Virtual Coppersmiths – Exploring Iron Age non-ferrous metalworking utilising 3D scanning and printing.

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Abstract

In recent years there has been a flood of interest and practice of three dimensional scanning and recording of archaeological landscapes and artefacts. Yet from this flurry of recording, there has been little research into whether this practice enhances our understanding or is actively involved in analysis beyond the easy recall of scenes and sections.
Can 3D scanning and model production be used to greater effect in artefact analysis?
This study addresses this question by researching to what extent our understanding of artefacts can be enhanced by three dimensional scanning technology, specifically the analysis of non-ferrous mould fragments discovered at The Cairns, South Ronaldsay, Orkney.
Using the cheapest and most accessible 3D scanning method available, a photogrammetrical methodology was established to quickly yet effectively scan the mould fragments and produce 3D models. In turn, these models were assessed and manipulated to produce a 3D reconstruction of their resultant object, namely a detailed ring headed pin roughly dating to the 1st century AD. This pin was then 3D printed in bronze to assess its impact for both analysis and presentation.
The results indicate that although complex, the methods behind 3D scanning can indeed add new dimensions to artefact analysis, especially when employed to produce reproductions of unrecovered artefacts. It is also clear that this method can produce a potential funding avenue for excavations while providing analysis tools for further education and study. This technology will undoubtedly become easier and more cost effective in the future and should certainly be considered for active analysis of archaeological sites and artefacts.

1. Introduction

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Can 3D scanning and model production be used to greater effect in artefact analysis?

This study addresses this question by researching to what extent our understanding of artefacts can be enhanced by three dimensional scanning technology, specifically the analysis of non-ferrous mould fragments discovered at The Cairns, South Ronaldsay, Orkney.

Utilising the middle Iron Age non-ferrous metal working mould assemblage recovered from The Cairns broch, this paper explores to what extent our understanding of non-ferrous metalworking can be enhanced by utilising three dimensional scanning technology. In order to assess the impact of 3D scanning technology on the mould fragments, it was necessary to produce three dimensional scans of a selection of non-ferrous metal working moulds and use them in the analysis of non-ferrous metal working. Specifically 3 fragments were singled out as being likely from the same mould of a ring headed pin and these were used in this study.

Figure 1 - Mould fragments: Finds #1931 (lower left), #1996 (upper left) & #1995 (upper right).

2. Material and methods

2.1. Method of Photogrammetry

Due to the restrictions of time and finance it was decided that a cut down photogrammetrical approach would be used for the 3D scanning of the moulds. A Canon 1100D DSLR camera was used in conjunction with a Canon EF 100mm f/2.8 Macro USM lens as suggested by Yanagi & Chikatsu (2010). This allowed the necessary focal length to capture the macro detail but presented the additional problem of depth of field.

Traditionally this depth of field issue would have been resolved by focus stacking, however a motorised focus rail was not available for this study and tests revealed that manual focus stacking for photogrammetry would take too much of the available time. Given that focus stacking required an average of 14 pictures per compiled image and an average of 92 images were needed per photogrammetrical model of each mould fragment, the total number needed increased from 92 to 1288 images. This plus the associated processing time meant an increase of around 10 hours for what is usually a 20 minute process.

Therefore, an alternative was devised that could provide a reasonable level of focus in one shot that used the following settings:

Figure 2 - A comparison of focus methods.

F-Stop	Exposure	ISO
F18	¼ second	3200 (or Auto)

Figure 3 - Favourable camera settings for one shot focus of macro objects using a 100mm lens.

An LED Light ring was used to get direct light onto the fragments and eliminate as much shadow and contrast as possible, as this is detrimental to the photogrammetry process.

Figure 4 - Camera setup with light ring and mould fragment on custom made cradle.

The set up was as shown in figure 5.

