Original Study

Christine Morris*, Alan Peatfield, Brendan O'Neill

'Figures in 3D': Digital Perspectives on Cretan Bronze Age Figurines

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Abstract: The largest corpus of clay figurines from the Cretan Bronze Age comes from ritual mountain sites known as peak sanctuaries. In this paper, we explore how the 'Figures in 3D' project contributes to our understanding of these figurines, aiding in the study of the technologies of figurine construction and the typological analysis of distinctive styles. We discuss how the project has, more unexpectedly, begun to create new dialogues and opportunities for moving between the material and the digital by taking a multifaceted approach that combines the data from 3D models and 3D prints with experimental work in clay.

Keywords: 3D scanning and modelling; Minoan; Cretan Bronze Age; terracotta figurines; archaeological representation

1 Introduction

For archaeologists and cultural heritage practitioners the material world lies at the heart of our work; our varied physical engagements may, for example, involve walking landscapes, excavating sites, or curating and analysing artefacts. Or, to put it another way, "archaeology is naturally involved with three dimensional space" (Kimball, 2016, p. 12). We also have the particular privilege of *handling* objects that most people will encounter only through museum displays or, at even greater distance, via published images (whether in books or increasingly online); indeed a considerable portion of archaeological material lies firmly, and often permanently, out of sight in museum storage. The development of 3D technologies for generating both digital and printed models has already created new kinds of engagements with sites and objects for everyone, from scholars and students to a wider interested public. For example, large-scale initiatives such as the '3D Icons Ireland' project offer access to digital models of iconic sites and monuments (http://www.3dicons.ie). The popular online platform 'Sketchfab' hosts 3D models created both by individuals and by major institutions such as the British Museum (https://sketchfab.com), while major museums increasingly offer full access to interactive digital models from their collections (for example, the Smithsonian X 3D Explorer: https://3d.si.edu).

These examples amply illustrate the mainstream uses and impact of 3D digital technologies for archaeology, irrespective of whether the technologies are viewed as 'tools' (even 'digital toys') to be passively deployed, or as a 'science', having the capacity to affect interpretation and the framing of research questions (Kimball, 2016, p. 11; Zubrow, 2006). There are also obvious opportunities for the democratization of knowledge through wider and easier access to data, and for more interactive engagement with individual

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***Corresponding author: Christine Morris,** Department of Classics, Trinity College Dublin, Dublin, Ireland, E-mail: cmorris@tcd.ie
Alan Peatfield, Brendan O'Neill, Department of Archaeology, University College Dublin, Dublin, Ireland

objects/models (Di Giuseppantonio Di Franco et al., 2015), allowing the user to turn, zoom, use different lighting effects on the digital object, and – if desired – to 3D print a personal copy, thus making the digital material again. There is, however, ongoing discussion around the 'aura' or 'authenticity' of such prints, their relationship to the original, and their place within the spectrum of replication techniques (Cameron, 2007; Jeffrey, 2015; Rabinowitz, 2015; Birchnell & Urry, 2016).

In this paper we discuss how our 3D scanning project, 'Figures in 3D', has contributed to our study and engagement with terracotta figurines from the Cretan (or Minoan) Bronze Age. While this is an ongoing project, it is possible to identity some of the benefits – and challenges – of 3D recording of this type of material. The areas discussed include consideration of how digital models compare with other traditional methods for representing the figurines and how the models can aid the study of technologies of construction and stylistic choices. We also reflect on the – more unexpected – emergence of dialogues between the material and the digital which developed out of taking a multifaceted approach that combines the evidence of the 3D models and prints with 'hands on' experimental work in clay. More briefly, we comment on how we have begun to use 3D models and prints in outreach contexts as a way of introducing audiences to our project's archaeological material.

2 The Archaeological Context

On the island of Crete the Bronze Age, conventionally termed Minoan, begins around 3200/3100 BC, with the second millennium (from c. 1900 BC) marked by the emergence of complex society. The period is characterized by monumental palaces such as Knossos in north-central Crete, elite literacy, and sophisticated aesthetic and technological skills. These developments should also be set within the wider context of increasing interaction between the Minoans and their Mediterranean neighbours, especially in the Near East and Egypt, facilitating exchange of raw materials, finished objects and ideas.

