusion in the curatorial choice to present this depiction as a 3D touch-object as well as a 3D digital animation. Displaying the 3D printed model as a centrepiece in the main gallery places an emphasis is placed on the most confidently accurate depiction of Ta-Kush in life. The 3D animation of her dressed in various guises shown on a monitor secondary to the 3D print, denotes it as an ancillary visage. As such, we propose that these haptic and digital solutions offer particular affordances in heritage practices, encouraging critical discussion about the ethical display of human remains, accessibility - including digital 'unshelving'- and engaging younger audiences, whilst also pointing to ongoing challenges.

The combination of limited budget and high level of inter-institutional collaboration is noteworthy in this project, but more so is the willingness of a museum of this size and capacity to consider creative and innovative responses to displaying human remains in a public museum context. Maidstone museum's primary aim was to humanise Ta-Kush, and by extension, engage visitors in considering the not-unproblematic issue of collecting and displaying human remains, while considering how knowledge is constructed and communicated about these remains in a museological

context. In the case of Ta-Kush, scientific analyses enabled a rich biography of a particular woman, whose previous representation in the museum consisted, metaphorically speaking, of a roughly drawn outline, to assume a highly individual and detailed form.

Museums can provide a public facing portal for the synthesised and interpreted results of academic collaboration. The CT scans of Ta-Kush and associated mummified material in the same collection have enabled continued academic debate past the opening of the exhibition, opening up new research pathways and associations with items in other collections elsewhere in the world (Onderka and Jungová, 2015). Active use of existing digital technologies in 3D facial depiction, including the data from clinical imaging, and 3D printing, has demonstrated scientifically justifiable interpretation of human remains and production of accurate facial depictions for presentation to public audiences (Roughley and Wilkinson, 2019). Finally, the project highlights the continuing importance of attending to the ethics of conservation and display. The ICOM Code of Ethics for Museums (2006) states that,

> *Human remains and materials of sacred significance must be displayed in a manner consistent with professional standards and, where known, taking into account the interests and beliefs of members of the community, ethnic or religious groups from whom the objects originated. They must be presented with great tact and respect for the feelings of human dignity held by all peoples.*

As conservator and curator Sanchita Balachandran (2016) has pointed out elsewhere, we need to "recognize the ways in which conservation routinely excludes certain hands, voices, perspectives, histories and legacies…[c]onservation in the 21st century can no longer just be about objects. Conservation also has to be about the people whose lives are inscribed on them". Here, we propose that the production of knowledge, through optic and haptic interactions afforded by science, 3D digital technologies and art, may allow a respectful remembrance of the subject who is being presented for our consideration and our gaze.

The lack of repatriation requests relating to ancient Egyptian human remains, or indeed of 'informed consent' related to treating such ancient individual as 'knowledge objects' remain ethically troublesome. Whilst we cannot presume to know with any certainty the interests of Ta-Kush's immediate ancient community, the archaeological record supports elaborate funerary practices and cult rituals where evoking the name of the dead was believed to assure existence in the afterlife (Baines and Lacovara, 2002). Decisions to undertake contemporary depictions of Ancient Egyptians have been rationalised with reference to Ancient Egyptian concepts and practices of posthumous veneration and immortality. In other words, sensitive stewardship and non-destructive analyses afford a contemporary version of post-mortem veneration, particularly through visual representation. (Swaney and Balachandran, 2018). We would like to believe that restoring Ta-Kush's name and in-life appearance, and presenting a more sensitive display of her remains, all act as a contemporary echo of these ancient practices.

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