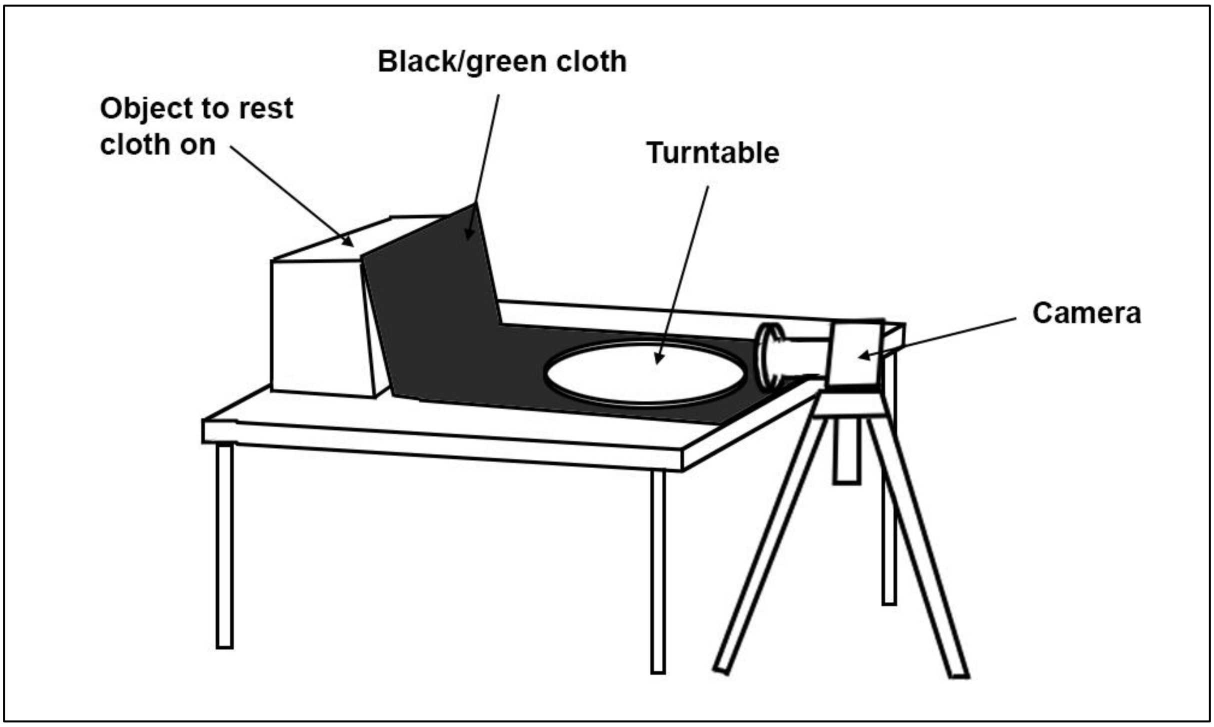

Figure 5 - Set up diagram for camera and turntable.

A black background cloth was used however a green cloth would also have been sufficient. The turntable was constructed from a cheap "lazy susan" purchased from eBay and marked with a line on one edge to show when a complete rotation had been achieved. No measured system was used to measure the distance of each rotation as it was deemed unnecessary however an average of 13 images were captured per full rotation.

While not necessary, both sides of the fragments were captured to create a complete model of the fragment. This was done by taking a series of images from 4 angles, then flipping the fragment and taking images from a further 3 angles as seen in figure 6. These later images were then rotated 180 degrees to capture the "underside" of the fragment in the eyes of the processing software used.