The figurine material, the largest corpus of Minoan terracotta figurines, comes from a class of ritual mountain sites conventionally known as 'peak sanctuaries', which have been identified across most of the island. While more than 50 sites have, at various times, been claimed as peak sanctuaries, a smaller number (between 25–30) can be more confidently identified on the combined criteria of topography and portable finds (Peatfield, 1990, 2009; Nowicki, 2007). Thousands of terracotta figurines were brought to these ritual sites and there deposited as votive offerings during the Minoan palatial periods (the second millennium BC). These figurine assemblages comprise anthropomorphic figures, animals (mainly domesticated, and especially bovines) and anatomical human body parts, also referred to as 'votive limbs'. In addition, figurines may form part of models, including architectural and landscape compositions (Rethemiotakis & Christakis, 2011, p. 212).

While there is some data to suggest earlier ritual activities in these mountain settings (e.g. at Atsipadhes: Morris and Batten, 2000; and at Traostalos: Chrysoulaki, 2001, p. 63), the major periods of use coincide with the two main palatial periods. The evidence suggests that they were ritual sites that served their local communities during the Protopalatial period (Middle Minoan IB–II; c. 1900–1700 BC). By the succeeding Neopalatial period (MM III–LM I; c. 1700–1460) the reduction in the number of active sites, the investment in built structures and in more varied and valuable finds suggests major shifts in their significance, and that these became more closely linked with elite centres and their ideologies (Peatfield, 1987, 1990), though only Knossos and Iuktas provide evidence of a direct 'palace-peak' model (Adams, 2017, p. 157).

Peak sanctuaries, as the name implies, are located within the mountainous landscapes of the island, but unlike many ritual traditions connected with mountains they are not situated in remote locations, accessed only through long and arduous journeys. Rather, although they vary greatly in their absolute altitudes (from 212 to 1168 metres above sea-level), they are consistently located on the peaks that are the most prominent from the nearby habitation areas, and the ritual landscape is nested *within* (not outside or beyond) landscapes used in numerous other ways, such as for agriculture, herding animals and the gathering of fragrant Cretan plants.

The earliest excavation of a peak sanctuary was of Petsofas in East Crete, undertaken by John Myres for the British School at Athens at the turn of the twentieth century. The report describes the discovery

of clay figurines "of men and women, legs, arms and other parts of the human body, and an enormous number of animals, some thousands in all" (Bosanquet et al., 1902-3, p. 276). This served to establish that a key criterion for the identification of a peak sanctuary, alongside inter-visibility with its local community and their settlements, is the presence of substantial numbers of clay figurines (Peatfield, 1983, 1990). Other excavated sites, such as Iuktas, Vrysinas, Traostalos and Atsipadhes, have also yielded thousands of figurines, a veritable terracotta crowd. It is important to note here that it is the *sheer number* of figurines that is a distinctive feature of peak sanctuaries; figurines are found in many other Minoan contexts, but in much smaller quantities. The earliest work at Petsofas also established that one important function of these sites was the performance of rituals relating to health and healing, an idea that arose initially from comparisons with anatomical offerings from other healing cults, past and present (Myres, 1902-3, p. 381, Arnott, 1999, Morris & Peatfield, 2014).

3 Representing Peak Sanctuary Figurines

Our long-term research on Minoan peak sanctuary figurines, of which 'Figures in 3D' now forms a key part, draws primarily on our work in scanning figurines from two distinct, and rather different, projects. Firstly, the fully excavated site of Atsipadhes Korakies in western Crete which yielded over 5000 fragments of figurines, all plotted *in situ* and now integrated into an intra-site GIS (for reports of the 1989 excavation, see Peatfield, 1992, Morris & Peatfield, 2012). And then secondly, an ongoing museum-based project, in collaboration with Costis Davaras, to record and publish heritage material, excavated in the 1970s, from East Cretan peak sanctuaries (ECPSP: the East Cretan Peak Sanctuaries Project).

Among the factors that initially attracted us to the use of 3D scanning were the sheer quantity of our material, the challenges of recording it both for study and for publication, and – increasingly on our minds – the additional potential for engaging wider audiences without specialised archaeological knowledge. Relevant too was our own focus on the overall life cycle or biographies of the figurines (from production to consumption), through which the physicality and agency of the figurines was more explicitly foregrounded. It seemed to us that the full physicality of the figurines and the scope of past human actions such as shaping and making them, and of holding, grasping or carrying them, could be more effectively captured and communicated through 3D modelling.

In terms of their production, the hand-modelled peak sanctuary figurines represent a series of local, and perhaps regional, traditions of style and technique that nest within the wider overall or shared peak sanctuary figurine style (Morris, 1993, pp. 51–56). This variation presented challenges in terms of recording and representing this material; challenges that required a multifaceted approach, combining established and developing techniques. Although much work remains to be done on refining our understanding of local styles and preferences, 3D technologies offer an excellent opportunity to advance such studies for these and other comparable bodies of figurines.

In order to create 3D models of the artefacts in question, and taking into account issues of portability and cost, two main options presented themselves: 3D laser scanning or structure from motion (SfM). 3D laser scanning has the advantage of allowing users to produce extremely high quality and regular underlying meshes and associated textures. With certain scanners this accuracy is predicated on the fixed distance between scanner and object, providing consistency in the positioning of points within the point cloud (Counts, 2016, p. 210; Garstki, 2017). On the other hand, the position of points in SfM models is relatively less consistent. This is due to the fact that the locations of points that make up the model are assigned based on shared features across photographs and not by direct scanning of an object (Garstki, 2017).

Since this project sought to produce models of small to medium sized objects (Means, 2013; White, 2015) as geometrically accurate as possible, and taking into account the practical considerations mentioned above, a NextEngine 3D laser scanner was chosen (Fig. 1). This allowed details of production to be documented while capturing 3D data for later analysis outside of Greece. It also allowed watertight models of extremely high precision (up to 40k points/in2) to be rendered and later printed in a range of different materials (for further technical details relating to this equipment consult Means, 2013).

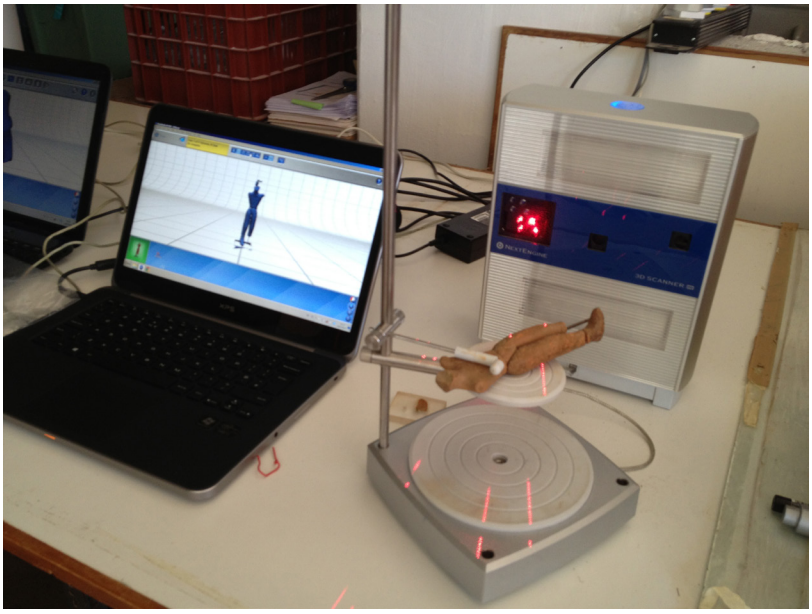

Figure 1. Figurine held in position for scanning on the rotating turntable.

The project began in 2011 with a small pilot, scanning a handful of fragmentary figurines from Petsofas (in the Classical Museum of University College Dublin) in order to evaluate the performance, speed and accuracy and to establish a methodology for this object class. This was followed by a short exploratory season in two Cretan museums where the scanner was, at times, challenged by the hot and dusty conditions. By 2013, with the support of Irish Research Council funding, work began in earnest on scanning figurines from East Cretan peak sanctuaries held in the Ayios Nikolaos Museum.

Informed by the earlier pilot sessions, a consistent workflow was applied with a typical scan of an anthropomorphic figurine (of c. 15–20 cm in height) taking about twenty minutes and producing a file size of 30–40 MB. This timeframe can in theory be extended by complex geometry of certain figurines and the need to position them in such a way to scan as much of the object as possible (Kaimaris et al., 2011). While this can make the actual scanning potentially time consuming, there is comparatively little post-processing if compared to other methods such as SfM (Molloy et al., 2016).

Another potential drawback of NextEngine's associated software (Scanstudio) is its tendency to blur the colour of finished models. Nevertheless it should be noted that this is only a failing of this software's ability to display and not a reflection on the model itself. If exported and viewed in other programmes, such as Meshlab, models are visually more realistic and the underlying data is so detailed that extremely high quality 3D-prints can be produced from them.