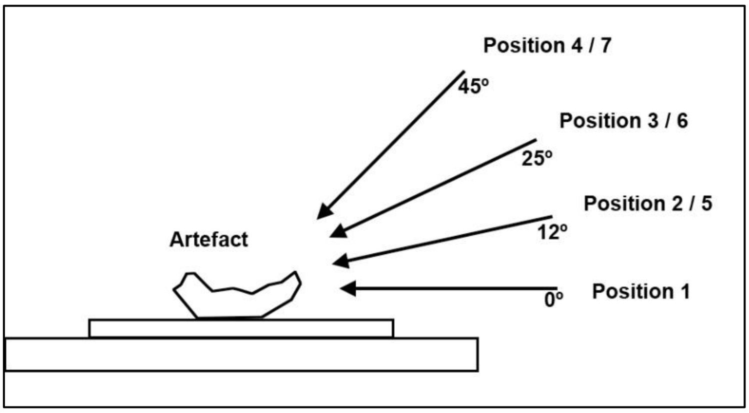

Figure 6 - Angles used in the image capture process.

2.2. Method of Processing

Agisofts Photoscan Pro was used to process the images into a 3D model using the highest settings possible. This resulted in three models that could be displayed and analysed however it presented the opportunity take the study further, specifically to digitally "cast" the resultant object.

The mould models were then further processed in Autodesk's Maya software to this end. The casting surfaces of the moulds were cut from the rest of the model and the normals were then reversed to effectively invert the model surface. All three surfaces were then brought together for assembly. Some reconstruction was necessary as a full quarter of the full mould was not present as well as some of the spaces between the fragments where detail had been lost.

The pin shaft was the most affected by this, and so it was decided to replicate and mirror the bottom half of the pin shaft creating a whole pin.

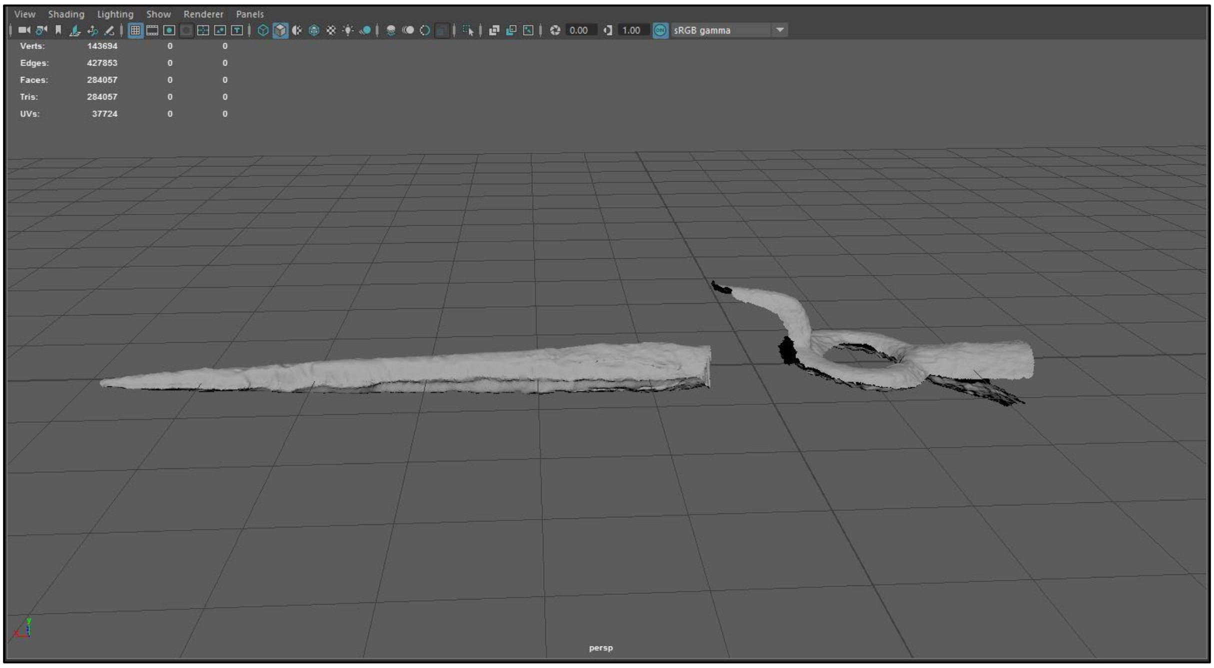

Figure 7 - Pin surfaces in Maya, showing a completed pin shaft.