In order to evaluate the benefits, challenges and opportunities that 3D scanning presents for portable artefacts, as this topical issue invites contributors to do, it is important first to consider the ways in which the figurines have traditionally been recorded and how this parallels or differs from a digital representation. The earliest figurine illustrations come from Myres' (1902-3) journal article on the Petsofas excavation. Selected figurines (whole and fragmentary) are organized according to basic types ('men', 'women' 'votive limbs', 'animals'), showing a single, frontal viewpoint, as groups on black and white photographic plates. More imaginatively, two watercolour reconstructions are used to try to capture the original forms and polychrome painted surfaces of the human figures. The value of such watercolour images has been discussed in relation to the work of Piet de Jong (whose iconic images of sites and objects are well-known within Aegean archaeology). Commenting on de Jong's painting of a Roman African red slip bowl, – where he captures the vessel's form, decoration and colour in a single image – Papadopoulos observes that it is effective in giving us 'a peek into all aspects of the pot' (Papadopoulos & de Jong, 2007, p. 264; Heath, 2013, p. 55).

A later catalogue of the material similarly relies primarily on black and white photographs, with multiple views of selected examples plus a few simplified outline drawings to show the basic figurine forms (Rutkowski, 1991). Engagement with the figurine material is heavily dependent on using the descriptive catalogue in tandem with the photographic plates. As is typical of archaeological publications, the need to be familiar with specialized vocabularies and other technical conventions is likely to inhibit access to the material beyond the scholarly community. Many of the key issues of interest for figurine studies, including technical features of construction (Rethemiotakis, 1997) or features of potential social significance, such as hairstyles (Morris, 2010; Pilali-Papasteriou, 1989), are often difficult (even impossible) to see in these kinds of representations, and are typically revealed only through actual handling or by illustrating multiple viewpoints.

One effective, and traditional, archaeological solution is to represent the material through conventionalized, technical drawings which emerged as a 'gold standard' for recording in the wider context of modern scientific illustration (Moser, 2014; Carlson, 2014). As Heath has observed, such illustrations 'utilize a code of sorts that requires considerable mental processing to move from their abstract representation to a sense of the real vessel' (Heath, 2015, p. 55). For the archaeologist familiar with the 'codes', technical drawings offer many advantages that are well worth considering alongside 3D modelling, since the latter is sometimes seen as challenging or usurping the important role of the highly skilled archaeological illustrator (Carlson, 2014; Nylund, 2011; Killackey, 2016a, 2016b). Surprisingly few peak sanctuary figurine drawings have been published, despite the standard use of drawings for figurine assemblages elsewhere. For this reason the Atsipadhes project invested in the skills of a professional archaeological illustrator, Jenny Doole, who worked closely with us throughout our annual museum study seasons and whose drawings form an important part of our publications.

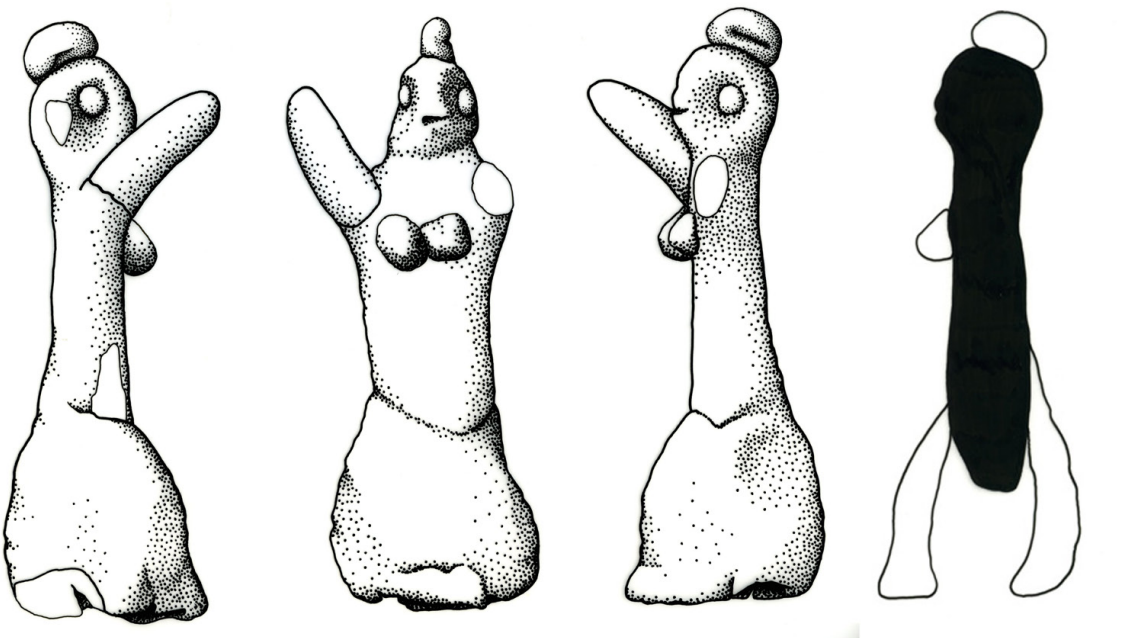

Figure 2. Female terracotta figure from Atsipadhes, drawn by Jenny Doole. Three views and a section to show pegged construction of torso and skirt. (RM 6785, with joining fragment, RM 20136).

Her drawings of a female figurine (RM 6785) from Atsipadhes exemplify the many benefits of this method of representation (Fig. 2). The three views give the viewer a clear sense of the physicality of the figure that is not captured in any single viewpoint; for example, the exact posture of the arms, the asymmetrical face formed by a thumb and forefinger pinch, or the folded wedge of clay for the topknot. An additional section

drawing demonstrates clearly how the solid clay body is 'pegged' into a roughly circular hollow skirt. Careful shading (stippling) provides a '3D feel' to the drawings, while damage and breaks are indicated by the convention of blank surfaces. All elements of the representation are the result of careful dialogue between archaeologists and illustrator – the drawings are technically accurate while also being artistic interpretations. As a scholarly resource they provide more complex data than a photograph, but they also tend to be harder for a wider audience to engage with intuitively.

4 From Traditional to Digital: Modes of Representation

How then do the 3D models of the figurines compare with these traditional methods of representation? For our project, we view them as *complementary* to (not a replacement for) photography and technical drawings, though digital capture using the NextEngine scanner has been our primary method of recording for the East Cretan figurine project since 2013. Key benefits of the digital models are the high level of accuracy and detail, giving us immediate 'take home' access to detailed data. Unlike other types of representation (photographs, drawings) the data is, of course, dynamic, allowing the viewer to interact with the model by turning it and zooming in on particular details, making it more intuitively accessible to non-specialists (Heath, 2015). Other studies have reported issues with capturing subtleties of colour and texture (with polished and reflective surfaces being problematic: e.g. Levoy et al., 2010), and our experience with this has also been variable. However, a significant benefit of the modelling process is the *option* to view the model as a plain surface (without the photorealistic colour/texture), which makes it easier to study and communicate subtle details of form and technology (Fig. 3).

a) b)

Figure 3. Example to show scanned model with photorealistic surface (3a) and plain modelled surface (3b). Worn torso fragment from Petsofas (University College Dublin, Classical Museum).

One potential concern, as the project got underway, was how (or if) the change in visual recording method might affect study and interaction with the objects. A particular benefit in the Atsipadhes project was the input from the illustrator, who came to know the material intimately, making significant contributions to the understanding of the often worn and fragmentary material through the drawings themselves and in wider discussion. That process of discussion and intimacy with the artefacts could, in principle, be lost if the scanning were undertaken in a purely mechanical way (by a technician rather than an archaeologist) or done separately from the other aspects of the archaeological study. In the case of 'Figures in 3D' the project was designed to maintain maximum dialogue, so that traditional cataloguing and scanning was done in tandem by the present authors during study seasons. This created a similar dynamic to working with an illustrator since questions around style, technology or discussion of damaged features could be bounced back and forth within the small team. In this particular collaboration, therefore, the 3D scans became an active element in helping to think about and also formulate new questions around figurine style and technology.

We turn now to introduce two brief case studies to illustrate how the scanning has enhanced our studies, using figurines from the ECPSP project, specifically the peak sanctuary of Prinias, located above the modern town of Sitia in East Crete. Figurine HN 5932 is a fragmentary female (preserved height 13 cm). The head, torso and upper edge of a belted skirt are preserved in three joining fragments; the skirt itself is missing, as is the lower right arm and the applied right breast, while the nose and the figurine's hat (polos) are chipped off. These features are visible in the high quality archival photograph (Fig. 4). The 3D model of the figurine offers a fuller and more intimate engagement with the figurine that has multiple benefits to a range of users (Fig. 5). As an archival record the model shows the form, joins and state of preservation clearly and, of course, three-dimensionally. The detailed rendering makes study of style and technology easier – and, importantly, makes it easier to communicate these features, especially for the viewer/reader who has not had the benefit of personal contact with the figurine.