This left the joining of the ring head halves and filling in the missing sections (see Figure 8). This was accomplished by moving the two surfaces so that the highest points were touching, then filling the gaps with new faces. No reconstruction was necessary for the majority of this however the join at the neck of the pin was missing from the moulds and required a different approach.

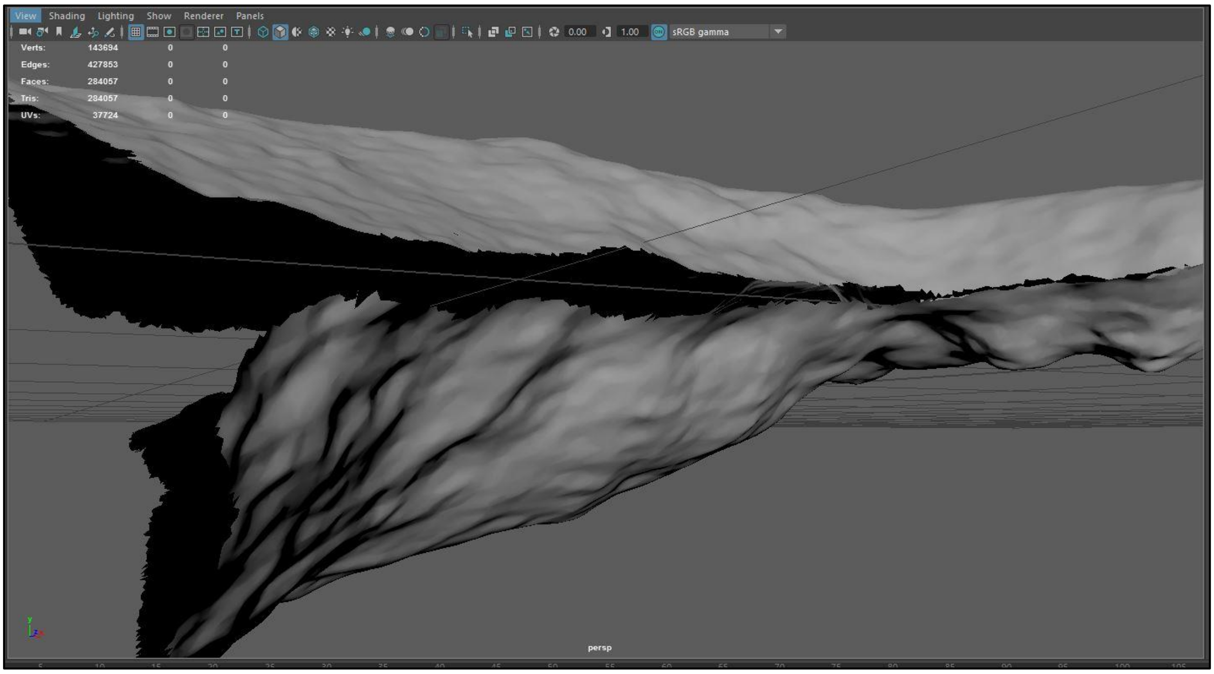

Figure 8 - Close up of the pour spout surfaces showing the gaps that needed to be filled.

The space left was filled in with a temporary structure to give it volume, then exported to Autodesk's Mudbox (Figure 9) where it was sculpted into a shape paralleled by other pins of the same era discovered on Orkney.