Figure 4. Female terracotta figurine from Prinias (HN 5932).

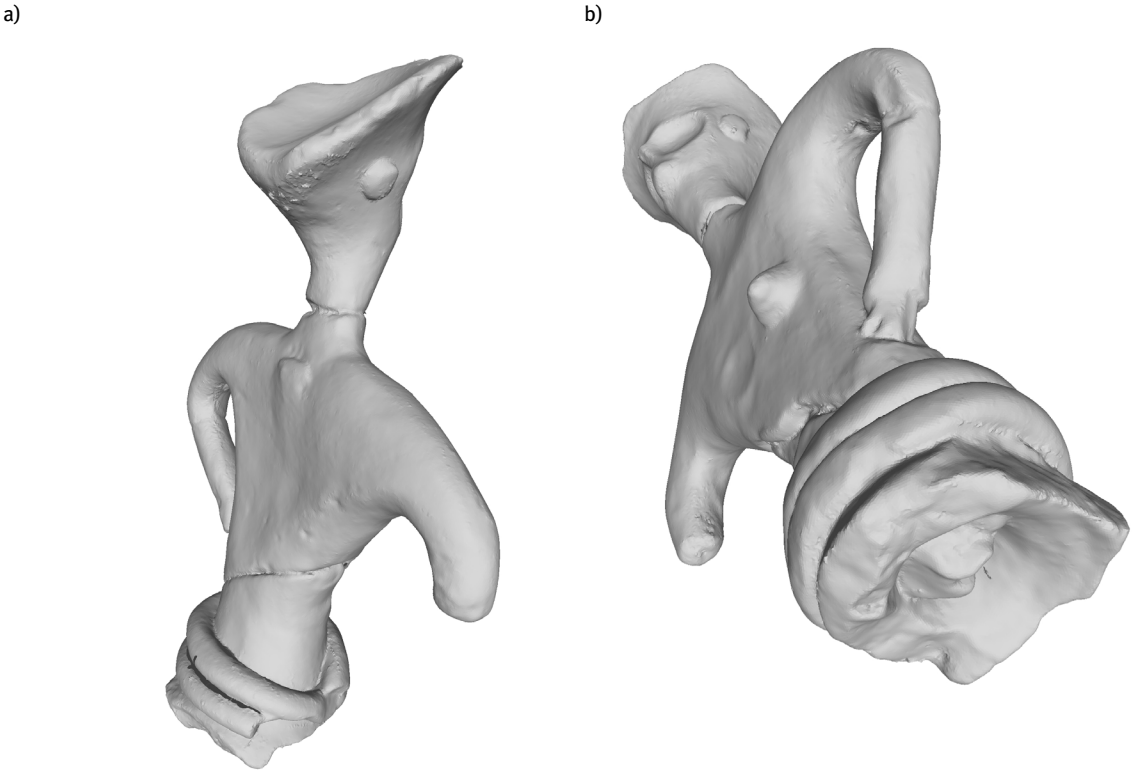

Figure 5. Stills from the digital model of HN 5932.

Looking a little more closely at HN 5932, the model makes stylistic and technological features more readily visible: the deep pinch for the face, small applied pellets for the ears, larger pellets for the breasts, one of which is preserved only as the attachment scar. The figurine follows a fairly standard form in that the lower body (as in the case of the Atsipadhes figurine discussed earlier) takes the form of a hollow skirt, the hem or rim of which allows the figurine to stand unsupported. The model shows the pegging of the torso into the (missing) skirt, and the added support from the applied belt, looping around the waist twice. A subtle feature, and one repeated on a number of Prinias female figurines, that appears between (or sometimes across) the shoulders is an piece of clay (or its scar) from an added layer of clay; this creates a shawl-like effect but also helps to support the heavy weight of head plus polos hat. The process of trying to understand how the figurines were constructed and the observation of these and other details were a catalyst to another element in our project, that is, attempting to replicate the manufacturing processes through experimental work. Thus, while working with our hands in clay and digital modelling may seem poles apart, we found them to be complementary approaches for exploring about figurine production.

Our second case study takes an unusual piece from Prinias, the terracotta head of a cat (HN 6080, height preserved 4.4 cm). The cat was scanned in 2013 (Fig. 6) and the process of cataloging and scanning generated considerable discussion about its form and technology. The smoothed and flattened edges at the neck immediately suggested that the cat could have been made as a head (or protome), rather than a full animal figurine, to be attached to the side of a vase (for which we now know that there are parallels amongst other, as yet unpublished, pottery from the Sitia region). In that context the hollow construction (lighter for attachment) also made better sense, and we began to wonder if the piece had been made in a mould. That question impressed itself on us more forcibly with the discovery of a second cat fragment, also from Prinias (HN 6305), preserving only part of the left side of the face with eye and ear, but also much more heavily worn than the whole cat's head.

Visually, these two pieces share certain characteristics while differing in others. The majority of their similarities are in their underlying structures, particularly the noses, brows and cheeks (Fig. 6). Onto this

base individualized detail was added through a combination of hand modelling and incision. This is most apparent in the ears and surface detail of the faces. Such a description is consistent with our contention that both heads were produced from the same mould, providing the shape of the face. Onto this, an individually modelled ear was added, attached at the open back of the face. On at least one of the heads (HN 6080) additional clay was added, creating and completing the back of the head down to the neck. At this stage the head could be removed from the mould and subtle details added.

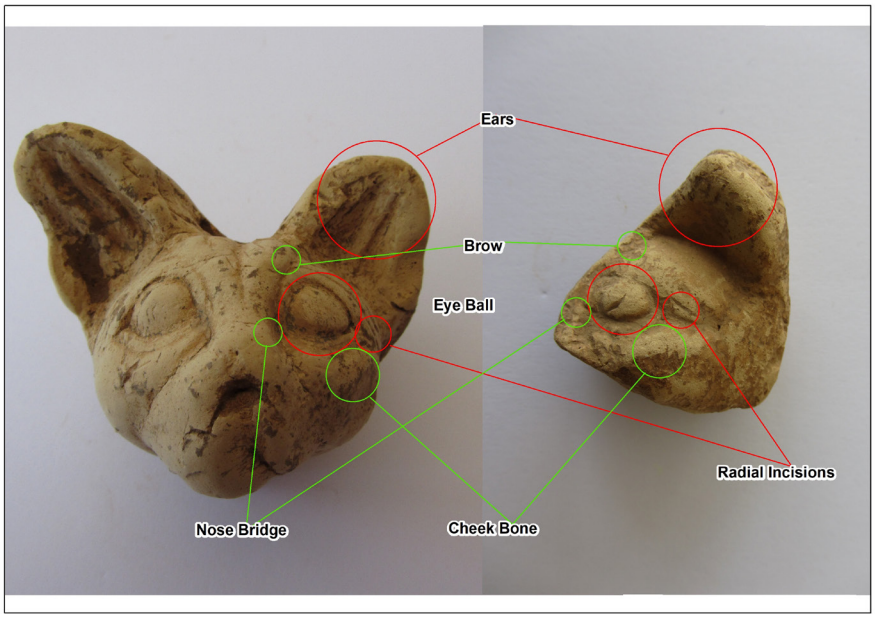

Figure 6. Comparison of moulded cat heads (HN 6080 Left and HN 6305 Right) indicating shared (green) and not shared (red) features.

a) b)