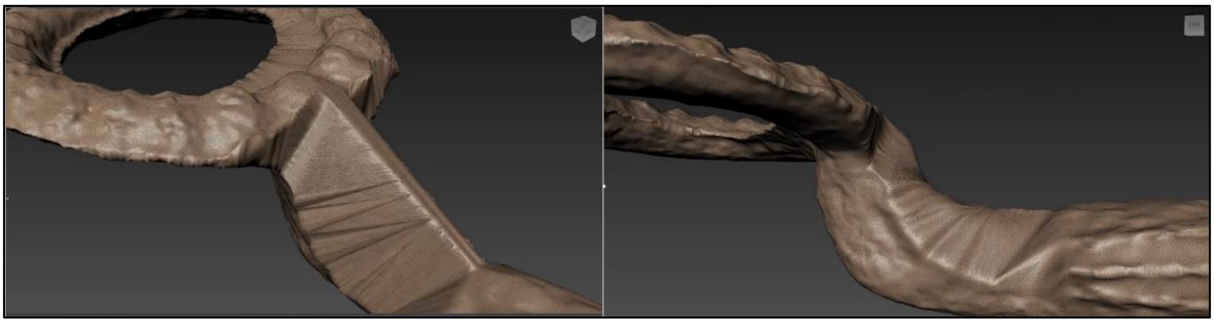

Figure 9 - Before Mudbox sculpting (left) and after sculpting (right).

3. Results

3.1. Focus Stacking vs Non Focus Stacking Photogrammetry

While this result didn't feature in the final 3D model it is interesting to note the differences between a model produced from focus stacked and non-focus stacked images.

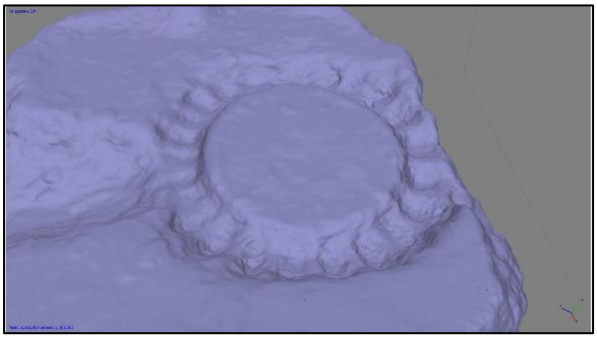

Figure 10 - Detail of mould #1995 using the "One Shot" focus method.

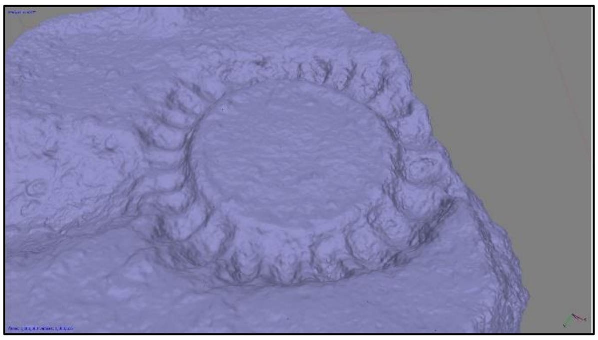

Figure 11 -- Detail of mould #1995 using the "Focus Stacking" focus method.

3.2. 3D model and printout

The primary result of this study was the creation of a virtual pin model from the mould fragments. The model was intended to be in a "just cast" state in that none of the flash has been removed, nor the pour spout.

Figure 12 - Completed ring headed pin model.

It was decided to take this a step further and 3D print the pin. Using a service from Shapeways, the pin was 3D printed in wax then cast using the lost wax method in a 90% copper, 10% tin alloy.

Figure 13 - 3D printed model of the ring headed pin in bronze

4. Discussion

The study resulted in some expected and unexpected avenues of thought and discussion, especially when presented and discussed with the UHI Archaeology Institute.

4.1. The value of 3D printing

The main goal of this study was to assess to what extent our understanding of non-ferrous metalworking can be enhanced by the use of 3D scanning technology. While the 3D scanning, model manipulation and physical production of the moulds and associated objects has undoubtedly stirred much thought, it is not a direct answer to this question. Certainly physical production of the pin has provided a very clear answer as to what the missing resultant object would likely have looked like, and even without a 3D print of the object, the 3D model would have provided nearly as much of this insight. The 3D models of the moulds themselves also allows the possibility of further work in the reconstruction of the moulds themselves, or to suggest new shapes for the missing pieces.