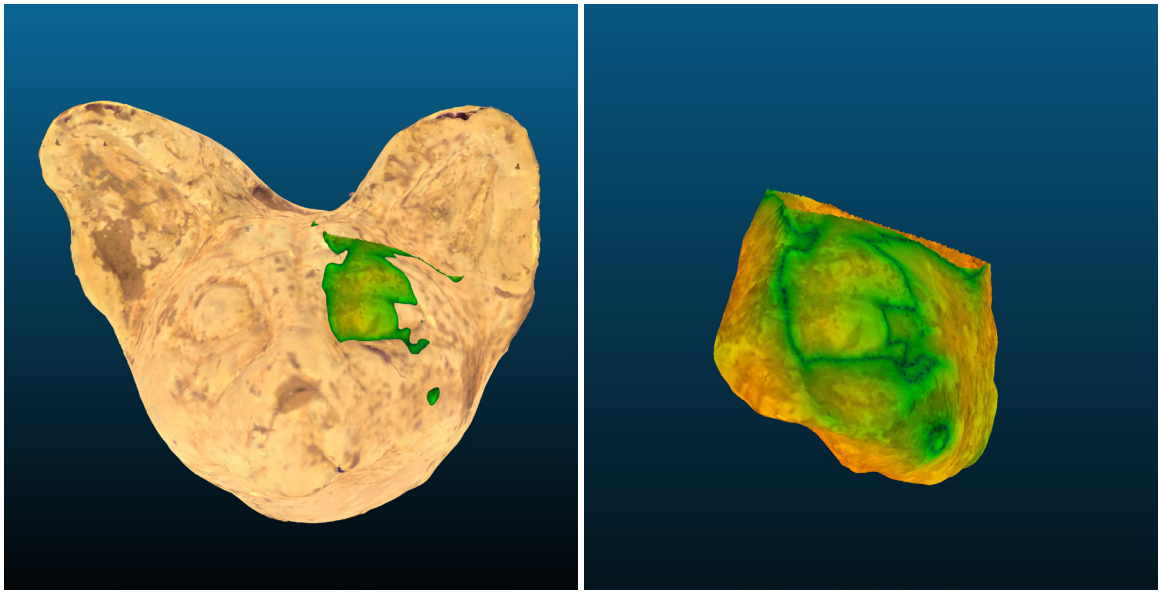

Figure 7. HN 6080 (a) and HN 6305 (b) overlaid and compared using Cloudcompare software. The ear has been extracted from HN 6305 point cloud. This shows the high degree of similarity with some areas on the surface of the face (green) with orange indicating areas of abrasion.

Although this may seem straight forward, the malleability of wet clay, the addition of incised detail and post depositional abrasion have each added small variations to the surface topography. Figure 7 (Cloudcompare pictures side by side) shows the degree of similarity between both artefacts detected using Cloudcompare software. Only in places that have been manually (the eye) or naturally (cheek) altered are differences, however slight, apparent.

This digital work was the catalyst to taking this a step further by doing some experimental work. The complete head was 3D printed, and the 3D print was then used to recreate a clay mould of the face, and from that more clay cats in the image of the Prinias cat. This was an unexpected avenue of research since, as noted earlier, most Minoan peak sanctuary figurines are handmade. However, the value of 3D technologies for working with mould made figurine traditions has been more extensively drawn upon by other projects, albeit with much larger data sets than our modest pair of cats (Papantoniou et al., 2012; Bevan et al., 2014).

Turning finally to wider questions of outreach and communication, this is a space where 3D technologies are widely and successfully utilized (e.g. https://3dpubarch.wordpress.com; Bevan, 2014). In this context, the Prinias cat has proved a brilliant 'calling card' for drawing in the public. Our cat acts as a 'voice' for weaving a story about Minoans on a mountain sanctuary 4000 years ago and allows us to showcase the methodologies used to do our research. In 2013 and again in 2015, for example, we participated in 'Discover Research Dublin' (part of European Researchers' Night, which aimed to bring the public, and especially young people, into conversation with researchers). We demonstrated the use of laser scanning to record archaeological objects, and invited visitors to handle our 3D prints, including, of course, the cat. We have also developed other ways of encouraging engagement, handling and conversations about the archaeology, such as deliberately making prints in bright attractive colours, and also printing figurine fragments and inviting our visitors to try to work out what they might be – a process that replicates our own actions as archaeologists trying to make sense of our material.

In conclusion, the 'Figures in 3D' project illustrates some of the varied ways in which 3D technologies can be effectively integrated into the study of portable artefacts, such as terracotta figurines. Discussions of the role of 3D technologies in an archaeological and cultural heritage context have, as noted earlier, sometimes characterized them either as merely digital 'tools' (comparable to a trowel or a camera), or as having a more active and powerful role to play in shaping research questions. Where the balance lies between these two perspectives will surely depend on the requirements and scope of individual projects, and even on the particular stage of research. In the case of our project, 3D modelling of the figurines has enhanced recording and communication of the material, and it clearly has the potential to make artefacts more vividly and intuitively available to a wide audience. The 3D project has also encouraged us to reflect on the role representation can play in discussing, interpreting and posing questions, and has – perhaps more surprisingly – acted as a catalyst for moving from the virtual/digital to the materiality of experimental replication of manufacturing techniques. Borrowing from reflections on the nature of 'spatial history', we may conclude that 3D modelling and printing is not only a tool but also "a means of doing research" (White, 2010).

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