Another avenue of use is that of an almost phenomenological approach, in that the items can assist in the study of the affordance of such items (Knappett, 2005). While the physicality of the object is not strictly speaking necessary, it could add an interesting angle to help in the thinking of how objects interacted with communities and the physical space around where they were found.

It was originally hoped that the 3D scanning might reveal new levels of detail that could help determine whether the moulds were reused. In actuality viewing this level of detail has not been possible with the scanning method used as the models simply don't show micron levels of detail that this would require (as seen in Figure 14). If this were the sole purpose of the requirement of a 3D model, it is feasible that micro photographs could be taken of the slip areas and a 3D model built in the method previously used. However

Figure 14 - Extreme close up of mould #1995 model showing the lack of microscopic detail.

given the length of time required compared to merely viewing from a microscope, it is likely that this is not a valuable use of analysis time unless value could be seen in a 3D model being used for presentation or educational purposes.

4.2. Accuracy in 3D scanning

The limited focus stacking photogrammetry test conducted for this study proved the marked improvement that focus stacked macro photography had over a quicker 'one-shot' focussing solution. The issue of speed of capture can be somewhat mitigated by investment in equipment and software, however the same can be said for any of the 3D scanning methods. It is suggested that the value of photogrammetry above the other methods is one of reusability of equipment rather than any accuracy or speed advancements. The fact that most of the equipment used in the photogrammetry process can be used for other archaeological recording purposes gives it a distinct advantage in a fiscally challenging work environment.

However the main issue this raises is that of detail and accuracy; how much detail is acceptable and required? The simple answer is that the acceptable method of detail is merely that which is required for its purpose. That is to say that detail and accuracy only become problematic if they're not available in sufficient quantities for the question that is being asked of it.

In this way it would appear that there is a subconscious desire amongst archaeologists to gather as much detail as possible without making the cost in time, energy and money too excessive. Again this is a very subjective matter and extends far beyond the scope of this study. A much larger study would be required to fully explore this angle and determine the feelings of the archaeological community at large. As far as this study is concerned the level of detail was sufficient to answer most of the questions asked, with only a very specific portion being denied by the method used.

4.3. Marketability and Ethics

Commercial considerations of the reconstruction of the pin (shown in Figure 15) were an interesting and unexpected development from this study. While 3D printing certainly opens up the possibility of marketing artefacts as products, a small amount of caution must be taken from an ethical standpoint. It is important to consider the potential problems with counterfeiting, however this could easily be managed by marking items in such a way that it is clear that it is a reproduction. Objects produced this way would have a distinct level of authenticity in their form and if packaged correctly with the appropriate background information, could be of benefit to collectors and educators alike.

Figure 15 - 3D printed pin in bronze on cm scale.

This then opens up a whole new avenue of funding for excavations and archaeological projects. While not every excavation turns up such interesting items, the funds generated could certainly be spread around if they are operated by a central group. While the market for such items is reasonably limited, sales of similar items from high profile excavations and sites appear to do reasonably well. The local example of this on Orkney are sales from the on-site shop during the Ness of Brodgar excavations each year. While this example might be unique to Orkney and its increased focus on tourism, it at least shows that such products are desirable. The pin was put on limited sale via the Shapeways 3D printing site over the Christmas 2016 period and generated over thirty sales in the space two weeks, showing there is a demand for reproductions such as this.

The study does appear to highlight that production of replicas and even objects that are resultant from artefacts have been made significantly easier and affordable to produce with modern technology. It has also opened up a further avenue of study into the sustainability of such an endeavour as well as its cost effectiveness. In some respects this study has partially addressed this by assessing one of the cheapest ways to record artefacts and produce 3D models, however the skillset required is more aligned to a technology discipline than an archaeological one. This is not necessarily a barrier to archaeologists as the skills required are learnable via casual study and would significantly benefit from an archaeological perspective.

4.4. 3D is not applicable in all situations

This study has shown that 3D scanning does have value for analysis but it is important to state that this does not apply for every situation nor every analytical avenue can be improved by the use of 3D scanning. Its power lies in achieving things that cannot be done through more traditional methods. This was shown with the inability to detect differences in the mould's slip lines in the 3D model, where a microscope would be able to detect this without issue.

5. Conclusions

The outcomes of this study have ranged from the mild to the extremely surprising in both the method and the results. It is surprising how long the photogrammetry process can take with such a small number of photographs per model. Full scale models can take many more hours and even days to process but the photographs themselves are fairly quick to take and use. By contrast the smaller scale photographs require more image processing in order to produce good results and this was not anticipated at the start. It has been shown that 3D scanning technology can add value to artefact analysis of Iron Age mould fragments and has the potential to produce results that cannot be achieved through other non-destructive methods. While other groups such as the Bradford Visualisations Fragmented Heritage project (Bradford Visualisations, 2013) are specifically attempting to digitally piece together broken prehistoric artefacts, to date no other study has attempted to virtually cast an object from an Iron Age mould set and publish their results. To this end, this study has potentially pioneered a new way to digitally engage with artefacts by attempting processes that cannot be conducted on physical artefacts without harming or destroying them. While the use of photogrammetry itself has not been new or ground-breaking, it is hoped that the results and lessons learned from this study will enable others to build upon its findings and reduce the setup time required for future study.

The reconstruction of the pin from the moulds and its 3D printing has been a rousing success and has opened the doors to many other avenues for consideration and study. The potential for public access and marketability appears to be relatively untapped in the archaeological world and could present new avenues for project funding. Interaction with heritage market specialists would be advised to take this further, especially in the area of maintaining authenticity while avoiding potential forgery problems.

Working with this unique collection of mould fragments has been enlightening, thought provoking and above all, inspiring. The potential avenues of further thought and study branch off into myriad directions, each equally enthralling as the next. The technology behind 3D scanning is only set to produce better results, in less time, with more accuracy and with less cost in the coming years. Archaeological study can only benefit from its inclusion and integration into the analytical process.

6. Acknowledgements

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7. References

Bradford Visualisations, 2013. *Fragmented Heritage.* [Online]
Available at: http://www.fragmentedheritage.com/
[Accessed 25 August 2016].

Knappett, C., 2005. The Affordances of Things: a Post-Gibsonian Perspectiveon the Relationality of Mind and Matter. In: E. Demarrais, C. Gosden & C. Renfrew, eds. *Rethinking Materiality: The Engagement of Mind with the Material World.* s.l.:Blackwell Publishing Ltd., pp. 43-51.

Mallison, H., 2015. *Photogrammetry tutorial 11: How to handle a project in Agisoft Photoscan.* [Online]
Available at: https://dinosaurpalaeo.wordpress.com/2015/10/11/photogrammetry-tutorial-11-how-to-handle-a-project-in-agisoft-photoscan/
[Accessed 31 August 2016].

Yanagi, H. & Chikatsu, H., 2010. 3D modeling of small objects using macro lens in digital very close range photogrammetry. *International Archives of Photogrammetry, Remote Sensing aand Spatial Information Sciences,* XXXVIII(5), pp. 617-622.

8. Further Viewing

3D models created during this project can be viewed with the following links.

Find #1995 – Detail mould fragment head: https://skfb.ly/QAW7

Find #1996 – Back of mould fragment head: https://skfb.ly/SMRW

Find #1931 – Half of shaft mould fragment: https://skfb.ly/SMVK

Completed pin reconstruction: https://skfb.ly/RuWP